

**Proceedings of the 2021 Joint Biennial Conference of the
Society of South African Geographers and the Southern
African Association of Geomorphologists**

2022



ONLINE

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**SOCIETY OF SOUTH AFRICAN GEOGRAPHERS & THE
SOUTHERN AFRICAN ASSOCIATION OF
GEOMORPHOLOGISTS**

2022



**Proceedings of the Joint Biennial Conference of the Society of
South African Geographers and the Southern African Association
of Geomorphologists**

Conference held online at Rhodes University from 6-8 September 2021.

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FOREWORD

The 2021 Biennial Conference was coordinated by both the Society of South African Geographers (SSAG) and the Southern African Association of Geomorphologists (SAAG). The SSAG was founded in 1994 when the (then) Society for Geography and the South African Geographical Society joined together. SAAG held its inaugural meeting in 1988. Both the SSAG and SAAG hold biennial conferences and meetings, alternating each year so that neither the SSAG nor SAAG hold conferences in the same year. However, due to the COVID-19 pandemic, neither the SSAG Biennial Conference, originally scheduled for 2020, nor the SAAG Biennial Conference, scheduled for 2021, could proceed in person. The decision was taken to combine forces and to hold a joint conference. This was held online using Zoom from 6-8 September 2021, bringing together topics in human geography, physical geography, and geoinformation science. While different from the normal order of how the conferences are held, both the SSAG and SAAG welcomed working together.

The Plenary was given by Professor Thembela Kepe, University of Toronto, on Monday morning (6 September). Tuesday morning was set aside for the SSAG Awards. On the final day (8 September), a Panel Discussion was held on how the pandemic affected work and professional lives, and what can be done to manage such effects. The conference was also registered with SACNASP for two CPD credits (validation number 2021-0681-001897).

Despite the significant change of the online format, the conference, nevertheless, had a varied number of excellent sessions on human geography, physical geography, and geoinformation science, bringing together all areas of geographical sciences. While sessions were designed to run in parallel, with a Human Geography focused session parallel to either a Physical Geography or GISc session, the online format allowed participants to easily change between these parallel sessions. As an exciting new initiative, one experienced researcher and one young geomorphologist or young geographer were also paired to co-convene each session. This allowed young and emerging researchers the opportunity to be involved, learn valuable skills, and help convene a session.

The conference Program & Book of Abstracts is available [here](#).

THEMES

The conference was organised along several themes, as listed below.

Human Geography:

- The future of tourism in Southern Africa
- Homes still apart?
- Urban geography in South Africa

Physical Geography:

- Applied physical geography/geomorphology
- Climate & climate change in sub-Saharan Africa
- From source to sink: sediment dynamics, monitoring, and management

Cross themes:

- Decolonising southern African curricula
- Geography 4IR
- Geography, education, and capacity building

GIS & Remote Sensing:

- GISc in geographical research

REVIEW PROCESS

Altogether 34 papers were submitted for consideration, of which 15 are included in the Proceedings following withdrawals and non-acceptance. A double-blind peer review process was followed in which each paper (abstract and full paper) was reviewed by at least two expert reviewers, with all papers reviewed by 31 reviewers in total. Full papers were selected on the grounds of academic merit and relevance to the conference themes. Recommendations were implemented and confirmed by the editors prior to final publication in the Proceedings.

PROCEEDINGS THEMES

The Proceedings consist of papers from several themes. These are given below.

Theme	Papers
Human Geography: Urban geography in South Africa	3
Physical Geography: Applied physical geography/geomorphology	4
Physical Geography: Climate & climate change in sub-Saharan Africa	2
Cross theme: Geography, education, and capacity building	2
GIS & Remote Sensing: GISc in geographical research	4

REFEREES

The editors wish to thank the referees for their valuable input and assessment of papers:

Adeline Ngie, Adriaan vd Walt, Adrian Nel, Arthur Chapman, Babatunde Abiodun, Ben Nyikadzino, Delia Ah Goo, Dirk Cilliers, Edmore Kori, Hennie Smit, Henry Ndaimane, Innocent Sinthumule, Jan Marx, Jay le Roux, Jennifer Fitchett, Joshua Edokpayi, Leonard Chitongo, Liezel Rudolph, Lodene Willemse, Manfred Spocter, Manna Stander, Maronel Steyn, Oni Mutanga, Richard Ballard, Ronnie Donaldson, Samuel Adelabu, Simone Dahms, Theuns de Klerk, Thulebona Mbhamali, Tshepang Gaeatlholwe, Tyrel Flugel.

CONFERENCE PROCEEDINGS PEER REVIEW EVALUATION CRITERIA

The review criteria were as detailed below.

Title of manuscript:

Authors: Double blind review process

The Editors rely on the Reviewers' judgment in deciding whether to accept or reject a paper for the SSAG-SAAG peer reviewed conference proceedings. Please indicate your evaluation and overall general comment of this paper for each of the following statements. All comments will be kept confidential.

1 The title of the paper is adequately phrased:

Strongly agree (5)	Agree (4)	Neutral (3)	Disagree (2)	Strongly disagree (1)	N/A

Comments (if applicable):

2 The language and writing style are of an acceptable standard:

Strongly agree (5)	Agree (4)	Neutral (3)	Disagree (2)	Strongly disagree (1)	N/A

Comments (if applicable):

3 If any, the tables and figures are correct and of an acceptable standard, and are meaningfully titled:

Strongly agree (5)	Agree (4)	Neutral (3)	Disagree (2)	Strongly disagree (1)	N/A

Comments (if applicable):

4 The paper and reference list are correct:

Strongly agree (5)	Agree (4)	Neutral (3)	Disagree (2)	Strongly disagree (1)	N/A

Comments (if applicable):

5 The paper has cited relevant literature/published work:

Strongly agree (5)	Agree (4)	Neutral (3)	Disagree (2)	Strongly disagree (1)	N/A

Comments (if applicable):

6 The paper includes unethical, discriminatory and potentially harmful information/statements:

Strongly agree (5)	Agree (4)	Neutral (3)	Disagree (2)	Strongly disagree (1)	N/A

Comments (strongly agree or agree please elaborate why you say so):

Overall assessment:

Manuscript can be accepted as is	5
Manuscript can be accepted with minor technical, editorial corrections	4
Manuscript has to be resubmitted to editors only	3
Manuscript has to be resubmitted to reviewer	2
Manuscript cannot be published at all	1

General comments to the Editors:

AUTHORS

Altogether 33 authorships represent 12 separate institutions, comprising nine South African universities and one Zimbabwean university, one South African government department, and one additional institution outside of South Africa. A summary of institutions is given here. The value in brackets reflects the number of authorships (and rounded percentage) from that institution.

1.	Bindura University of Science Education:	1 (3%)
2.	North-West University:	1 (3%)
3.	Stellenbosch University:	10 (30%)
4.	University of Johannesburg:	2 (6%)
5.	University of KwaZulu-Natal:	5 (15%)
6.	University of Limpopo:	1 (3%)
7.	University of Pretoria:	3 (9%)
8.	University of South Africa:	4 (12%)
9.	University of the Free State:	1 (3%)
10.	University of Venda:	2 (6%)
11.	StatsSA:	1 (3%)
12.	ZINWA Mzingwane Catchment:	2 (6%).

Luke Sandham, Christel Hansen, and Ian Meiklejohn (Editors)

November 2022

PAPERS

THEME: Human Geography – Urban geography in South Africa

Applying the City Development Index (CDI) to measure the quality of life in the local municipalities of the Northern Cape between 2001 and 2011

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Abstract

Unlike single indicator measures of well-being, such as income, quality of life (QOL) comprises several different variables that measure various well-being outcomes. South Africa's Bill of Rights affirms the democratic values of human dignity, equality, freedom, and the right to life. Despite 28 years of democracy, the country still struggles with racial and class-based inequality characterised by a highly fragmented space-economy driven by speculative urbanism. This situation is no different in the Northern Cape; the province, with its highly unique settlement pattern scattered across vast open spaces, has been experiencing significant economic crises and general stagnation driven by various factors, which negatively impacts infrastructure and service-delivery developments and overall QOL. This study aims to calculate the City Development Index (CDI) to determine the QOL in the local municipalities of the Northern Cape for 2001 and 2011. The CDI comprises the following dimensions: health, city product, education, waste, and infrastructure; each with their own calculation methods. Generally, the municipalities with more economic opportunities have higher CDI scores compared to more rural and tribal authority areas. Certain municipalities continue to struggle disproportionately with most of the CDI-dimension scores, with overall poverty and inadequate infrastructure and health services remaining significant problems across the province. A robot system visualises the dimensions that require less, average, and more attention per municipality, thus making it easier for municipalities to adequately distribute scarce resources to positively influence QOL.

Keywords: City Development Index (CDI); Local municipalities (LM); Quality of life (QOL); Northern Cape.

Introduction

Quality of life (QOL) is a multidimensional concept comprising many dimensions relating to the terms well-being, satisfaction, and happiness (Organisation of Economic Co-operation and Development [OECD], 2022a). Hall (2014) defines the term happiness as an emotion (i.e., "Are you happy?") or as an evaluation (i.e., "Are you happy with life overall?"). QOL has many definitions, but generally refers to people's ability to live long and healthy lives with the help of various resources (United Nations Development Programme [UNDP], 1990). During

apartheid, QOL was inextricably linked to racial classifications as highly skilled jobs, facilities, and services were reserved for white people only, resulting in poorer and under-developed group areas for other racial groups. As migration to cities increased, black people were forced to settle in townships far from the city centres characterised by inadequate housing, infrastructure, facilities, and services, thus exacerbating extreme poverty and very poor to unhealthy living conditions (Bhorat & Kanbur, 2005; Harrison, Todes & Watson, 2008). The post-apartheid government implemented many policies to improve the socio-economic living conditions of people including the Reconstruction and Development Programme (RDP) (1994), and Growth, Employment and Redistribution (GEAR) (1996), and the Accelerated and Shared Growth Initiative for South Africa (AsgiSA) (2005). The RDP focused on the eradication of apartheid inequalities by providing basic services to everyone. GEAR emphasised micro- and macro-economic growth strategies for the economy, while AsgiSA highlighted the importance of overall economic growth and the reduction in poverty, unemployment, and inequality through infrastructure investment projects (South African History Online [SAHO], 2019).

Post-apartheid policies addressing the negative consequences associated with apartheid's spatial planning strategies included the Development Facilitation Act (DFA) (1995), Urban Development Framework (UDF) (1997), and the Breaking New Ground policy (BNG) (2004). The DFA facilitated the implementation of RDP projects in relation to land, while the UDF promoted the effective and consistent implementation of the RDP and GEAR strategies within a broader urban development policy framework (Department of Housing, 1997). BNG advocated for sustainable human settlements through increased accessibility to economic opportunities, services, and facilities (Department of Human Settlement [DOHS], 2004). Generally, the DFA, UDF, and BNG aim to restructure urban development by ensuring the creation of sustainable and efficient human settlements through housing and infrastructure strategies to achieve more compact and mixed land-use developments (Harrison, Todes & Watson, 2008).

More recent policies include the National Development Plan (NDP) (2011), National Infrastructure Plan (NIP) (2012), and the Spatial Planning and Land Use Management Act (SPLUMA) (2013). The NDP encourages longer term development to ensure sustainable and inclusive development through job creation and infrastructure and service delivery expansion to improve citizens' QOL (National Planning Commission [NPC], 2011). The NIP identified 18 strategic projects to improve the provision of electricity, water, sanitation, transportation, human settlements, health, education, and communication (Department of Public Works, 2014). South Africa is also in the process of drafting a 25-year National Infrastructure Plan to conceptualise the longer-term direction for the built environment (post-COVID19) (Department of Public Works and Infrastructure, 2020). The DFA was repealed by SPLUMA (2013) offering a framework for spatial planning and land-use management in South Africa.

Despite 28 years of democracy, South Africa still struggles with racial and class-based inequality characterised by a highly fragmented space-economy driven by speculative urbanism. This in turn places significant emphasis on racial- and income-related QOL measures in the country (Bhorat & Van der Westhuizen, 2009; Møller, 1998, 2013). The application of QOL measures and indices remain limited in South Africa, with studies about the Northern Cape being even more scant. This study thus aims to calculate the City Development Index (CDI) to determine the QOL in the local municipalities (LM) of the Northern Cape for 2001 and 2011.

Measuring QOL: Experiences from the literature

Defining QOL and its measurement

The concept QOL developed from the work done by sociologist William Ogburn in the 1930s who measured social change from an economic (Gross Domestic Product and per capita income) perspective. Soon thereafter researchers used Ogburn's approach to measure people's QOL by calculating how much resources (money, goods, and services) they consume. The industrial boom resulted in increased patterns of urbanisation and globalisation as people moved to the cities in search of better socio-economic opportunities, but people also experienced many challenges with city life (Land, Michalos & Sirgy, 2012; Stiglitz, Sen & Fitoussi, 2009). People are complex; what makes them happy today may not necessarily make them happy tomorrow, as people experience some aspects of their life as either positive or negative. If the positives outweigh the negatives, QOL can be considered as relatively acceptable (Diener & Suh, 1997). The need to measure QOL in a more comprehensive way by including a variety of variables, and people's perceptions, preferences, and experiences thus soon became apparent (OECD, 2022a; Stiglitz, Sen & Fitoussi, 2009).

The World Health Organisation (WHO) (2012) defines QOL as people's perceptions, preferences, experiences, and ability to achieve their goals relative to their position in life contextualised within their cultural norms and standards. The OECD (2022a) has a more holistic definition for the concept including variables like income, employment, education, health, housing, social connections, civic engagements and governance, environmental quality, personal security, freedom, and subjective well-being. QOL is also strongly linked to overall human development, which has two facets: 1) human capabilities (linked to health, knowledge, and skills), and 2) what people do with these capabilities (i.e., their participation in societal activities) (UNDP, 1990). QOL can be measured objectively (i.e., quantitative calculations) or subjectively (i.e., people's perceptions, preferences, and experiences with components of their lives), or through a combination of both. Subjective measures can also be converted into objective measures (Diener & Suh, 1997). This study uses objective measures to calculate QOL through the CDI calculation.

Measuring QOL: Studying QOL indices

Various indices have been developed to measure QOL in varying ways throughout the world and in South Africa. Most QOL indices include a variety of countries that are ranked according to the variables chosen and are executed with the aim of improving overall human development through improved planning processes to deliver efficient infrastructure, services, and facilities (OECD, 2022a; UNDP, 1990, 2022).

The OECD's (2022a) Better Life initiative is based on three pillars (each comprising many variables) including material living conditions (e.g., income, jobs, and housing), a domain based QOL (e.g., health, education, environment, safety etc.), and sustainability (e.g., human, social, economic, and natural capital). The biggest issues facing South Africa include the low levels of GDP per capita, productivity and employment rates, higher than average inequality, and air pollution through increased levels of carbon dioxide emissions (OECD, 2022b). The World Happiness report (2022) has 6 key indicators including GDP per capita, social support, healthy life expectancy, freedom to make life choices, generosity, and freedom from corruption. South Africa ranked 91st in a list of 146 countries with the GDP and dystopia being the biggest influences on people's overall happiness.

The Social Progress Index (Social Progress Imperative, 2021a) measures social and environmental performance of 168 countries relative to its overall economic development. It comprises three main components including basic human needs, foundations of well-being,

and opportunity (subdivided into six tiers of social progress, 12 sub-components, and 53 indicators, e.g., safety, shelter, access to knowledge, health and wellness, personal rights, and access to advanced education etc.). Higher-income countries generally achieve higher social progress than low-income countries, but income levels do not necessarily correspond to social progress levels, especially in the middle- and lower-income countries. South Africa was ranked 80th of 168 countries and falls in the fourth tier with a score of 69.17. Personal rights and shelter received the highest scores in South Africa, while safety, health, and wellness were the most problematic aspects in the country (Social Progress Imperative, 2021b).

The World Values Survey (2020) studies people's changing beliefs, values, and motivations impacting their social and political life including themes around family, gender, religion, work, politics, economics, environment, democracy, and social cohesion etc. In 2013, South Africa's overall life satisfaction was rated as 6.63 out of 10 on average. A high level of economic growth, fighting rising prices, and crime were amongst the important aspects requiring attention in the country (World Values Survey, 2018).

Two other QOL indices include the Human Development Index (HDI) and the CDI (Bilbao-Ubillos, 2013; United Nations Human Settlements Programme [UNHSP], 1996). The HDI measures human development using life expectancy (the ability to live a long and healthy life), education (knowledge and access to education), and purchasing power (related to the GDP). In 2022, South Africa is ranked as number 114 out of 192 countries with a HDI score of 0.7090 and its biggest problem is inequality (UNDP, 2022). The CDI has been developed from the HDI to determine QOL for smaller geographic areas. Two additional dimensions (waste and infrastructure) were added to the CDI calculation (Bilbao-Ubillos, 2013; UNHSP, 1996).

Although studies on QOL indices are limited for the African continent, three indices stand out including Afrobarometer, the Numbeo Africa: QOL Index, and the KPMG Africa Good Life Index. Afrobarometer runs public attitude surveys on democracy, governance, the economy, and society (Afrobarometer, sine anno.). South Africans ranked unemployment, crime and security, corruption, housing, and education as the most important problems the government should address (Afrobarometer, 2021).

Numbeo's Africa: QOL Index comprises a purchasing power index (higher is better), pollution index (lower is better), house price to income ratio (lower is better), cost of living index (lower is better), safety index (higher is better), health care index (higher is better), traffic commute time index (lower is better), and a climate index (higher is better). South Africa was ranked in the top position in Africa with an overall score of 136.02 (Benson, 2022); with safety, the commuting time to work, purchasing power, and overall cost of living requiring the most attention (Numbeo, 2022a). The KPMG Africa Good Life Index defines QOL based on three pillars including socio-economic conditions, the environment, and governance comprising 22 indicators aggregated to create 12 underlying themes. South Africa was ranked 6th with its three strongest attributes being its legal system, freedom, and politics, while safety, health, employment, and income were its most problematic aspects requiring attention (KPMG, 2016).

QOL studies from a South African and Northern Cape perspective

Although South African studies generally use the same types of variables as international studies to measure QOL, the country faces a similar problem because the studies do not use the same variables, thus complicating comparisons. The variables chosen to measure QOL also paint a different picture of what QOL looks like in the country (Naudé, Rossouw & Krugell, 2009). South African QOL studies are generally grouped along three themes including a political / racial, geographical, and socio-economic / poverty perspective.

Studies focusing on the political / racial perspective of QOL indicate that apartheid legislation significantly hampered the living conditions of the marginalised and oppressed in the country as higher-order infrastructure, services, facilities, and economic opportunities were only available to a select few in society (Møller, 1998, 2003). Black people who were subjected to the most oppression during apartheid were the most optimistic about a post-apartheid future, but despite a general growth in the black middle-class, a racial (and now class-based) hierarchy of QOL, remains (Harris, 2007). Despite the gap between the “haves” and “have nots” narrowing over time, there is a widening gap between aspirations and expectations amongst South Africans as many are forced to trade-off certain aspects of their QOL against other aspects (Bhorat & Van der Westhuizen, 2009). The Human Sciences Research Council (HSRC) has been monitoring public perceptions on social, economic, and political values amongst South Africans through the South African Social Attitudes Survey (SASAS) since 2003. SASAS 2020 results confirm that South Africans remain deeply polarised along racial classification. South Africans are generally unified in reducing the inequality gap, but the country remains highly divided on the ways to address the unjust legacies of the past (Nyamnjoh et al., 2020). The Centre for Risk Analysis’ (CRA) (2021) QOL Index study confirms that South Africa continues to battle deep racial-based inequalities as white people have the highest living standards in the country with a mean QOL index score of 7.8 out of 10, while black people only manage an average score of 5.3 and perform the worst on all the QOL indicators in their index.

Studies focusing on the geographical perspective of QOL include the CRA’s QOL Index, South African Everyday Quality of Life Index (EQLI), Gauteng City Region Observatory (GCRO) QOL Index, Numbeo’s QOL Index, and a non-monetary QOL study. The CRA (2021) QOL Index compares well-being across the nine provinces and four main race groups. The main indicators used include the matric pass rate, unemployment, expenditure levels, household tenure status, access to piped water, electricity for cooking, basic sanitation facility, waste removal, medical aid coverage, and the murder rate. The Western Cape and Gauteng significantly outperformed the other provinces as residents have relatively high standards of living. The worst performing provinces were the Eastern Cape and Mpumalanga, thus clearly indicating the influence of an urban/rural dichotomy influencing unemployment patterns and access to efficient basic service delivery. The South African EQLI also defines QOL from an urban/rural dichotomy by using variables like socio-economic status, urbanisation, health, the environment, satisfaction of human needs, connectivity, optimism, and subjective well-being. Results indicate the dire need for rural upliftment through improved job opportunities and housing, while the urban poor continue to struggle disproportionately (Higgs, 2007).

The GCRO’s QOL Index uses 33 variables grouped into seven dimensions including services, socio-economic status, government satisfaction, life satisfaction, health, safety, and participation. Results indicate a gradual increase in QOL scores from 2013/2014 to 2017/2018 but show a marked decrease in 2020/2021 largely attributed to the impacts associated with the Covid-19 pandemic. The services and safety dimensions experienced slight increases, but all the other dimensions declined, with a marked decline being visible in the socio-economic status and government satisfaction (De Kadt et al., 2021; Naidoo, 2021). Numbeo’s (2022b) QOL Index for South African cities ranks Cape Town as having the highest QOL in South Africa with an overall QOL Index of 147.08, followed by eThekweni, Tshwane, and Johannesburg. Cape Town and Tshwane’s safety and commuting time received the lowest scores, while eThekweni and Johannesburg mostly struggle with safety concerns, and Johannesburg with a high pollution index count.

Naudé, Rossouw and Krugell (2009) conducted a non-monetary QOL study on South African cities using subjective indicators that were converted into objective measures through

regression models. The study specifically focused on cities' ability to translate improvements in monetary QOL into non-monetary QOL. Results indicate that the inland cities (Johannesburg, Tshwane, and Ekurhuleni) outperform the coastal cities (Cape Town, eThekweni, and Port Elizabeth) in terms of monetary QOL measures. A somewhat reversed pattern is however observed when looking at non-momentary QOL as Cape Town was ranked first, followed by Ekurhuleni, and then eThekweni, and Port Elizabeth, with Johannesburg and Tshwane making up the rear. Based on a composite QOL score, Cape Town and Port Elizabeth performed the best, thus indicating that monetary and non-momentary measures should be used to determine QOL.

Studies focusing on the socio-economic / poverty perspective of QOL include the Multidimensional Poverty Index (MPI), Living Conditions Survey (LCS), and Decent Standard of Living report. Statistics South Africa (StatsSA) published the MPI report in 2014 and the LCS report in 2017. The MPI uses Census data to measure poverty and deprivation in the country through 10 indicators grouped into three main dimensions including education, health, and living standards. The standard of living and education dimensions improved from 2001 to 2011, thus indicating improvements to the general service-delivery situation in the country. Conversely, the economic activity dimension increased significantly, thus affirming the seriousness of the unemployment situation in the country. Although Gauteng had the highest average intensity of poverty, the Eastern Cape still recorded the highest MPI score. Generally, the provinces with more rural areas have higher MPI scores (StatsSA, 2014a). South Africa's unemployment rate stands at 33.9% (second quarter of 2022) (StatsSA, 2022), resulting in chronic poverty and the inability of South Africans to reach their goals of employment and access to basic needs including housing, water, food, education, health etc., which in turn negatively influences QOL (NPC, 2011). Black people continue to struggle disproportionately with chronic poverty (Higgs, 2007; Møller, 2013).

The LCS (StatsSA, 2017) compares income levels to household consumption and expenditure patterns. Results indicate that the main expenditure items were on housing and utilities, transport, food, and miscellaneous goods and services. The Western Cape and Gauteng have the highest expenditure patterns, while the Northern Cape and Limpopo experienced the lowest scores. Poorer households spend proportionately more on food compared to wealthier households that have higher spending patterns on housing and transport. LCI results on race indicate less inequality in white-headed household expenditure patterns, while large disparities are still visible for black people. The Southern African Social Policy Research Insights' (2018) research report on "A Decent Standard of Living" indicated that a monthly income of roughly R7 000 per person (2018) and R7 541 (updated for 2020) is considered an economic measure of a decent standard of living. Other aspects like material possessions, features of the local neighbourhood, and social networks also assist in the construction of a decent living standard.

The situation is no different in the Northern Cape, which in addition to all the impediments mentioned above, struggles with being the largest and most sparsely populated province in South Africa. Its unique rural settlement pattern is characterised by isolated urban and quasi-urban areas, scattered across approximately 1000km in length from east-to-west (Province of the Northern Cape, 2012). It comprises 37289km² taking up 30.5% of South Africa's land area but has only roughly 1-million citizens (creating a population density of just 3 people per km²) This significantly impacts infrastructure and service delivery, and economic activities, as the province only contributes 2% to South Africa's GDP with primary industries being mining (and quarrying) and agriculture (Province of the Northern Cape, 2020).

The global economic recession negatively contributed to the collapse of many mining and railway settlements in the province. It also negatively impacted agricultural exports, which

experienced significant declines due to the continued drought affecting the province (Province of the Northern Cape, 2012; Van Aswegen, Retief & Drewes, 2020). Unemployment remains very high at 23.7% (second quarter of 2022) (StatsSA, 2022), as those with relatively low educational levels are unable to secure highly skilled jobs, creating a structural mismatch between the supply and demand of labour. This in turn negatively impacts people's QOL (Province of the Northern Cape, 2020). The HDI score for the province increased from 0.58 (2010) to 0.66 (2019), with increases being experienced in all the district municipalities (DM) over the same periods. Namakwa DM had the highest HDI score, while John Taolo Gaetsewe DM had the lowest in both years. This shows that development is taking place and that lives are showing slight improvements for the better in the province. Despite this, the Gini coefficient increased from 0.59 (2010) to 0.61 (2019), representing a slight increase in income inequality as most households fall in the R192 000-R360 000 income category per annum. The ratio between salaries and social grants as the main household source of income much lower in the Northern Cape (63.9% earn salaries, while 57% depend on social grants) compared to South Africa (62.2% earn salaries, while 46.2% depend on social grants) (Province of the Northern Cape, 2021).

Van Aswegen, Retief and Drewes (2020) indicate that South Africa's municipalities have been classified into 5 types of regions based on their economic centrality. Large parts of the Northern Cape are classified as a "resource-frontier" areas comprising "peripheral" and "deep peripheral" municipalities. "Peripheral" and "deep peripheral" municipalities comprise small, to very small (and scattered) service centres making a small (to marginal) contribution to economic growth, moderate to very small population densities, depended on largely depressed agricultural economic activities to small mining activities. Large parts of the Northern Cape are thus undergoing stagnation, a decline in its economic base, resource capital, and experience poor (to lacking) infrastructural enhancements. The Northern Cape also struggles disproportionately with negative net out-migration (StatsSA, 2011; Van Aswegen, Retief & Drewes, 2020). The provincial government is intent on eradicating informal settlements and the use of bucket toilets, while also making sure that all citizens have access to electricity for lighting and to water within a reasonable distance. This is hampered by the lack, and poor state of, critical infrastructure in rural areas and the exponential growth of informal settlements in urban areas. In terms of the water situation, it is a scarce commodity in the Northern Cape (Province of the Northern Cape, 2012). Most municipalities provide free basic services to its indigent households, which places a financial burden on these municipalities. Many towns are serviced by mobile clinics, but because the Northern Cape is such a large province, it has the lowest frequency for mobile clinic visits in the country (once in 6.7 weeks on average) (Province of the Northern Cape, 2003).

The application of QOL measures and indices remain limited in South Africa, with studies about the Northern Cape being even more scant. StatsSA (1996) applied the HDI in South Africa to measure the provincial QOL in 1980, 1991 and 1996, while the Western Cape government applied the HDI and CDI to determine the QOL of the municipalities and towns in 2005 (using Census 2001 data) (Province of Western Cape 2005). The HDI and CDI were also applied to measure the QOL of those people residing within the municipalities of the Northern Cape in 2009, but this report experienced certain challenges associated with data availability (Myburg & Kruger, 2009). The CDI was also applied by the South African Cities Network (SACN) (2002) to rank nine of the largest municipalities in South Africa according to their level of development.

Materials and Methods

The methodology discusses the data collection and data processing and analysis steps taken to execute this study. The aim of the study was to calculate the CDI to determine the QOL in the local municipalities of the Northern Cape for 2001 and 2011. In 2011, the Northern Cape had 27 local municipalities (referred to as LM in the results section) (Figure 1), split into five district municipalities (referred to as DM in the results section) including Frances Baard, John Taolo Gaetsewe, Namakwa, Pixley Ka Seme, ZF Mgcawu. The Mier and //Khara Hais local municipalities have since been amalgamated into the Dawid Kruiper local municipality.

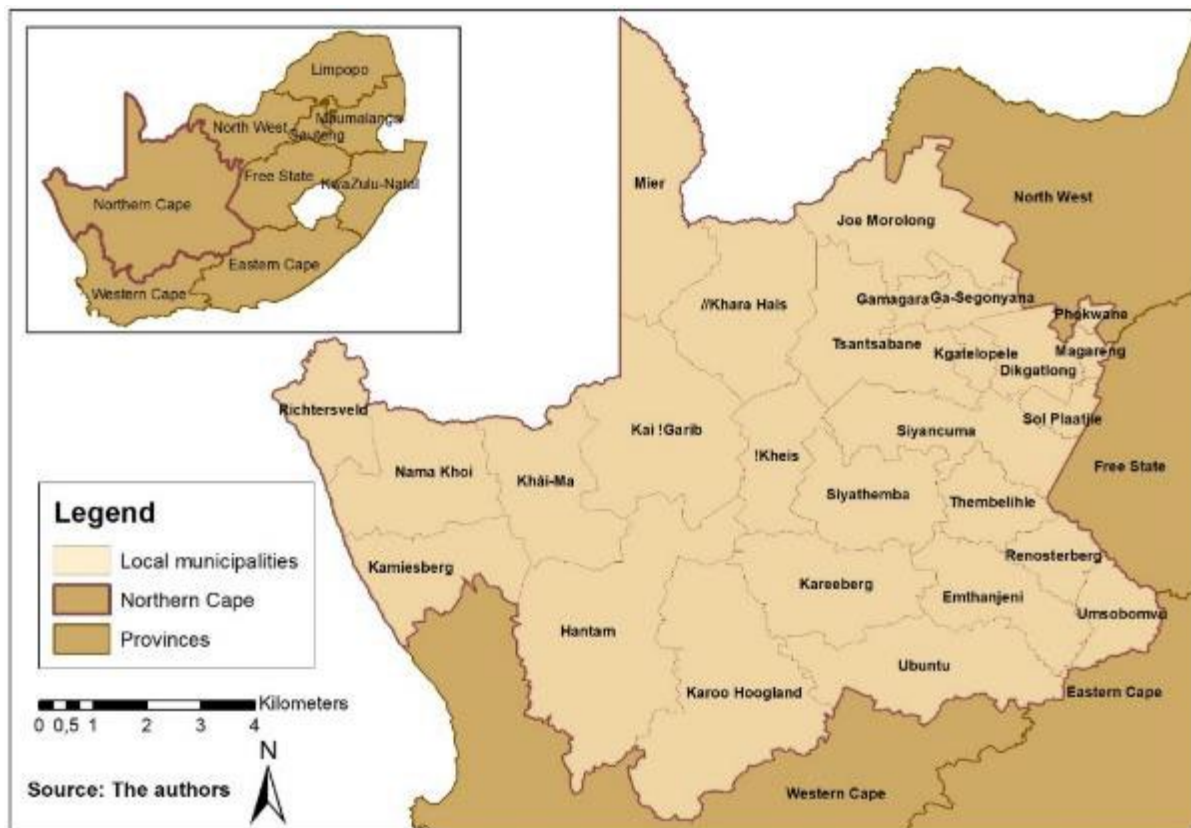


Figure 1: Study area map of the local municipalities in the Northern Cape.

The CDI comprises five dimensions of which three overlap with the HDI including health (a long and healthy life), education (knowledge), and city product (a decent standard of living). The remaining dimensions are waste (solid waste removal and wastewater), and infrastructure (water, sewerage, telephone, and electricity provision). Table 1 provides a detailed description of the variables used in the study and the data sources where the variables were obtained. It is important to note that two adjustments were made to the variables used in the study. The GDP in the city-product dimension was replaced by mean income (as recommended by the UNHSP, 1996), while the wastewater figures were not included into the calculation because the data was not available for all the local municipalities (as recommended by the UNHSP, 1996).

Table 2 shows how the CDI was calculated for each of the dimensions. The calculations for the CDI were done as stipulated by the UNHSP (1996). Microsoft Excel was used to do all the calculations, and to create the radar graphs. Radar graphs plot each CDI dimension (and the composite CDI score) on its own axis radiating from a central point, thus simplifying which dimensions require attention in which local municipalities. The CDI score results vary between 0 and 1. A score closer to 0 indicates a lower QOL level, a score around 0.5 indicates an average QOL level, while a score closer to 1 indicates a higher QOL level (UNHSP, 1996). Seeing as

very limited academic research has been done on QOL in the Northern Cape, results from the CDI calculations were interpreted using the findings in the municipal Integrated Development Plans (IDPs).

Results and Discussions

The composite CDI scores are discussed first, followed by a discussion of the individual CDI dimensions. Figure 2 represents all the results in the form of radar graphs grouped according to the district municipalities (2001 in blue and 2011 in red).

Table 1. Application of the variables and data sources.

Application of the variables within the QOL dimensions	Data sources
Health dimension	
Age split into 5-year categories used to calculate life expectancy	StatsSA Census (2001, 2011)
Number of deaths per age and municipality used to calculate life expectancy	StatsSA unpublished data (2001, 2011)
Infant (child) mortality per municipality	Northern Cape Department of Health statistics (2001, 2011)
Life expectancy calculated according to StatsSA's mid-year estimate calculations for 2013 (StatsSA 2014b)	StatsSA Census (2011, 2011) StatsSA Mid-year population estimates (2013) (StatsSA, 2014b)
City product dimension	
Mean income was derived from the Census' annual household income variable. It was not possible to use the GDP as is advocated by the United Nations Human Settlements Programme (UN-Habitat 1996) because GDP data is not available on municipal level in South Africa	StatsSA Census (2001, 2011)
StatsSA uses the following methodology to calculate the mid-points of the mean income groupings for 2001 and 2011, because the categorisation differs significantly between the two years: <ul style="list-style-type: none"> a. No income (multiplied by 0) b. R1-R4 800 (2/3 of the highest amount used for this group) c. R4 801-R9 600 up to R1 228 801-R 2 457 600 (smallest and highest amount multiplied with each other, then calculate the square root of the answer) d. R2 457 601 and more (amount is multiplied by two) 	
The mean income mid-points were multiplied with the number of people falling into the specific mean income categorization. The answers were added together and divided by the total number of people earning an income, thus providing the average income per municipality	
Education dimension	
Literacy was calculated using the highest level of education. Additionally, the Western Cape Government (2005) and Development bank of South Africa define literate people as people who are older than 20 and have completed 7 or more years of education	StatsSA Census (2001, 2011)
Gross enrolment ratio was defined according to EUStat (2014) as the number of people who are presently attending school, divided by the number of people between the ages of 6 and 22 in each municipality	
Waste dimension	
Solid waste disposal was calculated using StatsSA's refuse disposal variable. All the types of refuse removal were added together, and a percentage was calculated for each municipality	StatsSA Census (2001, 2011)
Infrastructure dimension	
Water supply was calculated using Stats SA's main water supply variable. All the variables for people who have water within 200m from their house were added together, and a percentage was calculated for each municipality	StatSA Census (2001, 2011)

Application of the variables within the QOL dimensions	Data sources
Sewerage supply was calculated using StatsSA's toilet facility variable. Flush toilets, chemical toilets and pit toilets with ventilation were added together, and a percentage was calculated for each municipality	
Electricity usage was calculated using StatSA's energy for lighting variable. All the variables for people who use energy for lighting were added together, and a percentage was calculated for each municipality	
Telephone / Cell phone usage was calculated using StatsSA's telephone and cell phone facilities variables. The telephone variable and cell phone variable were added together, and a percentage was calculated for each municipality	

Table 2. Calculating the CDI and its dimensions.

Calculating the CDI and its dimensions
Health dimension
<ul style="list-style-type: none"> • Measured by using life expectancy and child mortality • Health index = $((\text{life expectancy} - 25) \times (50/60) + (32 - \text{child mortality}) \times (50/31.92)) / 100$
City product dimension
<ul style="list-style-type: none"> • Measure by using mean income • Calculating the mean income index: The minimum value is set at 500 and the maximum value is set to 150 000 • Mean income index = $((\text{actual mean income} - \text{minimum value}) / (\text{maximum value} - \text{minimum value}))$
Education dimension
<ul style="list-style-type: none"> • Measured by using literacy and gross enrolment ratio • Education index = $((\text{literacy} \times 50) + (\text{gross enrolment} \times 50)) / 100$
Waste dimension
<ul style="list-style-type: none"> • Measured by using waste removal availability • Waste index = Removed by local authority or private company once a week + Removed by local authority or private company less often
Infrastructure dimension
<ul style="list-style-type: none"> • Measured by using adding water supply, sewerage supply, electricity usage, and telephone / cell phone variables • Infrastructure index = $(\text{water supply} + \text{sewerage supply} + \text{electricity usage} + \text{telephone} / \text{cell phone usage}) / 4$
Composite CDI score
<ul style="list-style-type: none"> • $(\text{Health index} + \text{Mean income index} + \text{Education index} + \text{Waste index} + \text{Infrastructure index}) / 5$

Composite CDI results

The three municipalities that achieved the highest composite CDI score for 2001 were Kgatelopele LM (0.81), Nama Khoi LM (0.79), and Gamagara LM (0.77), while two municipalities maintained their top three standing in the composite CDI score for 2011 including Kgatelopele LM (0.86) and Nama Khoi LM (0.82), the Richtersveld LM showed a 0.11 improvement to achieve a composite score of 0.86 in 2011. These municipalities outperformed the others because there are many well-established mining areas that supply work in alluvial diamond and lime fields, which significantly increases its city-product scores (i.e., mean income scores). Mining towns are also notorious for having improved infrastructure development and service delivery. In addition to a private hospital, the mining companies in Kgatelopele LM offer clinic services, recreational clubs, and swimming pools, while educational facilities in the form of primary, and especially secondary schools, contribute to a reasonably well-educated population. The Go-Ghaap route is a regional development initiative offering economic opportunities through heritage and tourist attractions to various towns stretching along the Ghaap Escarpment to the Orange River in the South (Kgatelopele LM, 2021).

Nama Khoi LM was nominated as the best municipality in the country in an independent study done by Empowerdex in 2009, as 94% of the inhabitants had access to basic services. The municipality has a relatively low Gini coefficient and high HDI score, which would improve living conditions. Mining is by far the strongest contributor to the local economy, with the sector showing an exceptionally high location quotient relative to the same sector in the national economy. The tourism sector also functions as an economic pillar in the municipality, while the community services sector offers many job opportunities as well (Nama Khoi LM, 2022). The Richtersveld LM is the administrative region of the Namakwa DM, and has the highest HDI score in the district, but with a relatively high Gini coefficient it remains one of the most unequal local municipalities. The municipality experienced relative increases in education levels from 1996 to 2016. Mining, agriculture, and manufacturing are the main economic sectors, and the existing airstrip and airport at Alexander Bay offer many tourism and economic development opportunities in the future (Richtersveld LM, 2022).

Two local municipalities that performed the worst in terms of the composite CDI score for both years were Joe Morolong LM (0.40 in 2001, 0.58 in 2011), and Kai !Garib LM (0.59 in 2001, 0.58 in 2011). Ga-Segonyana LM (0.56) had a relatively low score in 2001, while Ubuntu LM (0.61) performed poorly in 2011. These municipalities were also ranked at the bottom of the infrastructure and city-product dimensions (StatsSA, 2011). Joe Morolong LM and Ga-Segonyana LM are tribal authority areas with very limited economic activity taking place, resulting in very low-income levels. Infrastructure and service delivery are also not provided to the same extent in these more rural and tribal authority areas (Ga-Segonyana LM, 2021; Joe Morolong LM, 2021). In the case of Ga-Segonyana, residents are heavily reliant on mining activities located outside its municipal boundaries for employment opportunities. Residents work in neighbouring municipal manganese, iron ore, tiger's eye, and blue asbestos mining. The expiry of the mining rights in 2009 has boosted the local economic development opportunities for small, medium, and micro enterprises (SMMEs) who want to participate in mining activities in the Kalahari mining basin. The local economy is also supported by cattle and game agricultural activities (Ga-Segonyana LM, 2021), but job opportunities have been heavily influenced by the severe and on-going drought in the province (Van Aswegen, Retief & Drewes, 2020). Kuruman and the surrounding villages offer the strongest potential for commercial and institutional growth in the municipality because it is situated along the N14 main route between Gauteng and Namibia/Cape Town via Upington (Ga-Segonyana LM, 2021).

Joe Morolong LM is the poorest municipality in the John Taolo Gaetsewe DM and comprises 8 tribal authorities and many small to rural villages. In addition to two privately owned commercial farms, and some government owned farms, community services and mining are the main economic sectors (Joe Morolong LM, 2021). Kai !Garib LM is situated along the Orange River, which is the main driver of economic activities in the municipality. The municipality has three main towns including Kakamas and Keimoes situated near intensive irrigation farming activities, and Kenhardt (focusing on livestock farming). The vineyards, pecan nut and citrus plantations offer seasonal employment during the harvesting periods. Farm workers do not get paid high wages, and during out-of-season times have no income, resulting in very high poverty levels in the municipality (Kai !Garib LM, 2022). Ubuntu LM has experienced a significant stagnation in its economic activities over the last few years, with low literacy levels and limited job opportunities, it is not surprising that economically active adults migrate to other local municipalities in search of economic opportunities. The municipality has placed a lot of emphasis on poverty alleviation programmes, as there is a high demand for social services. As a mostly rural municipality, towns are located far from each other and have

extremely low population densities, which complicates infrastructure and service delivery efforts (Ubuntu LM, 2022).

The local municipalities that experienced the biggest increases in the composite CDI score from 2001 to 2011 were Joe Morolong LM (0.17-points), Karoo Hoogland LM (0.12-points), and Richtersveld LM (0.11-points). Joe Morolong LM sees its employment opportunities in the government, mining, and construction sector as strengths, while rural agricultural activities in the form of livestock farming have the potential for growth in the area (Joe Morolong Local Municipality 2021). Planned mining activities by Menar Investment in the East Manganese field will also offer future job opportunities in the mining sector, which will have positive spill over effects for the cattle and game farming in the municipality (Mining Review Africa, 2020).

Karoo Hoogland LM has significantly expanded its tourism opportunities through the Square Kilometre Array (SKA) telescope, Southern African Large Telescope, and Karoo Array Telescope projects (Karoo Hoogland LM, 2009). Increased job opportunities in the mining and agricultural sectors, together with tourism-related developments in the Port Nolloth and Alexander Bay areas, and tourism and conservation-related developments along the Orange River and Eksteensfontein areas, contribute to improved composite CDI scores in the Richtersveld LM (Richtersveld Community Conservancy, 2006; Richtersveld LM, 2022). Ubuntu LM, Thembelihle LM, Siyancuma LM and Kai !Garib LM all experienced decreases in their composite CDI scores from 2001 to 2011, with Ubuntu LM having the biggest decrease from 0.64 to 0.61. It is noteworthy that all these municipalities recorded significant decreases in their health dimension scores.

Health dimension of the CDI

Renosterberg LM (0.89 in 2001, 0.86 in 2011) and Kgatelopele LM (0.88 in 2001, 0.86 in 2011) performed very well in terms of the health dimension, with only marginal decreases being observed in the 2011 scores. Mier LM had the highest health-dimension score in 2001 (0.96), while the Richtersveld LM managed to do the same in 2011 (0.95). Municipalities that experienced major increases in their health-dimension scores in 2011 include Richtersveld LM (0.66 to 0.95) and Karoo Hoogland LM (0.47 to 0.74). Municipalities that perform well in the health dimension have the highest life expectancies (top 10) in the province and recorded significant decreases in infant mortality rates (StatsSA 2001, 2011). Renosterberg LM has a very small population and has many natural assets, holiday resorts, and camping facilities, thus making it mostly a holiday destination; subsequently placing less pressure on the health services (Pixley Ka Seme DM, 2022). Kgatelopele LM and Richtersveld LM are well-established mining towns; the mining companies supply healthcare facilities and services to the municipality, thus contributing to increased scores. Kgatelopele LM also has a private hospital (Kgatelopele LM, 2020; Richtersveld LM, 2022).

Tsantsabane LM (0.35) and Sol Plaatje LM (0.37) recorded the lowest health dimension scores in 2001. Sol Plaatje LM has the only two district hospitals in the entire district municipality, which places a heavy burden on these hospitals to operate effectively and efficiently, which in turn makes healthcare options more expensive (Frances Baard DM, 2017). Although //Khara Hais LM (0.37) was also one of the poorest performers in 2001, the municipality experienced a 0.27-point increase in its health-dimension score in 2011. The municipality (now known as Dawid Kruiper LM) has implemented many HIV and AIDS awareness, and employee wellness programmes, and has improved the number of hospitals, community healthcare centres, and clinics available (Dawid Kruiper LM, 2022). Ubuntu LM not only had the lowest health dimension score in 2011 (0.11), but it also experienced one of the most significant decreases (0.44-point) from 2001 to 2011. Other municipalities that fared poorly in 2011 include Kai !Garib LM (0.14) and Umsobomvu LM (0.26), while Siyancuma LM and Thembelihle LM

dropped by 0.47 and 0.43 points, respectively. These municipalities list poverty as a major contributing factor to overall poorer health, poor health services (including great travelling distances to services, irregular visits of mobile clinics, and severe problems with HIV and AIDS), and a lack of staff at clinics as major challenges in their IDPs (Dawid Kruiper LM, 2022; Kai !Garib LM, 2022; Siyancuma LM, 2020; Thembelihle LM, 2020; Ubuntu LM, 2022; Umsobomvu LM, 2020).

City product dimension of the CDI

Kamiesberg LM relies on various economic sectors for job opportunities including agriculture, forestry, fishing, mining, government and community services, and tourism (Kamiesberg LM 2021), thus explaining why it had the highest city-product score in 2001 (0.86) and, despite a small decrease, a relatively high score in 2011 (0.81). Municipalities that recorded high city-product scores including Kgatelopele LM (0.84 in 2001), Gamagara LM (0.76 in 2001, 0.92 in 2011), and Tsantsabane LM (0.87 in 2011) all have well-established mining activities driving their economic growth and offering job opportunities (Gamagara LM, 2021; Kgatelopele LM, 2021; Tsantsabane LM, 2021). Seeing as Sol Plaatje LM (0.88) is the administrative and economic hub of the provinces, it is not surprising that it performed well in 2011 (Frances Baard DM, 2017).

Joe Morolong LM (0.53), Dikgatlong LM (0.61), and Mier LM (0.61) had the lowest city-product scores in 2001, but experienced great improvements in 2011 (a 0.18, 0.13, and 0.17-point increase, respectively). Mier LM (now known as Dawid Kruiper LM) struggles with a shortage of job opportunities and job creation because the natural resource-based economy does not have the capacity to support the total population. Residents thus migrate in search of job opportunities, and earn low incomes, which subsequently reduces the buying power (Dawid Kruiper LM, 2022). Magareng LM (0.76) also had a low score in 2011, while Ga-Segonyana LM reported the most significant increase from 0.63 to 0.81. Joe Morolong LM and Ga-Segonyana LM are both predominantly characterised by tribal authority and rural areas with limited economic opportunities, resulting in increased levels of poverty, which explains its poor performance in terms of the city-product dimension (Ga-Segonyana LM, 2021; Joe Morolong LM, 2021).

Education dimension of the CDI

Sol Plaatje LM was one of the three municipalities that received the highest education-dimension score in 2001 (0.80) and 2011 (0.84). As the administrative and economic hub of the province, the municipality offers many early childhood development centres, libraries, primary and secondary schools, the National Higher Education Centre (assisting students to study towards degrees at partner universities) and the Sol Plaatje University that opened its doors in 2014. The municipality focuses its educational development on science, technology, astronomy, geology, archaeology, and palaeontology, enabling a strong link to the solar and mining industries and the various astronomical developments (Province of the Northern Cape, 2005; Sol Plaatje LM, 2017). Nama Khoi LM (0.79) also had a high education-dimension score in 2001, while Tsantsabane LM performed the best in 2001 (0.83) but dropped slightly in 2011 (0.76). Gamagara LM experienced the greatest increase in its education-dimension score in 2011 (from 0.62 to 0.81). Mining companies in these three municipalities are renowned for expanding educational facilities in the municipalities, thus ensuring improved educational performance (Gamagara LM, 2021; Nama Khoi LM, 2022; Tsantsabane LM, 2021).

Siyancuma LM (0.55) and Joe Morolong LM (0.58) recorded the lowest education-dimension scores in 2001 but showed great improvements in 2011 (0.70 and 0.71, respectively). Conversely, Karoo Hoogland LM was one of the three municipalities that had the lowest

education-dimension score in 2001 (0.69), which decreased slightly to 0.65 in 2011. The development of educational awareness campaigns for small scale and commercial farmers in the municipality has been highlighted as a key priority in IDP of the municipality. Emphasis is also placed on ensuring that educational achievements are more evenly spread along racial lines, as the previously disadvantaged communities continue to struggle disproportionately (Karoo Hoogland LM, 2017).

Another municipality that experienced a drop in the education-dimension score in 2011 was Kamiesberg LM (from 0.78 to 0.71); as suggested by the IDP most of the population remains semi-skilled and unskilled in 2021 as there are no schools in some communities and children must be home-schooled (Kamiesberg LM, 2021). The education-dimension scores generally suggest a shortage of schools and teachers, and good-quality education, which is especially problematic when considering the structural mismatch between supply and demand of labour, and the inability of many people to obtain highly skilled jobs due to low levels of education, were still prevalent in 2020 (Province of the Northern Cape, 2020). The education dimension also plays a major role in the general economic stagnation experienced in the province (Van Aswegen, Retief & Drewes, 2020).

Waste dimension of the CDI

Again, municipalities with well-established mining activities have more residents who earn higher incomes, making it possible for them to pay for waste removal services, resulting in these municipalities having the highest waste-dimension scores. These municipalities include Gamagara LM (0.90 in 2001, 0.93 in 2011), Nama Khoi LM (0.88 in 2001), and Kgatelopele LM (0.92 in 2011). Nama Khoi LM highlights routine and efficient waste removal services in most areas, while various initiatives have been implemented in areas that use their own refuse dumps including the installation of wastebins alongside the main streets and regular cleaning campaigns. The municipality is also in the process of identifying an additional landfill site seeing as the existing one is being over-used (Nama Khoi LM, 2022).

Sol Plaatje LM had the highest waste-dimension score in 2001 but experienced a slight drop to 0.86 in 2011. The municipality has three waste dumping sites including the Kimberley Landfill Site, Richie, and Riverton sites (Sol Plaatje LM, 2017). Tsantsabanae LM recorded the greatest decrease from 0.84 in 2001 to 0.66 in 2011, which could be attributed to the Sishen-Saldanha railway line area that produce more hazardous wastes. Agricultural wastes and minimal recycling efforts (limited to mostly cardboards and paper) also negatively contribute to the waste-dimension score (Tsantsabane LM, 2021). The now amalgamated Dawid Kruiper LM, comprises //Khara Hais LM (0.90) that scored one of the top three spots in the waste dimension in 2011, while Mier LM experienced the most significant increase of 0.41-points.

The municipalities that performed the worst in the waste dimension have more rural and tribal authority areas and highlight a lack of landfill sites and capacity, refuse removal, and solid waste disposal as priority issues in their IDPs (Frances Baard DM, 2017; GA-Segonyana LM, 2021; Joe Morolong LM, 2021; Kai !Garib LM, 2022). The waste-dimension scores for these municipalities were: Joe Morolong LM (0.00 in 2001, 0.07 in 2011), and Ga-Segonyana LM (0.21 in 2001, 0.22 in 2011). Other municipalities that performed poorly include Kai !Garib LM (0.56 in 2011) and Dikgatlong LM. AfriForum audited 15 landfill sites in the Northern Cape, as part of 135 sites across the country. None of the 15 sites adhered to the national standards set out by the National Environmental Management Waste Act (59 of 2008). This is mainly attributed to poor municipal management with either no or poorly maintained earth-moving equipment to help with the recycling of waste. Additional problems included the absence of waste management licenses, no fences around the sites, and unauthorised people living on the sites (AfriForum, 2020).

Infrastructure dimension of the CDI

The infrastructure dimension comprises water and sewerage supply, electricity usage, and telephone / cell phone usage. It is difficult to supply bulk infrastructure and services in sparsely populated areas, resulting in a general decrease in electricity and water supply, and sanitation services in the Northern Cape relative to the country (Province of the Northern Cape, 2021). The infrastructure-dimension scores are again generally higher in the municipalities with well-established mining activities, e.g., Gamagara LM (0.85 in 2001, 0.81 in 2011), Richtersveld LM (0.83 in 2001, 0.82 in 2011), Kgatelopele LM (0.83), and Nama Khoi LM (0.82) in 2011. The Richtersveld LM for example has various strategic infrastructure projects offering many job opportunities like the Water Services Development Plan of 2010 focusing on the development of boreholes, recycling of wastewater effluent, and desalination of ground- and seawater (Richtersveld LM, 2022).

As the main economic and administrative hub in the province, Sol Plaatje LM has three wastewater treatment plants (including Riverton, Richie, and the Newton reservoir stations-tower-zone), and three sewerage pump stations (including Gogga Sewer Pump Station, Homevale Treatment Works, and Cartersglen Bulk Sewer Network) that receive regular repairs and upgrades, thus positively influencing its infrastructure-dimension score in 2001 (0.79). The telecommunication and information technology field has also expanded in Sol Plaatje LM linked to the various astronomical developments (Sol Plaatje LM, 2017). Most of the households in these municipalities have electricity supplied to their home, water inside their dwelling and/or yard, and have flush toilets (Gamagara LM, 2020; Kgatelopele LM, 2020; Richtersveld LM, 2022; Sol Plaatje LM, 2017).

Although Mier LM (0.55) (now known as Dawid Kruiper LM) was one of the worst performing municipalities for the infrastructure dimension in 2001, its score increased by 0.14-points in 2011. Various upgrades have been done to the municipal wastewater treatment plants, and a Solar Special Economic Zone was established to improve electricity supply, but the municipality continues to struggle disproportionately with water services as water is pumped to the original Mier LM from the Kalahari East Supply Scheme. A lack of revenue to deliver services (especially water) is also problematic (Dawid Kruiper LM, 2022).

Despite some improvements in 2011, Joe Morolong LM and Ga-Segonyana LM recorded the worst infrastructure-dimension scores in both years. Infrastructure and service delivery in these municipalities are highly unequal; more developed areas have a wider variety, while tribal authority and rural areas suffer disproportionately with a general lack of delivery, higher costs of supply, and poorer maintenance (Ga-Segonyana LM, 2021; Joe Morolong LM, 2021). Additionally, the high poverty headcounts in these municipalities complicate revenue collection to provide and maintain the infrastructure and services (StatsSA, 2014a).

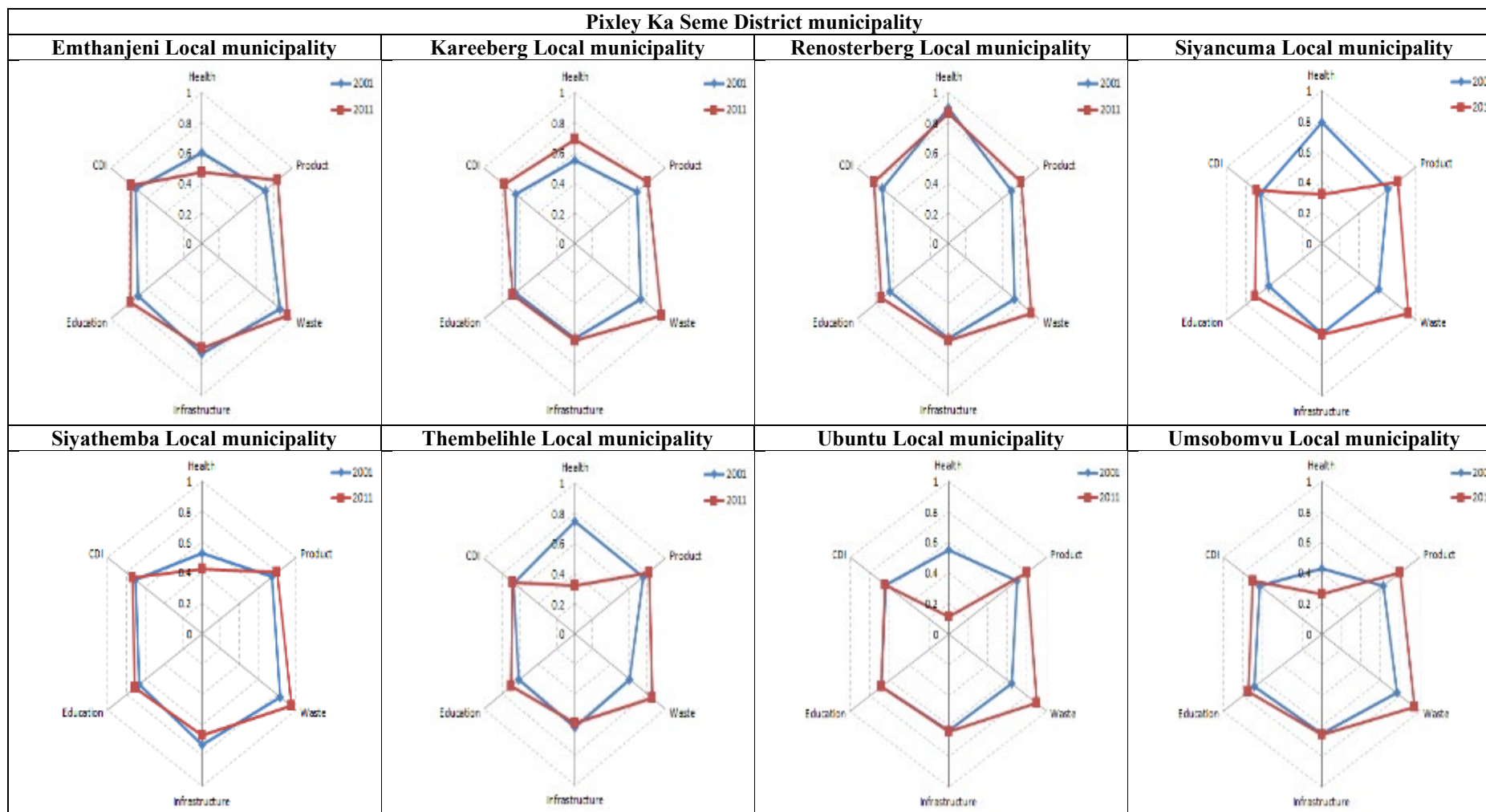


Figure 2: Radar graphs with composite CDI scores and its individual dimensions (2001 and 2011).

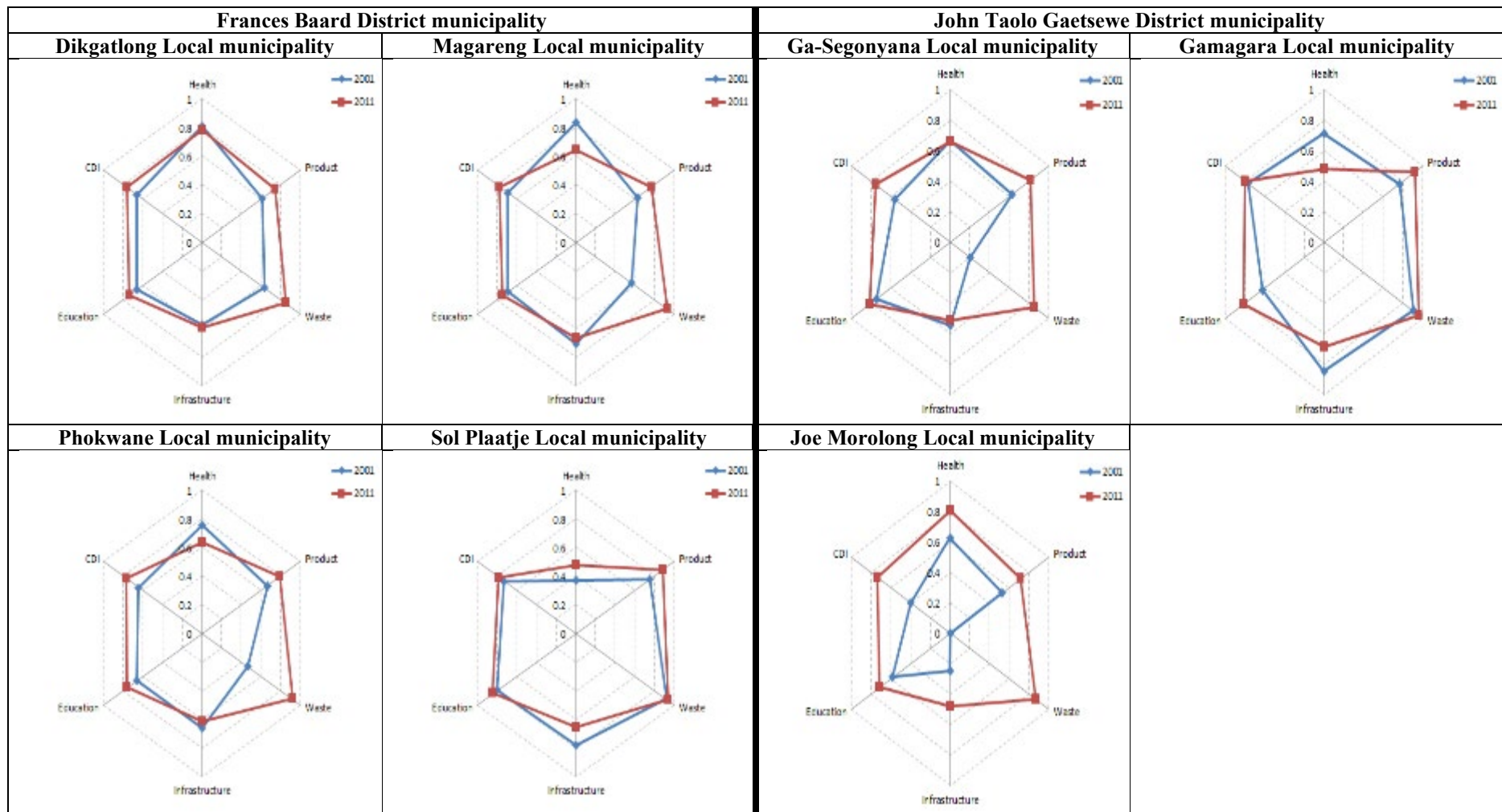


Figure 2: Continued

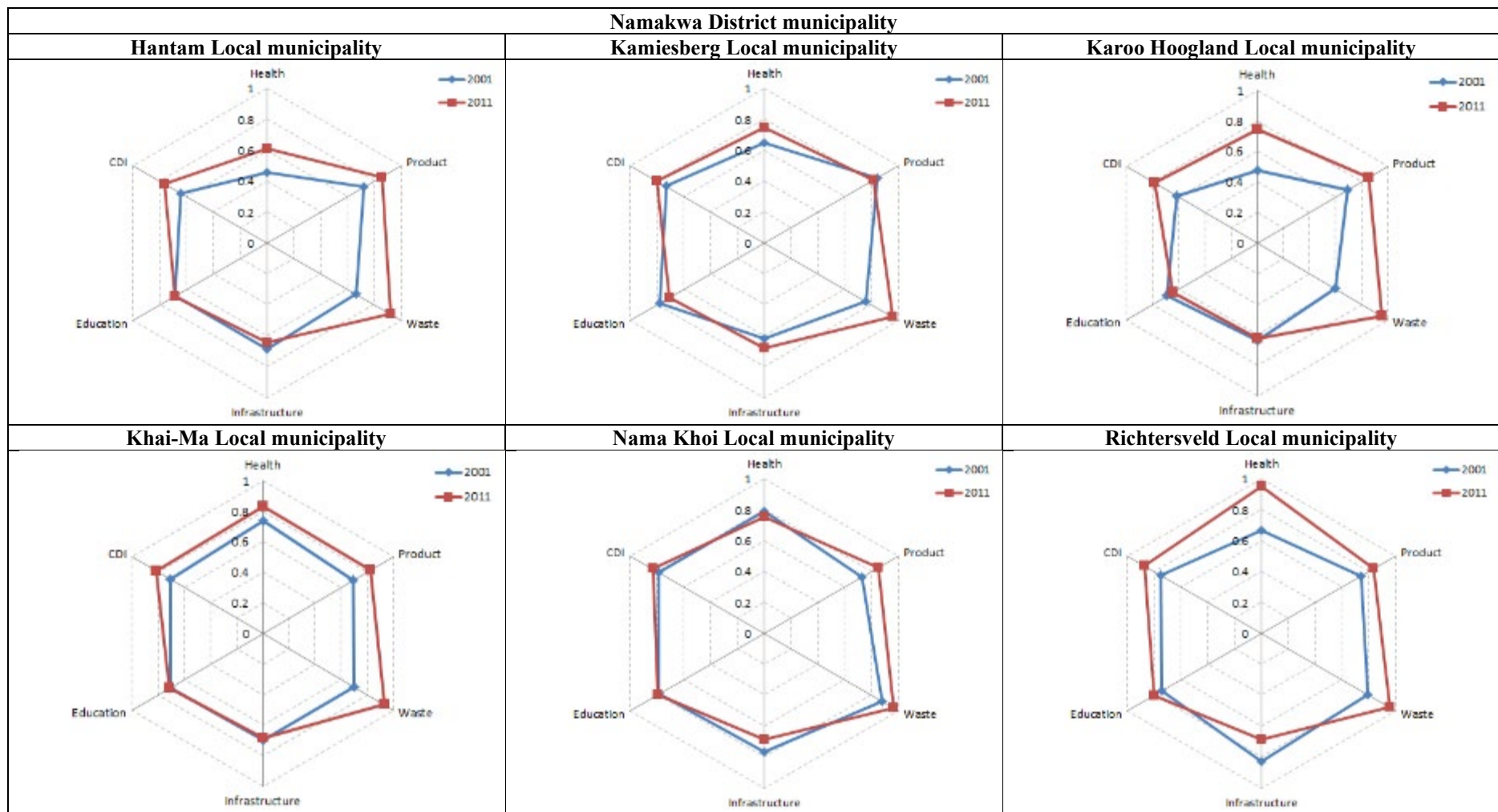


Figure 2: Continued

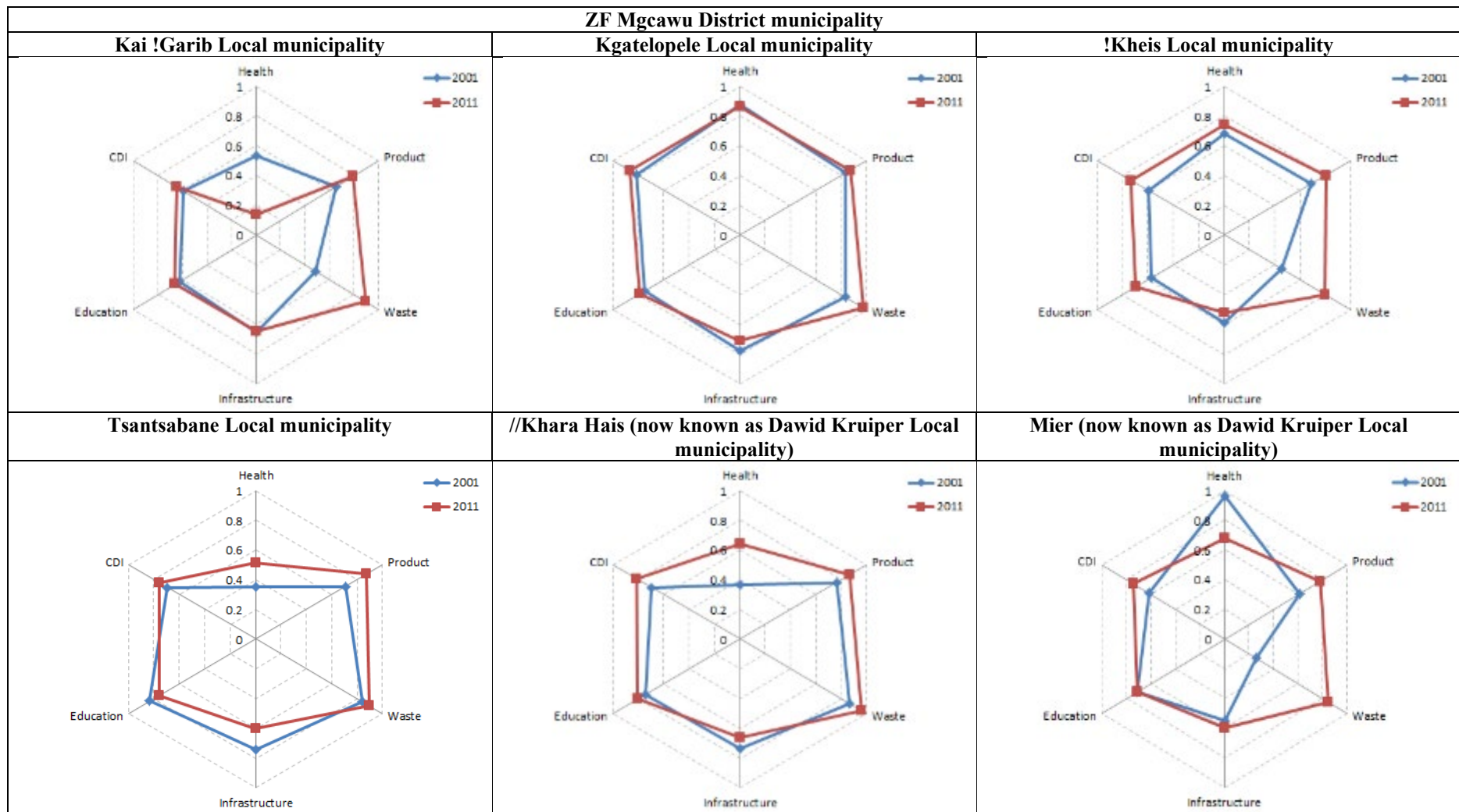


Figure 2: Continued

Conclusions and Policy Implications

The aim of the study was to calculate the CDI to determine the QOL in the local municipalities of the Northern Cape for 2001 and 2011. The CDI comprises the following dimensions: health, city product, education, waste, infrastructure dimensions; each with their own calculation methods. The radar graphs provide a visual indication of the specific CDI dimensions that require attention in specific municipalities. Generally, results indicate that the local municipalities with a wider variety of economic sectors contributing to its economic performance (especially mining, agriculture, and tourism) perform better not only in the individual dimensions of the CDI calculations, but also in the composite scores. Conversely, the local municipalities with more tribal authority and rural areas have less socio-economic development, and therefore lack larger-scale infrastructural projects, facilities, and services, thus resulting in decreased CDI scores. Generally, poverty remains a major problem in many municipalities, as there simply is not enough economic opportunities available in such a sparsely populated province (Province of the Northern Cape, 2020, 2021; Van Aswegen, Retief & Drewes, 2020).

This study confirms the difficulty in calculating QOL, and that different variables result in slightly varied results. The study does however recommend that the municipalities calculate the CDI instead of the HDI; the HDI measures are well-established and data for this is readily available. Adding the waste and infrastructure dimensions will thus provide a more comprehensive analysis of the living conditions in the municipalities and allow for an improved distribution of very scarce resources, infrastructure, services, and facilities across the province to positively influence people's QOL. Table 3 graphically visualises the dimensions through a robot system. Those dimensions that require less attention are marked with green ticks (indicating an increased CDI score), dimensions requiring "average" attention are marked with yellow minus signs (indicating relatively unchanged scores), while dimensions that require more attention are marked with red crosses (indicating decreasing CDI scores). The health and infrastructure dimensions are by far the most problematic across the province. This robot system allows municipalities to see which dimensions require more urgent attention, thus making it easier for municipalities to adequately distribute scarce resources to positively influence QOL.

Table 3. Graphic representation of dimensions requiring attention.

Municipality	Health dimension of CDI	City-product dimension of CDI	Education-dimension of CDI	Waste-dimension of CDI	Infrastructure-dimension of CDI
Pixley Ka Seme District municipality					
Emthanjeni Local municipality	✗	✓	✓	✓	–
Kareeberg Local municipality	✓	✓	–	✓	–
Renosterberg Local municipality	✗	✓	✓	✓	–
Siyancuma Local municipality	✗	✓	✓	✓	–
Siyathemba Local municipality	✗	✓	–	✓	✗
Thembelihle Local municipality	✗	✓	✓	✓	✗
Ubuntu Local municipality	✗	✓	–	✓	–
Umsobomvu Local municipality	✗	✓	✓	✓	–
Frances Baard District Municipality					
Dikgatlong Local municipality	–	✓	✓	✓	–
Magareng Local municipality	✗	✓	–	✓	✗
Phokwane Local municipality	✗	✓	✓	✓	✗
Sol Plaatje Local municipality	✓	✓	–	–	✗
John Taolo Gaetsewe District municipality					
Ga-Segonyana Local municipality	–	✓	–	✓	✗
Joe Morolong Local municipality	✗	✓	✓	–	✗
Gamagara Local municipality	✓	✓	✓	✓	✓
Namakwa District municipality					
Hantam Local municipality	✓	✓	–	✓	✗
Kamiesberg Local municipality	✓	–	✗	✓	✓
Karoo Hoogland Local municipality	✓	✓	✗	✓	–
Khai-Ma Local municipality	✓	✓	–	✓	–
Nama Khoi Local municipality	✗	✓	–	✓	✗
Richtersveld Local municipality	✓	✓	✓	✓	✗
ZF Mgcawu District municipality					
Kai !Garib Local municipality	✗	✓	–	✓	–
Kgatelopele Local municipality	–	–	–	✓	✗
!Kheis Local municipality	✓	✓	✓	✓	✗
Tsantsabane Local municipality	✓	✓	✗	–	✗
//Khara Hais (Dawid Kruiper) Local municipality	✓	✓	–	✓	✗
Mier (Dawid Kruiper) Local municipality	✗	✓	–	✓	–

Notes: Green tick = less attention, yellow minus = average attention, red cross = more attention

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Determining the socio-demographic and socio-economic factors influencing the selection of the mode of transport to work in the City of Johannesburg and City of Tshwane

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Abstract

Efficient transport infrastructure is fundamental to ensure people's access to a variety of economic opportunities, facilities, and services. Two multinomial logit models were run to determine the existence of significant relationships between the dependent (mode of transport) and independent (socio-demographic and socio-economic) variables to determine the likelihood of a particular mode of transport being selected over another in the City of Johannesburg and City of Tshwane in 2013. Results indicate that cars remained the most dominant form of transport for work-related travel in the City of Johannesburg and City of Tshwane, despite the government's attempts to promote public and non-motorised transport. White, coloured, and Indian/Asian men between the ages of 25 and 34 years old who are highly educated and earn higher incomes from formal employment, and have a driver's licence and own car, are more likely to travel by car. Conversely, most black people with lower education and income levels are employed in the informal sector and cannot afford to purchase cars; thus, increasing the usage of public and non-motorised transport. The existing transportation services thus reinforces the racial and class-based social exclusion of the South African society.

Keywords: Factors influencing transport patterns; Private transport (cars); Public transport (trains, buses, and taxis); Non-motorised transport (walking); City of Johannesburg; City of Tshwane.

Introduction

South Africans, like people worldwide, are increasingly dependent on transport to provide them mobility to participate in their day-to-day activities (Duffy, 2009). South African transport usage patterns are influenced by both apartheid and post-apartheid policies. During apartheid, the Group Areas Act (1950) separated four racial groups into discrete areas separated by buffer zones (e.g., railway lines, roads, or greenbelts), while the Reservation of Separate Amenities Act (1953) segregated the services and facilities per group area. Despite these two policies, black urbanisation to peripherally located townships continued in search of better living conditions. Higher-order services and better-quality infrastructure were reserved for the white group areas (Harrison, Todes & Watson, 2008), while much lower-quality services and infrastructure were provided in townships. Nevertheless, apartheid's infrastructure still had to facilitate the movement of black labourers into the largest cities, which was mostly achieved

through public buses and railway lines offering long, costly, poor-quality, and unreliable commutes. The deregulation of taxis in 1987 facilitated the boom in the minibus taxi industry that predominantly services poorer black and coloured people (Edwards, 2007; McKay, 2020).

The White Paper on National Transport Policy (1996) advocated a sustainable transport system to address inaccessibility and other constraints created during apartheid by increasing available modes of transport (Department of Transport [DoT], 1996). Cars are however the most dominant form of transportation throughout South Africa (Statistics South Africa [Stats SA], 2015). There are many negative consequences associated with car usage including: increased congestion and travel time, a loss of productive work time, an increased number of road-rage incidents and traffic accidents (which contributed approximately 12% to the non-natural deaths in South Africa in 2013) (Stats SA, 2014a: 39). When given a choice, South Africans are less likely to use public transport than private transport, because of inaccessible route locations, unreliable infrastructure, unpredictable and uncompetitive services, reckless and lawless behaviour of some inept drivers (especially taxi drivers), high travelling costs and a lack of safety and accidents (Sustainable Energy Africa, 2009). Despite the National Development Plan (National Planning Commission, 2011) advocating for improved access to a variety of transport opportunities to allow people to access various economic opportunities and subsequently improve their living conditions (Chakwizira & Mashiri, 2009), car usage remains largely prevalent amongst white higher-income people (Otto, 2010). Conversely, black and coloured people continue to struggle disproportionately to access private transport and rely on disconnected (Khan, 2014; O'Malley, 1990) and expensive public transport (Simpson et al., 2014; Vanderschuren & Cloete, 2006). This study aims to determine the socio-demographic and socio-economic factors influencing the selection of the mode of transport to work in the City of Johannesburg and City of Tshwane (hereafter referred to as Johannesburg and Tshwane).

The mode of transport used by people vary based on the type of activity they participate in and according to their socio-demographic and socio-economic characteristics. Some people can choose to either use private (cars), public (buses, trains, or taxis), or non-motorised (walking or cycling) transport, while others are forced to use public transport or to walk. The literature review describes the theoretical perspectives of transport-related social exclusion, changes in private, public, and non-motorised transportation usage patterns worldwide, and the socio-demographic and socio-economic factors influencing these changes.

Theoretical perspectives of transport-related social exclusion

Transport-related social exclusion refers to a lack of accessibility to opportunities preventing people from participating in economic, political, and social life (Lucas, 2012). Various factors contribute to the inaccessibility of transportation services including residing in peripheral neighbourhoods further from the city centre, facilities and amenities located far away, physical barriers (e.g., vehicle design and restricted services or facilities), high travelling costs, a lack of time, and fears for personal safety within improperly managed public spaces (Church, Frost & Sullivan, 2000). Increased car mobility is the enemy of social solidarity because it isolates some people that are unable to access alternative transportation modes (Grieco, 2006). South Africa (and more specifically Gauteng) is one example of what McKay (2020) terms “transport poverty”, inhibiting especially poor residents from seeking employment, and accessing community and social services, thus constraining general participation in urban life. Travel costs are generally higher than people can afford because the South African transit system has not been able to adapt to increased demand for diffuse work and non-work travelling patterns in peak and off-peak times (McKay, 2020).

Private transport (car)

Cars are by far the most common form of transport worldwide (and its usage has also been increasing). Studies from the Organisations for Economic Co-operation and Development (OECD) (Buehler, 2011; Buehler & Pucher, 2011), European Union (EU) (Fiedler, 2007), the United States of America (USA) (Buehler 2011), Ireland (Commins & Nolan, 2008), Sweden (Pyddoke & Swärdh, 2015), the Netherlands (Limtanakool, Dijst & Schwanen, 2006), Malaysia, Algeria, Libya (Miskeen, Alhodairi, and Rahmat 2013; United Nations Human Settlements Programme [UNHabitat], 2014), and South Africa (Stats SA, 2014b) all indicate marked increases in car usage. Car usage percentages in the EU remain lower than in OECD countries (Buehler, 2011; Fiedler, 2007). Car usage in Germany has decreased despite people having greater access to them (Buehler & Pucher, 2011), and cars are still only the second most common form of transport in Malaysia despite rapid increases in their usage over the years (Nurdden, Rahmat & Ismail, 2007).

An increase in car usage is associated with various socio-demographic and socio-economic factors including gender, age, income, car and driver's licence ownership, land-use patterns and the type of dwelling where people stay, the distances travelled and the time spent travelling, convenience, safety and government policies. It is predominantly men who drive cars in Sweden (Pyddoke & Swärdh, 2015), the Netherlands (Limtanakool, Dijst & Schwanen, 2006), Libya (Miskeen et al., 2013), and Malaysia (Nurdden, Rahmat & Ismail, 2007), while car usage increases mostly amongst women in Germany (Buehler, 2011; Fiedler, 2007). Car usage patterns also differ among varying age groups. Studies in Ireland (Commins & Nolan, 2008), Sweden (Pyddoke & Swärdh, 2015), Malaysia (Chee & Fernandez, 2013), and South Africa (Simpson et al., 2014) show that cars are common among younger working individuals up to the age of roughly 50 (between 40 and 44 years old in Ireland, 50 in Sweden and 55 in Malaysia), after which car dependence begins to decrease. Conversely, studies about the EU (Fiedler, 2007), Netherlands (Limtanakool, Dijst & Schwanen, 2006) and Libya (Miskeen et al., 2013) found that cars are more common among the elderly (people aged above 50 in the Netherlands in particular but 55 in the rest of the EU). An increase in income is associated with an increase in car usage in Sweden (Pyddoke & Swärdh, 2015), Africa (UNHabitat, 2014), Malaysia (Chee & Fernandez, 2013) and South Africa (Simpson et al., 2014). Middle- to higher-income individuals in Africa rely mostly on cars (UNHabitat, 2014), and people in the highest income quintile in South Africa travel to work mostly in their cars (Simpson et al., 2014).

In the USA (Buehler 2011), Libya (Miskeen et al., 2013) and South Africa (Simpson et al., 2014) people generally drive cars if they own a car. Likewise, people who owned cars in the Netherlands were less likely to make use of buses and trams (Limtanakool, Dijst & Schwanen, 2006). Car ownership in Algeria resulted in such an increase in its usage that richer people relocated to peripheral locations thanks in part to the convenience associated with car travel, resulting in rapid urban expansion into rural areas (Democratic Republic of Algeria, 2014; UNHabitat, 2014). Car usage in Malaysia is associated with an increase in the ownership of a car and a driver's licence (Chee & Fernandez, 2013).

Sprawling land-use patterns associated with low-density detached dwellings located closer to the peripheral and rural areas of a city significantly increase the likelihood of car travel in Algeria (Democratic Republic of Algeria, 2014), OECD countries (Buehler & Pucher, 2011), Sweden (Pyddoke & Swärdh, 2015) and Ireland (Commins & Nolan, 2008). Conversely, people staying in apartments in more compact city designs in the EU and Ireland demonstrated a less rapid increase in car usage (Buehler & Pucher, 2011; Commins & Nolan, 2008). Car usage patterns are also affected by the distances travelled and the time people spend travelling. In the USA (Buehler, 2011), Netherlands (Limtanakool, Dijst & Schwanen, 2006) and South Africa (Mokonyama, 2008) driving cars allows for shorter travelling times and offers more flexibility. In Libya, cars are considered a more convenient form of transport when multiple stops are

required along a journey (Ismail & Elmloshi, 2011), while it is considered the safest form of school transport in Ireland (Commins & Nolan, 2008). Certain government policies in developed countries, but especially in developing countries and in South Africa, favour car-orientated travel (Simpson et al., 2014).

Public transport

The use of public transport (trains, buses, and taxis) increased in some countries worldwide, while other countries indicate a decrease, despite the governments' promotion of public transport as an ideal. In Germany, the number of people using public transport has doubled over the last three decades, with the share of trips rising from 11% to 18% (Buehler & Pucher, 2011). Buses are the second most common form of public transport in Malaysia (Nurdden, Rahmat & Ismail, 2007), while the use of taxis increased rapidly in South Africa: approximately 65% of the working age population now depends on this form of travel to get to work. Buses have also become more common in South Africa (Simpson et al., 2014). Conversely, residents in Ireland (Commins & Nolan, 2008) and Australia (Hensher, 2000) are less likely to make use of trains and buses.

Like car usage, public transport usage is associated with certain socio-demographic, socio-economic factors including gender, age, race, income, ownership of a car and a driver's licence, as well as land-use patterns, but also inconvenience, poor service, and a lack of safety. An integrated public transport system must offer a variety of forms of public transport and address these concerns.

Women are more likely to make use of public transport in Ireland (Lawson, McMorro & Gosh, 2013) and Malaysia (Nurdden, Rahmat & Ismail, 2007), while men use trains more often in South Africa than women (Simpson et al., 2014). Different patterns can be observed among the various age groups that use public transport worldwide. Public transport is more common among people aged 55 years and older in Malaysia (Chee & Fernandez, 2013), while mostly younger people use it in Germany (Buehler, 2011), Ireland (Lawson, McMorro & Gosh, 2013), South Africa (Vilakazi & Govender, 2014) and Australia (Corpuz, 2007). Australian users of public transport are generally younger than 20 and workers aged 15-24 years old in Ireland (Corpuz, 2007; Lawson, McMorro & Gosh, 2013). Race also plays a role in the use of public transport, e.g., train usage in Johannesburg and Tshwane is mostly associated with black patrons. Income plays a large role as well: in both Australia (Hensher, 2000) and South Africa (Simpson et al., 2014), rising income levels result in a decrease in the use of public transport, and in Australia, bus usage decreased where citizens owned a car and a driver's licence.

People residing on the periphery of cities in Australia made less use of buses than other forms of transport (Hensher, 2000) while those in Germany who work close to train stations typically use train services more often (Buehler & Pucher, 2011). Studies in South Africa (Vilakazi & Govender, 2014) and Malaysia (Chee & Fernandez, 2013) indicate that public transport is inconvenient, delivers a poor service and is unsafe. For example, some South Africans do not use trains due to poor services, insufficient capacity on trains and safety concerns. Additionally, many people have to walk some distance to train stations and often trains are late, which increases the traveling time of passengers substantially (Chakwizira & Mashiri, 2009; Gauteng Provincial Government, ca2015). It is therefore important to ensure that an integrated public transport system offers a variety of public transport options to increase its usage. For example, in Germany the train and bus service timetables are fully integrated and are displayed in real-time at all train and bus stops (Buehler & Pucher, 2011).

Non-motorised transport

Non-motorised transport (walking and cycling) has increased in popularity worldwide (Bhat, Guo & Sardesai, 2005; Bickford, 2013; Department of Transport, 2008), but its usage is

dependent on the socio-demographic and socio-economic factors present in developed and developing countries. Walking and cycling are considered more ecologically responsible in the USA (Bhat, Guo & Sardesai, 2005) and across Europe (Rietveld, 2001), and more cost effective than driving amongst wealthier South Africans (Department of Transport, 2008; Transport for Cape Town Directorate, 2005). Likewise in Germany, walking is more common amongst the higher-income population, elderly, and retired population (Buehler, 2011). Higher-density mixed land-use developments allow people (regardless of their economic class) to walk or cycle shorter distances to work and facilities in Germany (Buehler, 2011), China and India (Rietveld, 2001) and Ethiopia (Gebeyehu & Takano, 2007), thus reducing travel time significantly.

Conversely, bicycles have become more expensive in Kenya and Tanzania, putting cycling beyond the means of many people (Pendakur, 2005), while it is difficult to use bicycles in Ethiopia due to the inconvenient topography (Gebeyehu & Takano, 2007). Younger people between the ages of 15 and 44, as well as the elderly, were more likely to cycle in South Africa (Stats SA 2014b). Walking and cycling to work are common amongst lower-income and poorly educated men in Ethiopia (Gebeyehu & Takano, 2007), Kenya and Tanzania (Pendakur, 2005), China and India (Rietveld, 2001), and South Africa (Stats SA, 2014b). To summarise, Table 1 indicates recommendations from the literature for South Africa to achieve a sustainable and integrated transportation system.

Table 1. Some recommendations to achieve a sustainable and fully integrated transportation system.

<p>Overall policy initiatives to ensure an effective transportation system</p> <ul style="list-style-type: none"> • Ensure the integration and alignment of policy and legislation among the national and local spheres of government to ensure effective and sustainable transport planning that offers everyone easy access to a variety of activities through various modes of transport (National Planning Commission, 2011). • Assess the performance of the transport system in relation to current policy objectives, improvements, and recommendations on a periodic basis (Buehler, 2011). • Conduct regular travel demand surveys to identify the most common modes of transport to inform transport initiatives (Du Toit & Mbatha, 2013). • Assess and research the financial and spatial implications for improved public and non-motorised transport infrastructure development (Bickford, 2014; Chakwizira & Mashiri, 2009).
<p>Recommendations to reduce car usage</p> <ul style="list-style-type: none"> • Discourage the usage of cars by increasing the expenses associated with purchasing and maintaining cars and making it more uncomfortable to drive longer distances. Examples of this include: <ul style="list-style-type: none"> • increasing the tax payable when purchasing cars and forcing drivers to service their cars regularly (Du Toit & Mbatha, 2013), • limiting car ownership and tightening the conditions to obtain a driver's license (Chee & Fernandez, 2013), • increasing car registration fees (Buehler, 2011), • petrol prices (Corpuz, 2007; Pyddoke & Swärdh, 2015) and parking fees (Buehler, 2011; Chee & Fernandez, 2013; Corpuz, 2007), • implementing toll roads is another example that can be used to increase the costs associated with car travel (Chee & Nolan, 2008), and • reducing speed limits by constructing speed bumps and other traffic-calming methods along busy roads (Du Toit & Mbatha, 2013).
<p>Recommendations to increase the usage of public transport (trains, buses and taxis)</p> <ul style="list-style-type: none"> • Establish an integrated public transport system that will not only reduce commuter fares, but also increase people's accessibility between various day-to-day activities (Chee & Fernandez, 2013; Commins & Nolan, 2008; Corpuz, 2007; Sustainable Energy Africa, 2009). • Subsidise the public transport industry (e.g., the taxi industry) to ensure accountability and safety of users (Chee & Nolan, 2008; Nurdden, Rahmat & Ismail, 2007; Vilakazi & Govender, 2014).

- Establish real-time integrated train, bus, and taxi timetables, and increase the public transport options available during off-peak hours (Bickford, 2014; Corpuz, 2007; Sustainable Energy Africa, 2009).
- Upgrade public transport infrastructure regularly to ensure the safety of users (Commins & Nolan, 2008; Nurdden, Rahmat & Ismail, 2007).
- Employ more security personnel on trains and buses and at pick-up and drop-off locations and add security cameras along main routes (Bickford, 2014; Department of Transport, 2008; Du Toit & Mbatha, 2013).
- Redesign the interiors of trains and buses to ensure easy travel for various day-to-day activities. For example, the Gautrain has a carriage designed specifically for the airport, which allows for the easy placement and movement of baggage. The same can be done for various day-to-day activities including the implementation of workstations for the placement of laptops and dedicated areas for shopping bags (Gautrain, 2018).

Recommendations to increase the usage of non-motorised transport (walking)

- Create car-free zones that encourage people to walk to various activities in close proximity (Commins & Nolan, 2008; Rietveld, 2001).
- Implement speed restrictions and speed bumps to reduce car speeds in zones where pedestrians, cyclists and motorists are supposed to use the same road (Du Toit & Mbatha, 2013).
- Promote pedestrian-friendly transport infrastructure including wide enough sidewalks, cycling lanes, traffic-control devices (i.e., traffic lights for pedestrians and cyclists, speed bumps), grade separations (underpasses), kerb ramps, crosswalks, pedestrian-friendly intersections, and well-connected walkways (Bickford, 2014; Department of Transport, 2008).
- Ensure proper street-lighting to increase the visibility and safety of pedestrians and cyclists (Department of Transport, 2008; Rietveld, 2001).

Gauteng's urban transport context

Gauteng is the largest economic hub in South Africa resulting in mass migration patterns and rapid urbanisation. The inherited spatial fragmentation and sprawling socio-economic development patterns result in many transportation challenges: long commuting times, long journey times and great distances that buses, motorists, and trains travel between areas of residences with respect to areas of socio-economic opportunities (Chakwizira, Bikam & Adeboyejo, 2018). The Gauteng Spatial Development Framework (Gauteng Provincial Government, ca2015) promotes compact higher-density mixed land-use developments along existing and emerging nodes, corridors, and transit precincts to improve overall accessibility. Nonetheless, most South Africans continue to prefer single-use, low-density sprawling developments far from city centres that increase car dependence (Simpson et al., 2014). Likewise, many poor people in Johannesburg and Tshwane reside in townships located on the periphery, far from the city centre and socio-economic opportunities (Chakwizira, Bikam & Adeboyejo, 2018; Luke & Heyns, 2020).

Gauteng's Freeway Improvement Project aims to upgrade and expand the freeways across the greater Gauteng (more specifically in Johannesburg and Tshwane) to relieve congestion and improve accessibility. Road construction and highway expansion formed the key physical components of the project, while e-tolling was a financial mechanism (Chakwizira, Bikam & Adeboyejo, 2018) to upgrade and expand the urban road network by widening freeways, improving interchanges, and installing traffic-management systems amongst other things. It was also believed that tolling would reduce traffic volumes and encourage public transport usage, but in the absence of alternative routes and effective public transport, tolling received heavy resistance from various stakeholders (McKay, 2020).

The Bus Rapid Transit System and Gautrain were implemented to attract more public transport users (McKay, 2020; Oxford, 2013). Johannesburg and Tshwane's Bus Rapid Transit Systems comprise dedicated busway lanes. Johannesburg's route operates from Soweto and passes through Noordgesig, New Canada, Pennyville, Bosmont, Coronationville, Newclare,

Westbury, Westdene, Melville, Auckland Park and Parktown, and it links to the city centre. Tshwane's route will ultimately comprise 51 stations stretching from Soshanguve to Mamelodi and passing through the city centre and its surrounding suburbs (Musakwa & Gumbo, 2017; Rahim, 2014; South African Government, 2018). The Gautrain connects Gauteng's three metropolitan municipalities through three routes operating north-south between Hatfield and Parktown, east-west between Sandton and Rhodesfield, and Sandton and the OR Tambo airport (Gautrain, 2018). The Gautrain project does however suffer from inadequate and incomplete geographic coverage and spread (Chakwizira, Bikam & Adeboyejo, 2018).

Metrorail, the commuter rail operator of the Passenger Rail Authority of South Africa (PRASA) services limited neighbourhoods throughout Johannesburg and Tshwane. The Metrorail rolling stock is generally run-down and requires infrastructural refurbishments (Gauteng Provincial Government ca2015), while its integration with other public transport modes is complicated due to limited off-peak services. Many residents of Gauteng thus see taxis as more reliable public transport (City of Johannesburg, 2013; McKay, 2020). Taxi use in Gauteng has increased from 3% in 1975 to 41% (2009), while bus usage decreased from 22% to 4%, and train usage from 20% to 8% (Chakwizira, Bikam & Adeboyejo, 2018). Some taxi operators have no public accountability due to being privately owned, and subsequently participate in reckless and lawless behaviour on the roads including speeding, drunk-driving, unlicensed and uninsured vehicles, and disregarding road rules (Gauteng City-Region Observatory, 2013; Oxford, 2013; Saturday Star, 2014; Sustainable Energy Africa, 2009; Vanderschuren & Cloete, 2006).

Public transport can also be expensive (City of Johannesburg, 2013; McKay, 2020), with Johannesburg residents' (especially poorer black and coloured people) spending more than 10% of their income on transport (Vanderschuren & Cloete, 2006) due to longer travel distances to work (Simpson et al., 2014). Public transport users also fear for their safety (e.g., thefts occur regularly in overcrowded trains during peak times) (City of Johannesburg, 2013). Some taxi drivers ignore the warning signs at train-road crossings, resulting in accidents between trains and taxis (e.g., a train collision in Johannesburg in 2015 left 200 passengers injured) (eNCA, 2015; SABC, 2015). Overall, 34.6% of traffic accidents in South Africa in 2013 involved taxis, and a further 10.3% involved buses (Du Toit & Mbatha, 2013). Gauteng has the highest number of pedestrian fatalities contributing to traffic accident statistics; with most of the incidents occurring amongst the working age population. These statistics are attributed to the poor quality, incomplete, obstructed, or sometimes non-existent pedestrian and cycling footpaths on streets where cars are prioritised, making it difficult to crossroads (Gauteng Provincial Roads and Transport Department, 2013; McKay, 2020; Oxford, 2013).

Integration between various modes of transport and the ability to switch between private transport (car) usage and different forms of public transport still require improvement in Gauteng. The lack of a well-established public transport system (with a single public transport ticketing system for example) offering choices and convenience to commuters, increases car dependence (Chakwizira, Bikam & Adeboyejo, 2018; Musakwa & Gumbo, 2017). "[Generally] our passenger transport system[s] are broadly inefficient and not sufficiently customer focused with poor levels of reliability, predictability, comfort, and safety" (Luke & Heyns, 2020: 3563). To overcome this car dependence will require local municipalities to work together to intensify corridor development along nodal developments and increase transit-orientated development strategies around road and public transport facilities benefitting the entire province (Chakwizira, Bikam & Adeboyejo, 2018; Luke & Heyns, 2020).

Materials and Methods

Johannesburg and Tshwane are two metropolitan municipalities in the Gauteng province that function as the powerhouse of South Africa's economy. The 2016 Community Survey estimates

Johannesburg's total population is roughly 4.9 million, while Tshwane has approximately 3.2 million residents. Domestic and international financial services dominate Johannesburg's economy including commercial, retail, merchant banking, mortgage lending, insurance, and investment services, while the mining, manufacturing, information technology, telecommunications, electronics, pharmaceuticals, and construction industries are also important (City of Johannesburg, sine anno). Most of the government services and international embassies are located in Tshwane, the administrative capital. Tshwane's economy is propelled by information technology, telecommunications equipment, research and development and bio-medical industries, finance, and business service-sector development, with specific emphasis on financial services and technology, auxiliary business services, corporate head-office location, and business tourism (City of Tshwane, 2011). Figure 1 summarises the methodological steps taken for data collection and analysis. Figure 2 shows the variables used in the study and the reasons for doing so, and the reference groups used in the multinomial logit models.

Data source and sampling

This study uses the National Household Travel Survey (NHTS) (2013) conducted by Stats SA. The NHTS tracks people's travel patterns for various activities. The NHTS (2020) could not be used because it was only made available in November 2021, despite being conducted from January to March 2020. In 2013, 51 341 private households were selected from the Master Sample to conduct the NHTS. This study only used work-related travels of people aged older than 15; thus, equating to a sample of 7103 and 5462 in Johannesburg and Tshwane, respectively. Two sampling stages were used; the first grouped similar enumeration areas (EAs) from Census 2001 boundaries to form Primary Sampling Units (PSUs). PSUs refer to spatial areas that consist of a single or multiple EAs containing 100 or more dwelling units. Overall, 3080 PSUs were selected through a probability-proportional-to-size sampling method. The second stage systematically sampled 10 dwellings in each PSU according to household size, gender, education, occupancy status, industry, and income. The NHTS is thus representative of the South African population (Stats SA, 2014b). The NHTS defines private transport as driving or being a passenger in cars, bakkies, trucks, company vehicles, scooters or motorcycles, public transport as trains, buses, and metred and commuter taxis, and non-motorised transport as walking (Stats SA, 2014b).



Data processing and analysis

Multinomial logit models are the most frequently used transportation planning models, because it mathematically determines behavioural choices and reflects the priority factors influencing people's decision-making. The model can predict the likelihood of a specific event (e.g. use of private transport) based on the independent variables / factors (e.g. age). It can also determine the functional form and strength of relationships between the dependent (Y) and independent (X) variables to estimate the likelihood that a certain event will occur (Khan, 2007; Minal & Sekhar, 2014; Miskeen et al., 2013).

Two multinomial logit models were run to establish the existence of significant relationships between the dependent (mode of transport) and independent (socio-demographic and socio-economic) variables and to determine the likelihood of a particular mode of transport being selected over another in Johannesburg and Tshwane in 2013. Therefore, the multinomial logit model has one polytomous dependent variable consisting of 5 categories in this case (cars, trains, buses, taxis and walking) and eight categorical independent socio-demographic and socio-economic variables.



The general multinomial logit model thus uses the following formula (1):

$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \dots + \beta_n x_n + \varepsilon$ (1) with β_0 = constant and, β_i = coefficient for x_i while the response in formula (1) is as follows

$$Y = \begin{cases} 1 & \text{if the transport mode is a train} \\ 2 & \text{if the transport mode is a bus} \\ 3 & \text{if the transport mode is a taxi} \\ 4 & \text{if the transport mode is a car} \\ 5 & \text{if the transport mode is non - motorised (walking)} \end{cases}$$

The final multinomial logit models for Johannesburg and the Tshwane thus use the following formula (2)

$$Y = \beta_0 + \beta_1 x_{\text{gender}} + \beta_2 x_{\text{age}} + \beta_3 x_{\text{race}} + \beta_4 x_{\text{level of education}} + \beta_5 x_{\text{employment sector}} + \beta_6 x_{\text{individual monthly income}} + \beta_7 x_{\text{driver's licence ownership}} + \beta_8 x_{\text{vehicle ownership}} + \varepsilon \quad (2)$$

Figure 1: Methodological steps taken to collect, process and analyse data.

Statistical testing and interpretation of the multinomial logit models: Understanding coefficients

The dependent and independent variables each have a reference group. The coefficients of each variable should be interpreted relatively to the reference group identified for that particular variable (see the reference groups in Figure 2). The association of a specific event occurring is indicated through the positive (+) or negative (-) signs of the likelihood coefficients. A + sign indicates the likelihood of an event occurring, while a - sign indicates the unlikelihood of an event occurring. The coefficients should therefore be interpreted as follows: + coefficients indicate that an independent variable is more likely to use public and/or non-motorised transport instead of cars, while - coefficients indicate that an independent variable is less likely to use public or non-motorised transport instead of cars, implying that it is more likely to use cars.



Statistical testing and interpretation of the multinomial logit models: Understanding z-values

The relationship to the dependent variable and the significance of the independent variables are determined based on the z- and p-values respectively. The z-statistic is based on the coefficient and the standard error, and is used to test against a two-sided alternative hypothesis that the coefficient is not equal to 0 i.e.

$$H_0: \beta_1 = \beta_2 = \beta_3 \text{ or } \beta_3 = 0$$

$$H_1: \beta_1 = \beta_2 = \beta_3 \text{ or } \beta_3 \neq 0$$

z-values are normally set at 2 since critical values for a 95% confidence interval are $z = 1.96$ thus indicating that if $z = |2|$ at a maximum significance level of 0.05, all values between -2 and 2 will indicate that the independent variable does not have a significant relationship with the dependent variable (StatsProf, 2014). The 99% confidence interval will hence indicate a larger z value ($z=|2.58|$) which satisfies the criteria of the rule of thumb.



Statistical testing and interpretation of the multinomial logit models: Understanding p-values

The p-value tests the level of significance of the relationship between the variables and is indicated by different levels presented by a different number of asterisks for each. For example, some results could be statistically significant at the 0.05 level, and it is indicated by an asterisk: *. Other results are statistically significant at a 0.01 level and are indicated by a double asterisk: **, while other results are significant at a 0.001 level and are indicated with a triple asterisk: ***. The insignificant parameter estimates were removed and are indicated in grey in Appendices 1 and 2.

Figure 1: Continued.

Results and Discussion

Two multinomial logit models were run to determine the socio-demographic (gender, age, race, and education) and socio-economic (employment sector, individual monthly income, driver's licence ownership, vehicle ownership) factors influencing the selection of the mode of transport to work in Johannesburg and Tshwane in 2013 (Appendices 1 and 2). The NHTS' (2013) descriptive statistics and literature are used to explain the findings.

Variables used in the study	Reference category in the Multinomial Logit Model	Reason for inclusion and the literature indicating the variables' importance
<p>Mode of transport (Dependent variable): Car Train Bus Taxi Walking</p>	<p>Car: To identify the use of public transport and non-motorised transport over that of car use.</p>	<p>These modes of transport are the five most frequently used modes of transport according to the NHTS (Stats SA, 2014b).</p>
<p>Gender (Socio-demographic independent variables): Male Female</p>	<p>Female: To identify the specific mode of transport used by men over its use by women.</p>	<p>To determine the differences in the mode of transport used by men and women (Buehler, 2011).</p>
<p>Age (Socio-demographic independent variables): 15-24 years old 25-34 years old 35-64 years old 65 years and older</p>	<p>25-34 year olds: To determine the specific mode of transport used by all other age groups over that of the 25-34 year olds.</p>	<p>To determine the differences in the mode of transport used by people of different ages and life stages. The age group 15-64 years old represents the working age population (Stats SA 2014b). This is divided into the younger working generation of 15-24 and 25-34 year olds and the older working generation of 35-64 year olds. The elderly are represented by those that are 65 years old and above (Stats</p>
<p>Population group (race) (Socio-demographic independent variables): African/Black Coloured Indian/Asian</p>	<p>African/Black: To determine the specific mode of transport used by other race groups over that of African/Black people.</p>	<p>To determine the differences in the mode of transport used by people of the different population groups in order to determine if the apartheid patterns associated with transport are still evident in the post-apartheid era (Simpson et al., 2014).</p>
<p>Level of education (Socio-demographic independent variables): No schooling Primary education (Grades 1-7) Secondary education (Grades 8-12) Tertiary education</p>	<p>Tertiary: To determine the specific mode of transport used by people with no schooling, primary and secondary education over those with tertiary education.</p>	<p>To determine the differences in the mode of transport used by people with different levels of education. A person's education level is also an important indicator of their socio-economic status and the level of inequality present in society (Stats SA, 2014b).</p>

Figure 2: Variables used in the study.

Variables used in the study	Reference category in the Multinomial Logit Model	Reason for inclusion and the literature indicating the variables' importance
<p>Employment sector (Socio-economic independent variables): Formal sector Informal sector</p>	<p>Informal sector: To identify the specific mode of transport used by people who are employed in the formal sector over its use by people who are employed in the informal sector.</p>	<p>To determine the differences in the mode of transport used by people who are employed in different economic sectors. The sector of employment is an important indicator of a person's socio-economic status and the level of inequality present in society (Lawson, McMorro & Gosh, 2013).</p>
<p>Individual monthly income (Socio-economic independent variables): None R1-R500 R501-R2500 R2501-R6000 R6001-R16 000 R16 001-R30 000 >R30 000</p>	<p>R2501–R6000: To determine the specific mode of transport used by people earning a lower and higher individual monthly income than the specified income category.</p>	<p>To determine the differences in the mode of transport used by people who earn different levels of income. A person's individual monthly income is an important indicator of a person's socio-economic status and the level of inequality present in society (Vilakazi & Govender, 2014).</p>
<p>Driver's licence ownership (Socio-economic independent variables): Yes No</p>	<p>Driver's licence ownership (Yes): To determine the specific mode of transport used by people who do not have a driver's licence over those that have a driver's licence.</p>	<p>To determine the differences in the mode of transport used by people who have a driver's licence and those that do not (Chee & Fernandez, 2013; Limtanakool, Dijst & Schwanen, 2006).</p>
<p>Vehicle ownership (Socio-economic independent variables): Yes No</p>	<p>Vehicle ownership (Yes): To determine the specific mode of transport used by people who do not have a car over those that have a car.</p>	<p>To determine the differences in the mode of transport used by people who have access to a car(s) or a company owned car(s) (Stats SA, 2015).</p>

Figure 2: Continued.

Socio-demographic factors

In Johannesburg, the coefficients for gender in train usage were positive, indicating that men were 0.54 times more likely to commute by trains than women. Additionally, the coefficients for bus and taxi usage were negative in Johannesburg and Tshwane, indicating that men were more likely than women to travel by car instead of bus and taxi (0.84 and 0.25 times more likely respectively in Johannesburg, and 0.67 and 0.7 times more likely respectively in Tshwane). Descriptive statistics indicated that cars are the most dominant form of transport to work, especially among men in Johannesburg and Tshwane. Men remained more inclined to travel to work by train compared to women in Johannesburg and Tshwane. Literature indicates that people who stay closer to train stations are more inclined to use it (Lawson, McMorrow & Gosh, 2013; Nurdden, Rahmat & Ismail, 2007; Simpson et al., 2014). Conversely, descriptive statistics indicated that women were more likely to travel to work by bus or taxi (Stats SA, 2014b), which supports the literature that women mostly use public transport (Lawson, McMorrow & Gosh, 2013; Nurdden, Rahmat & Ismail, 2007; Simpson et al., 2014).

The positive coefficients indicated that all of the age groups in Johannesburg relative to the reference age group (25–34-year-olds) were 0.83, 0.44 and 1.07 times more likely to use trains compared to cars. Conversely, the youth (15–24-year-olds) of Tshwane relative to the same reference group were 0.59 times more likely to use taxis over cars. Descriptive statistics indicated that the elderly was less likely to use cars compared to other age groups, while the use of taxis was more universal amongst all age groups, except the working population aged 35–64 years old in Johannesburg and Tshwane. The multinomial logit models and descriptive statistics for Johannesburg and Tshwane confirmed the literature's findings that younger people mostly used public transport but indicated somewhat contradictory findings pertaining to the elderly's usage of cars (Buehler, 2011; Corpuz, 2007; Lawson, McMorrow & Gosh, 2013; Vilakazi & Govender, 2014).

The negative coefficients in the racial categories indicated that all the race groups, relative to black people in Johannesburg and Tshwane, were more likely to use cars over public and non-motorised transport. Compared to black people, coloured and white people in Johannesburg were between 1.03 and 3.61 times more likely to use cars than trains, taxis, and walking (white people were also 2.87 times more likely to use cars than buses). Indian/Asian people were between 0.94 and 3.04 times more likely to use cars over buses, taxis and walking in Johannesburg. White people were between 1.15 and 2.09 times more likely to make use of cars over trains, buses and walking in Tshwane. Coloured and Indian/Asian people were 3.05 and 3.79 times more likely, respectively, to travel by car than taxi in Tshwane. Descriptive statistics confirm that cars were the chosen mode of transport to get to work for all the race groups in Johannesburg and Tshwane, except for black people who were more inclined to travel to work by taxi. This phenomenon is often explained by the unemployment rate being higher among black people and the fact that they are often employed in lower-skilled jobs, resulting in lower wages and an inability to afford cars (Simpson et al., 2014; Stats SA, 2014b).

The positive coefficients indicated that lower-skilled people in Johannesburg and Tshwane, compared to those with tertiary education, were more likely to use public and non-motorised transport than cars. Those with primary education in Johannesburg were between 0.95 and 1.33 times more likely to use public transport in the form of trains, taxis and walking to work, while those with primary education in Tshwane were 0.96 times more likely to travel to work with buses. Conversely, people with secondary education were between 0.67 and 1.5 times more likely to go to work with trains, buses, and taxis in Johannesburg, while those with a secondary education in Tshwane were 0.76 and 0.98 times more likely to travel by taxi and bus, respectively. The descriptive statistics also indicated that individuals with primary education in both Johannesburg and Tshwane mostly travelled to work by taxi or went on foot (Stats SA, 2014b). Generally, these findings also support the work of Duffy (2009) and Simpson et al.

(2014) which concluded that less-educated people usually have lower-skilled jobs with lower-paying wages, and consequently make greater use of public transport.

Socio-economic factors

The positive coefficients indicate that people who work in the formal sector in Johannesburg, compared to the informal sector, were 0.54 and 1.07 times respectively more likely to travel to work by train and bus than by car. The negative coefficients for walking (-0.49 in Johannesburg and -0.93 in Tshwane) indicated that people working in the formal sector mostly commuted by car instead of walking to work. Descriptive statistics and the literature confirm that people who are employed in the formal sector have a steadier and higher income than those in the informal sector and consequently have collateral to pay off loans for purchasing cars (Stats SA, 2014b). Furthermore, people who were employed in the informal sector in Johannesburg and Tshwane were almost three times more likely to walk to work in 2013 than those in the formal sector.

All the coefficients in the individual monthly income categories below the reference group (R2501-R6000) were positive for Johannesburg and Tshwane, indicating that these individuals were forced to walk instead of using a car. Johannesburg's residents who fall in the R501-R2500 income category were 0.67 times more likely to walk to work, while Tshwane's residents falling in the R1-R500 and R501-R2500 income categories were 0.99 and 0.57 times more likely to do the same, respectively. Conversely, all the coefficients in the individual monthly income categories above the reference group were negative for Johannesburg and Tshwane, indicating that these individuals commuted by car. People in the R6001-R16 000 category in Johannesburg were between 0.42 and 0.83 times more likely to use cars over trains, taxis, and walking. Those in the same income category in Tshwane were between 0.49 and 0.96 times more likely to use cars instead of trains, buses, and taxis. Car usage was between 1.04 and 1.73 times more common among people in the R16 001-R30 000 income category in Johannesburg compared to all forms of public and non-motorised transport, while car usage was 1.32 times more compared to taxis in Tshwane. Lastly, people in Johannesburg and Tshwane who earn more than R30 000 are 1.25 and 2.02 times respectively more likely to commute by car than taxi. Descriptive statistics confirm that lower- and middle-income people are unable to afford cars and consequently are dependent on public and non-motorised transport. The literature also indicates that car usage increases as income increases, and that lower-income people mostly travel to work by public transport (Chee & Fernandez, 2013; Pyddoke & Swärdh, 2015; Simpson et al., 2014; UNHabitat, 2014).

The positive coefficients indicated that people who do not have a driver's licence in Johannesburg were between 1.16 and 1.76 times more likely to use public and non-motorised transport over cars, while in Tshwane they were between 1.17 and 1.92 times more likely to do the same. Descriptive statistics confirm that roughly 79% and 75% of people in Johannesburg and Tshwane who owned a driver's licence drove cars to work. These trends can be found in the literature (Chee & Fernandez, 2013; Hensher, 2000; Simpson et al., 2014). Likewise, the positive coefficients indicated that people who do not own a car in Johannesburg were between 1.78 and 2.09 times more likely to use public and non-motorised transport, respectively, while in Tshwane they were between 1.66 and 2.25 times more likely to do the same, respectively. Descriptive statistics confirmed that almost everyone who owned cars in Johannesburg and Tshwane drove to work. These results confirm the literature's findings that people who own a car generally drive to work (Corpuz. 2007; Stats SA. 2014b).

Conclusions

The aim of the study was to determine the socio-demographic and socio-economic factors influencing the selection of the mode of transport used to get to work in Johannesburg and Tshwane in 2013. The literature indicates that cars are the most common form of transport

worldwide; it is mostly used by men of working age up to 50, as well as the retired in middle- and higher- income households. Increasing vehicle and licence ownership also increases the likelihood of car usage, and individuals who live on the periphery of urban sprawl use cars more often, because driving is perceived to reduce the travel time associated with public transport. Public transport usage varies in developed and developing countries; in developed countries it is used mostly in densely populated urban areas where more sustainable and energy-efficient public transport is available, yet in developing countries it is used most often by low-income people and racial minorities. Younger and older generations who do not have a driver's licence or car also use public transport. The use of non-motorised transport grew slightly especially in developed countries due to it being more sustainable and energy efficient. The shift towards non-motorised transport has been relatively slow in developing countries due to poor infrastructure provision and walking still being viewed as the poor person's transport.

The results confirmed the literature's findings that cars were more common among men than women, and that women were more inclined to commute with buses and taxis in Johannesburg and Tshwane. Men were also more likely than women to commute by train in Johannesburg. These patterns could be related to the gendered differentiation of the job market (Lawson, McMorro & Gosh, 2013; Nurdden, Rahmat & Ismail, 2007; Simpson et al., 2014), in which men are usually more likely to be employed in more formal jobs with higher incomes and thus the ability to purchase cars. Conversely, many women are generally responsible for housework and child rearing and when employed, many take up informal employment positions, and are unable to afford cars.

Men were more likely than women to commute by train in Johannesburg. Train usage has increased among all age groups in Johannesburg compared to the reference group (25–34-year-olds), which mostly drove cars. Conversely, compared to the reference group in Tshwane it was only the youth group (15–24-year-olds) who chose taxis over private cars. Cars remained the most common form of transport for all racial groups, except for black people who commuted to work mostly by public and non-motorised transport in Johannesburg and Tshwane. One explanation for this is the social class and race-based inequality that is still present since apartheid, resulting in unemployment levels being higher among black people, while others are often employed in lower-skilled jobs, resulting in lower wages and the inability to afford cars.

Less-educated people in Johannesburg and Tshwane usually have lower-skilled jobs with lower-paying wages, making car ownership virtually impossible. Consequently, they use public and non-motorised transport more than others – in Johannesburg trains and taxis are more preferable to buses, while buses are more common among Tshwane residents. The opposite applies to people in Johannesburg and Tshwane with a tertiary education. Car usage remain the most dominant form of transport to the workplace for those in formal employment in Johannesburg and Tshwane, confirming the hypothesis in the literature that employment in the formal sector offers higher income and collateral to meet car loan payments. Formal sector employees in Johannesburg have however started to use public transport, mostly in the form of trains (most probably the Gautrain) and buses, but a similar trend has not been observed in the formal sector of Tshwane, which could probably be attributed to the phased bus rapid transit system development. Additionally, formal sector employees in Johannesburg and Tshwane were less willing to walk to work than drive. Echoing the findings of some studies elsewhere, having a lower individual monthly income in Johannesburg and Tshwane makes it difficult to afford cars and public transport, resulting in more residents walking to work. Conversely, the higher the income patterns, the more likely people are to travel by car in both Johannesburg and Tshwane. People who do not own a car and driver's licence in Johannesburg and Tshwane were more likely to use public and non-motorised transport – in Johannesburg trains are the most common choice, while Tshwane residents without a driver's licence travel mostly by bus, but those without a car travel by train. The results confirmed the literature's findings.

In conclusion, cars remained the most dominant form of transport to get to work in Johannesburg and Tshwane. The typical car user profile in Johannesburg and Tshwane was a male between the ages of 25 and 34, white, coloured, or Indian/Asian, highly educated and employed in the formal sector, earning a higher-income and owning a driver's licence and a car. Ecologically, increased car usage results in poor environmental quality and air pollution, increased congestion, increased travel time and increased numbers of traffic accidents. Conversely, a reverse profile is observed for those who travelled to work by public and non-motorised transport. Trains are the most common form of public transport in Johannesburg, suggesting that the effects of the Gautrain initiative have been paying off, and the successes of the Bus Rapid Transit system are obvious as Tshwane residents made more use of buses to work. Although less common than trains and buses in some instances, more cost-effective taxis continued to be used in Johannesburg and Tshwane – despite the non-regulation of the taxi industry which negatively impacts the driving behaviour of the operators. The increase in walking in Johannesburg and Tshwane could be attributed to people's inability to afford an alternative means of transport – or that they reside in relatively close proximity to their workplaces, but currently poor pedestrian infrastructure results in an increase in pedestrian fatalities. Overall, these results confirm an improperly functioning, unsustainable, unintegrated, unsafe, and bad quality public transport system. The existing transportation services thus reinforces the racial and class-based social exclusion of the South African society. It results in white wealthier communities' continued reliance on cars to travel to work, while the disadvantaged communities are caught in a transport poverty trap, which increases their dependence on public and non-motorised transport (Lucas, 2012).

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Appendix 1: Selection of mode of transport for work-related travel in Johannesburg (2013).

Johannesburg									
Independent Variable	Categories	Transport mode (Reference mode = Private transport [car])							
		Train		Bus		Taxi		Walking	
		Coefficient	z-value	Coefficient	z-value	Coefficient	z-value	Coefficient	z-value
Gender	Male	0.54	2.79**	-0.84	-4.55***	-0.25	-1.96*		
	Female (Ref)								
Age	15–24-year-olds	0.83	2.67**						
	25–34-year-olds (Ref)	0.44	2.19*						
	35–64-year-olds	0.44	2.19*						
	65 years and older	1.07	1.97*						
Population group (Race)	African/Black (Ref)								
	Coloured	-2.29	-3.71***			-1.05	-4.42***	-1.09	-3.30**
	Indian/Asian			-3.04	-2.98**	-1.56	-5.34***	-0.94	-2.54*
	White	-2.97	-2.89**	-2.87	-3.92***	-3.61	-6.03***	-1.03	-3.02**
Level of education	No schooling								
	Primary education	1.33	2.70**			0.96	3.17**	0.95	2.79**
	Secondary education	1.05	2.62**	0.67	2.44*	1.00	5.38***		
	Tertiary education (Ref)								
Employment sector	Formal sector	0.54	2.14*	1.07	3.45**			-0.49	-2.57*
	Informal sector (Ref)								
	R1-R500								
	R501-R2500							0.67	3.45**

Individual monthly income	R2501-R6000 (Ref)								
	R6001-R16 000	-0.83	-3.08**			-0.42	-2.72**	-0.6	-2.76**
	R16 001-R30 000	-1.59	-2.10*	-1.04	-2.04*	-1.73	-4.74***	-0.88	-2.29*
	>R30 000					-1.25	-3.34**		
Driver's licence ownership	Yes (Ref)								
	No	1.76	7.83***	1.16	5.63***	1.64	11.76***	1.69	9.35***
Vehicle ownership	Yes (Ref)								
	No	2.09	9.14***	1.78	8.77***	1.96	14.44***	1.84	10.51***
-2 log likelihood = -3045.9493		*p<0.05; **p<0.01; ***p<0.001			Mcfadden Pseudo R ² =0.3173		Ref = Reference group		

Appendix 2: Selection of mode of transport for work-related travel in Tshwane (2013).

Tshwane									
Independent Variable	Categories	Transport mode (Reference mode = Private transport [car])							
		Train		Bus		Taxi		Walking	
		Coefficient	z-value	Coefficient	z-value	Coefficient	z-value	Coefficient	z-value
Gender	Male			-0.67	-3.50***	-0.7	-4.58***		
	Female (Ref)								
Age	15–24-year-olds					0.59	2.20*		
	25–34-year-olds (Ref)								
	35–64-year-olds								
	65 years and older								
Population group (Race)	African/Black (Ref)								
	Coloured					-3.05	-2.94**		
	Indian/Asian					-3.79	-7.30***		
	White	-1.59	-3.49***	-2.09	-4.64***			-1.15	-3.43**
Level of education	No schooling								
	Primary education			0.96	2.02*				
	Secondary education			0.98	2.70**	0.76	3.35**		
	Tertiary education (Ref)								
Employment sector	Formal sector							-0.93	-3.90***
	Informal sector (Ref)								
Individual monthly income	R1-R500							0.99	2.14*
	R501-R2500							0.57	2.40*

	R2501-R6000 (Ref)								
	R6001-R16 000	-0.96	-3.01**	-0.69	-2.58*	-0.49	-2.50*		
	R16 001-R30 000					-1.32	-3.75***		
	>R30 000					-2.02	-3.14**		
Driver's licence ownership	Yes (Ref)								
	No	1.59	6.28***	1.92	8.06***	1.17	6.77***	1.77	7.72***
Vehicle ownership	Yes (Ref)								
	No	2.25	9.10***	1.66	7.67***	2.04	11.83***	1.79	8.26***
-2 log likelihood = -2238.4807		*p<0.05; **p<0.01; ***p<0.001			Mcfadden Pseudo R ² =0.3026		Ref = Reference group		

An exploratory foray into visual street art and graffiti in south African cityscapes

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Abstract

Street art is a prominent feature of contemporary urban cityscapes. Locales such as South African cities offer a rich heritage of street art. This controversial phenomenon has been subject to both veneration and condemnation by its diverse audiences which range from law enforcement to the media to property owners and the public. In its interactions with public space, street art has been demonstrated to promote tourism and help to uplift communities. Moreover, it has permeated the realm of social (and geosocial) media so allowing insight into new complex linkages between the urban sphere and its inhabitants. Conversely, it has been censured as being nothing more than vandalism. The nuances of the value and disadvantages of street art are highly complex and dynamic in nature, so that only recently has comprehensive investigation into the urban processes which surround it, such as gentrification, commodification, and urban control, been undertaken in the distinctive South African cityscapes. This paper reviews the existing literature on street art and graffiti and the themes that have emerged which are vital to developers, planners, institutions and governments for better management and preservation of these complex urban art resources and their authentic historical and cultural landscapes.

Keywords: gentrification, geosocial media, graffiti, street art, urban geography

Introduction

South Africa offers a rich heritage of street art, and this controversial phenomenon has been subject to both veneration and condemnation by diverse audiences which range from law enforcement to the media to property owners and to the public. In its interactions with public space, street art has been demonstrated to promote tourism and aid the uplifting of communities. Moreover, it has permeated the realm of social (and geosocial) media so providing insight into new complex linkages between the urban sphere and its inhabitants. Conversely, it has been censured as being nothing more than vandalism. The nuances of the value and disadvantages of street art are highly complex and dynamic in nature and have received scant academic exploration. With the aim of addressing this knowledge gap, particularly in South African cities, this exploratory paper provides an integrative overview and synthesis of the existing writings on street art and graffiti from academic and grey literature sources (Snyder, 2019). The paper is organised to align with the dominant themes and trends

identified from international and local literature and the aim is to explicate some of the important terms and concepts. It is important that researchers provide clear and unambiguous definitions of the terminology and concepts to provide comprehensive explanations of street art and graffiti in South African cityscapes.

Overview of the main types of graffiti and street art

The main types of graffiti vary in their medium, content and intent, but they all have a similarity that is implicit in the processes and practices: graffiti practices are centred on identity. One of these practices is known as tagging. ‘Tags’ refer to graffiti writers’ and artists’ stylised signatures, usually one-dimensional and meant to stand out boldly. This is often achieved by using colours in sharp contrast with the surface on which a tag is placed (Figure 1). Tags are pseudonyms used by graffiti writers and artists, either to represent their signature style¹ or for anonymity.



Figure 1: A tag by the artist iwe on a fibre-cable box in Woodstock, Cape Town. Source: Authors (2020).

Another common type of graffiti is the bubble-style letters of ‘throw-ups’ (Young, 2012). A throw-up is essentially a stylised signature like a tag, except it is two-dimensional (Figure 2). Tags and throw-ups often aim to achieve recognition and to gain rapport with the graffiti community.



Figure 2: A throw-up by the artist BIAS on a boundary wall in Braamfontein, Johannesburg. Source: Authors (2020).

While tags and throw-ups are centred on the representation of the artists themselves, street art does not have a central focus but lends itself to many forms, techniques, and mediums. A valid distinction is that street art is often more image based, whereas graffiti is more writing based (Blanché, 2015). ‘Pieces’, short for masterpieces, are one of the most well-known forms of graffiti and street art. Pieces are murals with more than one dimension, like throw-ups, but they do not solely illustrate the artist’s name; they are more complex and have an image-based focus (see Figure 3).

¹ Graffiti names can be seen as stage or performer names, their personas as graffiti artists and their tags

are a form of branding in the urban space (Spoceter, 2004).



Figure 3: A piece by the artist Nardstar on a boundary wall in Woodstock, Cape Town. Source: Authors (2020).*

Apart from these commonly known types of urban artwork, street art is a diverse innovative practice which is usually not centred on the artist's name but extends to generating new creative revolutions for altering urban space. This includes the use of stencils, street sculpture, wheat paste, installations, stickers, mosaic, art intervention, yarn bombing and even modifying existing media such as billboards or posters (Young, 2012). Furthermore, these techniques are constantly being improved upon, for example by the creation of specialised 'eggshell stickers'.²

Because graffiti and street art are so notoriously diverse in scope and nature, there has been widespread debate about how precisely to define them, and how to differentiate between them. An artwork may thus be either graffiti or street art, or both in some cases. In this paper street art and graffiti are not deemed to be synonymous terms, although it is recognised that the genres do occasionally overlap. To aid classification, the distinctions between graffiti and street art are laid out as follows:

- Graffiti is centred on identity, on the artist's name, it is text based.
- Street art has more diverse visual elements which may or may not include the written name of the artist, often more picture based than text based.
- While graffiti can take on many forms, it is commonly limited to spray-painting or using markers or brushes for line work.
- Street art is widely diverse and can take on a multitude of forms such as stencils, installations, stickers, yarn bombs, mosaic, etc.

² Eggshell stickers are specifically designed for street artists and are made to crumble (like an eggshell) in response to efforts to peel them, so counteracting attempts at their removal. The removing of eggshell stickers are extremely time-consuming and laborious tasks.

Despite their extensive range and complex nature, one can usually quite readily classify what can be deemed to be either graffiti or street art. However, other issues need to be addressed to enable one to understand these dynamic urban phenomena more clearly, namely how do they shape perceptions and spaces alike, and how does one differentiate graffiti and street art from other visual phenomena such as vandalism, advertising, and formalised public art³ (Cavendish, 2019; Viljoen, 2015)?

Differentiating between public art, vandalism, graffiti and street art

Most urban residents can readily recognise graffiti and street art because they have either seen them or they may even know about famous street artists such as Banksy, Keith Haring or Obey (a.k.a. Shepard Fairey). However, finding a suitable and comprehensive definition across the literature on graffiti and street art has proven to be quite challenging, there being a multitude of definitions that are either too broad or too narrow in their scope. On the one hand the definitions are only applicable to specific types of graffiti and street art and on the other too broad to exclude other forms of visual art, such as formalised public art. Furthermore, graffiti and street art are used interchangeably in some literature but treated as distinctly different in other publications (MacDowall & De Souza, 2018).

Blanché (2015: 32) opines that “[s]ince about 2005, a range of academic authors have already tried to answer the question, “What is Street Art?” A lot of them don’t write in English.” The prominent street artist, John Fekner, stated that street art is “...all art on the street that’s not graffiti” (Lewisohn, 2008: 23). From this definition it can be deduced that graffiti and street art are different phenomena. Gleaton (2012: 1) asserts that graffiti and street art are different, but they do not explicate what the differences between the two are: “Typically the terms are used synonymously but works belonging to each term possess qualities that represent differences in style, motivation, and purpose.” Gleaton (2012) further maintains that under the umbrella term ‘unsanctioned art’ the phenomena have many forms and mediums. Furthermore, it is held that while artists have diverse incentives that motivate their work, they have the potential to contain powerful subversive messages for social engagement and activism (Gleaton, 2012; Spocter, 2004).

Ross (2016: 476) puts forward definitions which make a distinction Gleaton (2012) does not make, namely that graffiti “...refers to words, figures, and images that have been written, drawn and/or painted on, and/or etched into or on surfaces where the owner of the property has NOT given permission.” Alternatively, he defines street art as a “...wide range of expressions, including sculptures, installations, wall paintings and stencils, stickers, and artistic/noncommercial [sic] posters that are affixed to surfaces where the owner of the property has NOT given permission for the individual to place them on it. This may include words, figures, images and/or a combination of these” (Ross et al., 2017: 411). This is an acceptable, though not extensive enough, definition. Bengtson (2014) has asserted that it is impossible to ever define street art due conclusively to the constant negotiations on precisely what it comprises. However, Blanché (2015: 33) offers a more wide-ranging definition of street art

³ “...formal public art is required to conform to very specific standards and requirements. The implication of this is that much formalised public art is made from similar, long-lasting materials and are located in locations where investment is made – for example, civic areas, new developments, etc. Formal public art is sanctioned by a governing body or similar, and has generally gone through a process of curation, development and implementation. Examples include statues, murals, installations, sculpture, mosaic, etc...[m]ore informal versions of public art are called ‘graffiti’ or ‘street art’” (Cavendish, 2019: 18).

that allows a deeper understanding of the term and touches on multiple issues, the nature of which, contributes to its exclusion from other art forms, such as formalised public art, namely:

Street Art consists of self-authorized pictures, characters, and forms created in or applied to surfaces in the urban space that intentionally seek communication with a larger circle of people. Street Art is done in a performative and often site-specific, ephemeral, and participatory way...it differs from Graffiti and Public Art.

It is reasonable to conclude that (most) graffiti can be street art, but not all street art is graffiti, i.e., the one becomes "...a subcategory of the other" (MacDowall & De Souza, 2018: 5). Ross et al. (2017: 91) have pointed out "...that while the unsanctioned nature of graffiti and street art is often highlighted as a central characteristic, there are also scholars who use these terms to refer to sanctioned work." One such author is Kramer (2016) whose research centred on legal graffiti in New York City. What is problematic about this view is the distinguishing of graffiti or street art from formalised public art.

It seems implicit in the term 'street art' that it is located in the public sphere. Enquiry into the role of the 'street' in street art has become more commonplace (MacDowall & De Souza, 2018; Riggle, 2010). Riggle (2010: 244) advanced that "...'the street' is taken in a very broad sense to denote, roughly, any urban public space." He demonstrated the complication of this by the example of a gallerist unloading paintings from a car to take them into a gallery, but while they are outside on the street, leaning against the car, they are clearly not 'street art', even though it is technically 'art in the street'. Hence, we cannot simply say that street art is art placed on the street. It is certainly a feature of street art to be in the street, but what sets it apart is that the meaning of street art is inextricably linked to location and space. Consequently, the intrinsic meaning of street artwork is lost when removed from the street (Riggle, 2010).

One can surmise that street art can be defined on the grounds of three premises. First, street art comprises artwork of varying mediums and types, and it is either sanctioned or unsanctioned. Second, street art is in the public sphere. Third, the intrinsic meaning of street art is linked to its situation on 'the street'. While seemingly adequate for broadly defining street art, the premises raise problems for defining graffiti. The third premise implies that graffiti is not street art because the material use of the street is not essential to the meaning of a piece of graffiti. Therefore, while graffiti is in the public sphere, its location in the street makes no difference to the meaning of a piece of graffiti. Regarding graffiti, Riggle (2010: 251) contends that "[i]t means the same in a public bathroom, on an alley wall, or on a bus." Considering this contention, it is useful to differentiate between two different kinds of graffiti, namely what Kimvall (2014: 11) refers to as "graffiti vandalism and graffiti art", or what Riggle (2010: 251) classifies as 'mere' graffiti and 'artistic' graffiti:

Mere graffiti is ... graffiti that says, "so-and-so was here," or "Jack loves Jill." Mere graffiti is not art, so the question of its status as street art does not arise. The salient question is whether and when artistic graffiti is street art.

It is difficult to define artistic graffiti because it comprises so many various forms and techniques, and often the distinction between artistic and mere graffiti is blurred. Archetypal artistic graffiti is exemplified by the well-known graffiti produced in New York in the 1970s and 1980s (Riggle, 2010). This kind of graffiti has a clear intention and therefore its meaning is probably linked to the street. Artistic graffiti can be categorised as a subtype of street art. Riggle's (2010: 252) working definition of artistic graffiti is: "...artistic graffiti is public writing in a distinctive style, created with a particular attitude." But Riggle (2010) maintains that this definition does not necessarily submit proof that the material or physical use of the

street is intrinsic to its meaning, one can rather argue that the definition demonstrates the opposite. The intention, motives, and underlying message in artistic graffiti all, in a sense, manifest its bond to the tangible use of the street and serve to undermine government control by ‘hijacking’ state property, especially the state’s valuable (and visible) resources such as trains. Because ‘the street’ is state property, if artistic graffiti were located anywhere but the street, it would lose much of its meaning. The New York train graffiti was not simply communicative but had a distinctive visual style (most often bubble-style throw-ups), so its artistic merit was certainly recognisable. Distinctive style and attitude are the vehicles through which the physical, material street is used to give meaning.

We now have definitions of both street art and graffiti, but because they remain ambiguous a question persists that needs to be addressed: What differentiates street art and graffiti from public art? Certainly, all street art and graffiti are public art, i.e., art that is situated in the public sphere, but not all public art is street art or graffiti. Since graffiti and street art can be either sanctioned or unsanctioned, how does one differentiate between them and formalised public art? Riggle (2010: 253–254) gives the following example as illustration:

Richard Serra’s much-discussed Tilted Arc—a large steel slab 120 feet long, 12 feet high, and 2.5 inches thick, placed in the center of New York City’s Federal Plaza...enraged the public it addressed, and in 1989 it was dismantled against the will of the art world. Any street artist or street art enthusiast would deny that Tilted Arc is street art. Yet...:

- (1) *Tilted Arc’s use of public space is internal to its meaning.*
- (2) *By using this public space, Tilted Arc uses the street.*
- (3) *So Tilted Arc’s use of the street is internal to its meaning.*
- (4) *Therefore, Tilted Arc is street art.*

Premise (3) follows from (1) and (2) by simple logic, and premise (4) follows from (3) and the definition of street art. Premise (1) is very difficult to deny. Serra conceived and designed the piece specifically for Federal Plaza, and a National Endowment for the Arts Site Review Advisory Panel concluded that Tilted Arc was a site-specific piece.

An additional element which could be instrumental in the differentiation of formalised public art from graffiti or street art is ephemerality, that is whether the artwork in question is meant to remain as a planned permanent feature or if its temporal nature is left to chance (at risk of removal, vandalism, or destructive exposure to the elements). Virtually all use of public space by public monuments and sculptures lacks a commitment to ephemerality (Riggle, 2010). DeNotto (2014) has highlighted the importance of properly managing street art resources because of this ephemerality. He points out that unsanctioned street art is readily removed by authorities (because it is considered vandalism, and sometimes because it challenges the dominant status quo of which these authorities are part); often vandalised by the public; or simply weathered by the natural elements. Its fragile and fleeting existence, in combination with its value as a subject of research and its ability to stimulate social engagement, “...demonstrate the importance of street art curation and distribution in both online and print collections and archives” (DeNotto, 2014: 2).

Riggle (2010) gives five prerequisites for an artwork to be classified as graffiti and/or street art, so differentiating it from other forms such as vandalism or formalised public art. It must be artistic or stylistic; intentionally situated in the urban public realm, in the street (not in nature); it must be linked to its location on the street; it must be site specific; and it must be ephemeral in nature. Although these four provisions are adequate for differentiating graffiti and street art from other art forms, a unique situation can exist where ephemerality is inadequate for

separating them from formalised public art. Sommer (1975) used the term ‘street art’ to describe legal and planned murals as well as wall paintings in the United States of America as early as the mid-1970s, while later Derwanz (2013: 112) described street art as “an art form directed towards communicating with masses of inhabitants and passers-by that is planned and approved for exhibition in public spaces.” In Cape Town a situation exists where street art can retain its ephemeral nature while simultaneously being legal and planned. The City authorities can issue a permit to street artists to create a street artwork, thus avoiding the severe consequences of potentially being caught doing it illegally.⁴ An application for the permit requires a sketch of the design planned by the artists, which is approved or rejected by the deciding body. Mathews (2010) raised the matter whether the authorities have sole discretion in what content is acceptable or not. This virtually rules out all potential artwork having negative political overtones because governments would not approve any artwork which criticises them or would make the population question their actions. Notwithstanding official disapproval, such undemocratic behaviour, the ability and the freedom to deliver social and political commentary are essential to the historical subculture of graffiti and street art.

Public space, graffiti and street art

The urban spheres of the world do not exist arbitrarily as physical entities that simply happen to have come into being by rational and historical processes, nor do they exist in a vacuum as stand-alone entities; there have always been social and representational driving forces underpinning them. Whether by the hands of city planners, developers, the state, or community organisations, it has always been a human imperative to create, manage and control their environments, and with said control comes predictability, certainty and a sense of security. Hence the need for social entities to design a consistent, coherent representation of their ideal environment, and the necessity to go about the practices that enforce this representation. Part of this vision is the visual representation of a space (Mathews, 2008). The latter does not simply serve those who inhabit or routinely visit such spaces because a desirable visual representation of spaces acts as a marketing tool for acquiring investment by attracting tourists, new residents and new businesses (Mathews, 2008; 2010). The questions are: Who decides on the ideal visual representation in the public sphere? Who does it serve? And, perhaps more importantly, who does it exclude (Viljoen, 2015)?

Public images, especially public art, are one of the many tools used by developers, planners, institutions, and governments to create and promote a sense-of-place. Deutsche & Ryan (1984) articulated that images in urban areas, such as public art in cities, create the dynamic dialogues and discourses that shape the meanings and experiences associated with that space. They can then be conceived as fuelling the processes of urban control, policing, and security, and if used correctly they can obscure glaringly obvious social disparities and other inequalities (Mathews, 2008). Informal public art, such as graffiti and street art, can undermine the dominant authority that seeks to uphold a visual representation that does not necessarily fit harmoniously with the view of all citizens. Therefore, a great deal of energy (and expenditure) has been invested in public urban centres to control and vanquish the (often imaginary) threat posed by graffiti and street art (Viljoen, 2015).

⁴ The punishment as per the 2010 graffiti by-law is a R15 000 fine or three months’ imprisonment for first-time offences, and this doubles for subsequent prosecutions (Province of Western Cape, 2010).

Regarding the neo-liberal city, Mathews (2008: 2863) observed that public spaces (and consequently the public art contained within them) are routinely produced en masse through "...privatisation, rationalisation and commercialisation." This can be seen as the theming of spaces (Gottdiener, 2001) that often removes the visibility of the underlying reality by diminishing the value of anything to merely its image or symbol, or as Mathews (2008: 2863) maintains: "Themed spaces lead to ruptures in place, cutting into social, economic, historical and cultural contexts." Such ruptures can be seen in the reorganisation of existing authentic demographic strata where communities are reshuffled, and the resulting inequalities are hidden by the 'theme' or in the phasing out of long-established businesses to make way for those better suited to the new theme. This results in entire historical and cultural sense-of-place becoming lost, which is often elucidated by the process of gentrification.

Gentrification and its role in restructuring urban space

The process of gentrification is a phenomenon that has received much attention since some of its more deleterious effects were noted as early as the 1960s in many cities, for example Tokyo, Sydney, Toronto, and Hamburg (Smith, 2005). Individuals and institutions consider gentrification variously. Thus, gentrification has been described as "...the rehabilitation of working-class and derelict housing and the consequent transformation of an area into a middle-class neighbourhood" (Smith & Williams, 1986: 1). This definition is, however, oversimplified insofar as two major issues, displacement, and loss of sense-of-place, are excluded from the term's essence. Smith (2005: 28) has cited a 1988 article in the *New York Times* which described gentrification as "...the upgrading of housing and retail businesses in a neighbourhood with an influx generally of *private* [italics in original text] investment... a contributor to the diversity, the great mosaic of the city...." Conversely, Smith (2005: 30) hints at gentrification's undesirable nature in his scholarly definition:

Gentrification is the process... by which poor and working-class neighbourhoods in the inner city are refurbished via an influx of private capital and middle-class homebuyers and renters—neighbourhoods that had previously experienced disinvestment and a middle-class exodus. The poorest working-class neighbourhoods are getting a remake; capital and the gentry are coming home, and for some in their wake it is not entirely a pretty sight.

The term gentrification was coined in 1964 by the distinguished sociologist Ruth Glass who used it in reporting research about the linkages between housing and class struggle in London (Glass, 1964). A major issue of the phenomenon was that "[o]nce this process of 'gentrification' starts in a district it goes on rapidly until all or most of the original working-class occupiers are displaced [by middle-class newcomers] and the whole social character of the district is changed" (Freeman, 2016: 163). Many individuals were familiar with the negative impacts of gentrification, especially on the previous and contemporary poor inhabitants of gentrified areas. In Australia the term 'trendification' is used synonymously with gentrification where the middle class 'yuppies' who move into these gentrifying areas are referred to as the 'hipeoisie' who in turn describe gentrification as neighbourhood recycling, upgrading and renaissance (Lees, 2003; Smith, 2005; Wyly & Hammel, 2008). Such descriptions detract from the class and racial associations of gentrification. The early appeal of gentrification, according to Smith (2005: 30), was the apparent benefit and hopefulness of gentrification, "...the sense of modernization, renewal, an urban cleansing by the white middle classes." The philology of 'regeneration', 'recycling' and 'revitalising' insinuates that the areas to be gentrified are in one

or more ways deficient, devitalised, dilapidated, and “...culturally moribund...” (Smith, 2005: 30), therefore requiring gentrification for improvement.

The gentrification process can sometimes genuinely serve the betterment of an area, socially, culturally, physically, and economically. Unfortunately, gentrification is notorious for its negative impacts on neighbourhoods where authentic, valuable, and blameless working-class communities often become devitalised as their cultural, social, economic and physical structures become deracinated, reshuffled and even eliminated by the activities of the new middle-class residents (Smith, 2005). Donaldson et al. (2012) argue that while there are many urban policy frameworks for urban densification, inner-city regeneration and urban heritage conservation, there are often ‘hidden’ undesirable impacts resulting from gentrification.

Many of the prominent authors on gentrification have based their studies in the global North at sites like London, Vancouver, Chicago, New York, and Paris (Atkinson, 2000; Butler & Lees, 2006; Carpenter & Lees, 1995; Davidson & Lees, 2005; Hwang & Sampson, 2014; Ley & Dobson, 2008; Slater, 2004). More recently gentrification has become a prevalent research topic in the global South in countries such as China, India, Brazil, and South Africa (Lees, 2014).

Gentrification, graffiti and street art

The dynamic between gentrification and art in the urban sphere has been considerably transformed depending on economic, cultural, political, and social processes. Scholars have noted how graffiti and street art have influenced gentrification and been influenced by it in return. Some of the earliest academic research into the connections between art and gentrification developed in the context of New York⁵ where particular interest was directed at areas such as the Lower East Side, Tribeca and SoHo (Cole, 1987; Deutsche & Ryan, 1984; Mathews, 2010; Zukin, 1982). These findings clearly witnessed that art and the art establishment could be directly linked to gentrification. The extent to which these linkages exist, and their nature are specific to each diverse context and mirror the processes inherent within the underlying circumstances (Mathews, 2010).

Smith (2005) has drawn attention to graffiti being used to either mobilise events with the sentiment of opposition to gentrification and homelessness or to deliver social commentary on these topics in Sydney, New York, Goslar and Granada. The 1988 Tompkins Square Park riot in New York was one such event where both these specific embodiments of graffiti against gentrification and homelessness were present (*The Daily Beast*, 2010; Smith, 2005). Following the riot there was a visible increase in the creation of art that delivered social commentary, much of which was specifically directed at addressing gentrification and policing (as well as towards the art industry itself) (Smith, 2005). Because many artists (including many graffiti artists and street artists) were becoming homeless or were activists concerned with housing issues, much subversive and rebellious artwork appeared in various forms such as posters, flyers, and graffiti, some even in more contemporary and edgy gallery spaces. For example, the well-known work by Castrucci and Coen (1992), *Your house is mine*, is an oversized book documenting many of the posters, graffiti, street art, installations and other artwork resulting from the Tomkins Square Park riot. In these cases, the link between art and gentrification is

⁵ Some of the initial studies on graffiti and street art were also situated in the New York context as this was where they emerged in earnest as a recognisable new subculture.

quite apparent. Artists deliver socio-political commentary on the truth that gentrification can compromise the livelihoods of the working class, to exacerbate homelessness, and lead to the collapse of authentic neighbourhood imaginaries.

Deutsche and Ryan (1984), citing the Lower East Side in New York City, have commented on how art within a neighbourhood can actively participate and contribute to the area's gentrification. They further asserted that this process is not a coincidence, rather it is the result of the art industry's role in shaping the system within which the art is situated. They emphasised that the countercultural stance for which neo-expressionism⁶ in art was heralded, was actually a representation of the dominant culture which it sought to undermine, due to "...abstention from political self-reflection..." (Smith, 2005: 17). In other words, controversial, subcultural stances are still ones that have been born from the dominant system and remain part thereof. It is not surprising that art has become branded and commodified for consumers.

Contrasting South African cityscapes for street art and graffiti: Woodstock and Braamfontein

Woodstock, a neighbourhood in Cape Town, is a well-known focal point for research on gentrification and the street art and graffiti of the area are well documented. Woodstock is one of the few multiracial spaces which survived the deliberate 'whitening' of South African cities during apartheid. Enabled by the formalisation of the apartheid legal codes, racial segregation and institutional inequalities became entrenched in South African cityscapes. Woodstock was fatefully left untouched by the Group Areas Act of 1950, and it circumvented many of the large-scale, racially motivated removals which were characteristic of the apartheid government's urban planning. Consequently, the suburb retained a comparatively multiracial and culturally diverse community compared to the neighbouring suburb of District Six (Fleming, 2011). The end of apartheid and the transition to democracy in 1994 did not, however, result in the continuation of Woodstock's historic spatial integration. Since the early 1980s there has been a rise in residential prices in Woodstock which is associated with a sustained process of gentrification that has radically reorganised the dynamics of inclusion and participation. Regardless of the seemingly mixed racial and socio-economic inhabitants of Woodstock, gentrification has led to stark inequalities with the members of different communities being intermixed temporarily by market forces, but these communities live in contrasting relationships of power and participation. The low-income residents of Woodstock have become excluded through increasing evictions from low-income rental housing while the individuals and properties are being replaced by those of higher income (Fleming, 2011).

Preceding the 2010 FIFA World Cup™, the City of Cape Town sought to improve the city in preparation for the arrival of international tourists and potential investors who would attend the hallmark event. Hence the 2010 City of Cape Town Graffiti By-law was implemented to control unauthorised graffiti and street art (Mann, 2016). The same by-law was proposed (but never implemented) for Johannesburg in 2016 by Mayor Herman Mashaba and some areas in the city are known to be 'graffiti-friendly', the neighbourhood of Braamfontein being one of these (Sosibo, 2016).

⁶ Neo-expressionism is the late modernist and early postmodern painting and sculpture styles of the 1970s. Neo-expressionists were sometimes called Transavantgarde, *Junge Wilde* or *Neue Wilden*. Neo-expressionism is characterised by intense subjectivity and the rough handling of materials (Ingersoll, 2017).

Braamfontein has a wealth of documented graffiti and street art, and the area hosts street art events and festivals almost annually. Studies in Braamfontein have identified the urban phenomenon of studentification, a subtype of gentrification. Although extant literature makes mention of retail and commercial gentrification and how street art walks can contribute to slum tourism in the area (Gregory & Rogerson, 2019), the complex linkages between gentrification (and studentification) and graffiti or street art have yet to be subjected to intensive academic investigation. In the 1980s and 1990s Braamfontein began to exhibit early indicators of urban decay and stagnation caused by capital flight during that time in response to the dismantling of apartheid and the ‘greying’ of many inner-city neighbourhoods. This stimulated the call for urban redevelopment and rejuvenation through policy intervention which led to the establishment of one of the earliest city improvement districts, the Braamfontein Improvement District. This situation places the onus on the owners of private property to fund the private urban management of the area and, in combination with the rapid increase in the student population following the massification of tertiary education, the area developed into a hub for student activity and student housing (Gregory & Rogerson, 2019). The ensuing studentification has commercially gentrified the area and refocused its retail sector to suit student needs. Braamfontein contains certain retail spaces which are supportive of graffiti and street art, such as graffiti markers and spray cans, but if and how this is related to the studentification is yet to be uncovered. It appears that graffiti and street art have become the trendy features of the area – like the coffee shops, fashion and footwear stores, restaurants – as has happened in Woodstock. It has been noted that studentification inevitably fuels socio-spatial segregation, often because of the student populace’s short-lived residence in an area (Smith & Hubbard, 2014).

There is a knowledge gap in the available literature on both Woodstock and Braamfontein. Whereas studies have been conducted on the gentrification of Woodstock (Garside, 1994; Teppo & Millstein, 2015; Visser, 2002; Visser & Kotze, 2008), there are none which centre on the role of graffiti and street art in this urban process. Braamfontein has been the object of research regarding studentification as well as retail and commercial gentrification (Gregory & Rogerson, 2019), but the locale is wanting in a focus on how street art and graffiti are specifically linked to these phenomena.

Social media, geosocial media, graffiti, and street art

Although social media platforms are renowned for communicative functionality, they are valuable tools for end-users in their ability to capture and share lived experiences (Silva et al., 2013; Zhang & Feick, 2016). A virtual footprint of activities in the real world is being captured by social media. This ‘geosocial’ media has become more commonplace because of geographical information attached to the online activity of users owing to the vast increase in the number of location-aware devices, as well as improvements in the technologies they apply (Croitoru et al., 2013). A different type of geo-information has thus developed in the form of geosocial media and the volume, accessibility, and richness of data it provides allow for new approaches to (and present new challenges for) the understanding of dynamic urban contexts (Croitoru et al., 2013).

The effects of social media and geosocial media on place and space are often not overtly or immediately recognisable, perhaps because the online presence is carefully curated. Though it seems common knowledge that information posted online is the ‘highlight reel’ of experiences. The imaginaries and visualities that are created through engagement with these idealistic

images are lingering and can create a false sense of reality. Urban spaces and places are such entities which, in their virtual presence, can create unrealistic views of what those spaces really are. This ideal, virtual image becomes something that is strived for, and the theming of spaces is one such vehicle through which this can be realised (Gottdiener, 2001). Gentrification is often enacted in this theming process, so fuelling inequality and undermining authentic historical and cultural landscapes.

The demand for as well as the construction and consumption of the various forms of graffiti and street art are being formed and moulded incrementally by the design, structure and usage of social media networks, particularly by the social media platform, Instagram. Graffiti and street art have traditionally been consumed by viewers in a very specific manner – by visiting the actual site of the artwork and personally experiencing the piece first hand. Graffiti and street art are context- and site-specific phenomena, and it is their inextricable links to their location that makes them truly meaningful (Riggle, 2010). However, the various technologies made available in the digital era have led to the emergence of a different approach to this conventional method of engagement while simultaneously offering an immensely greater reach.

Audiences all over the world can view, share, and contribute to an artwork via social networking platforms such as Instagram. It is noteworthy that Instagram is not just a network where graffiti and street artwork are displayed, but the platform is also causing a profound rearrangement and restructuring of the experiences, norms, production and consumption practices of street art and graffiti (MacDowall & De Souza, 2018). This overhauling of the normal processes and aesthetic preferences surrounding street art and graffiti is a component of two broader global developments. First, the conversions street art and graffiti are undergoing (generally by technologies like programmed and virtual media, specifically by social media); and second, the ways in which the ‘media city’, as referred to by McQuire (2008), is changing our perceptions, experiences, and dealings with urban locales (MacDowall & De Souza, 2018).

Although the urban sphere and the various sites and locales it offers are instrumental in the creation and conceptualisations of street art and graffiti, street art and graffiti are becoming virtual or digital products for online spectators and consumers to a greater extent today than ever before. Not only has the size of the audience increased for any graffiti or street artwork published on a social media site, but the products also reap the benefits of an extended lifespan.

Academic enquiry into the role of ‘the street’ (Riggle, 2010) might problematise the construct of what can and cannot be deemed as ‘the street’ in the wake of new digital emergents. By Riggle’s (2010) definitions, a considerable contribution to the meaning of graffiti and street art is a derivative of the interface and exchange they have people. Location-based information also provides information about the wider contexts in urban areas. Therefore, “[t]he reshaping of graffiti and street art by digital media requires that notions of the street be also expanded to include the now complex interplay between the users and architecture of urban spaces and digital platforms” (MacDowall & De Souza, 2018: 5). The design and structure of Instagram gives access to an immense number of metadata, visual media, indications of preferences and affiliations, and other information whereby graffiti and street art can be examined. Finding a link between Instagram, theming, gentrification, and street art also becomes possible because the virtual image has concrete effects in reality which can shape space and place in the urban landscapes.

Conclusions

Graffiti and street art are prominent features of contemporary urban cityscapes. Despite their wide ranges in both number and form, it is often difficult to distinguish the one from the other, or the two from other art forms, such as public art, vandalism or advertising. Drawing on various authors' definitions of graffiti and street art, four defining characteristics have become apparent. First, graffiti and street art must be artistic or stylistic. Second, they must be intentionally situated in the urban public realm. Third, their meaning must be linked to its location on the street, in other words, it must be site specific. Fourth, it must be ephemeral in nature. Possessed with these characteristics, an artwork may be either graffiti or street art, or both in some cases. Street art and graffiti are not deemed synonymous terms (although the genres do occasionally overlap), so to aid classification and the distinction between graffiti and street art can be encapsulated as follows: Graffiti is centred on identity, on the artist's name, and it is text based; street art has more diverse visual elements which might or might not include the written name of the artist and it is often more picture based than text based.

Moreover, graffiti can have many forms, but it is commonly limited to spray-painting or using markers or brushes for line work, whereas street art is very diverse and can take on a multitude of forms. Accordingly, one is able to not only separate street art and artistic graffiti from things such as formalised public art or 'mere' graffiti, but one is able to differentiate between graffiti and street art themselves. Once one can identify both graffiti and street art, one can better understand these dynamic urban phenomena, and how they shape perceptions and spaces. Public images can be seen as vehicles through which developers, planners, institutions, and governments create and promote a sense-of-place and urban imaginaries. Often the theming that results in such spaces can further increase the likelihood of gentrification, with graffiti and street art being imbued with the ability to either fuel or undermine these processes. The advent of social media and geosocial media has also had an extreme impact on how space and art products are consumed. These media also have the potential either to expose or combat gentrification or to contribute to it through the promotion of an ideal, virtual image which could exacerbate inequality and unseat authentic historical and cultural landscapes. Research is needed about how these intricacies exist in and transform South African cityscapes to better understand and manage this creative resource on national and local levels and minimise potential issues that might arise in the future.

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‘Green’ militaries: the military-environment conundrum

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Abstract

In a world where the environment is constantly impacted by natural and anthropogenic effects, the relationship between military actions and a sustainable environment has never been more important. There is no quick resolution for the dilemma of militaries that need to effectively conduct their diverse missions while at the same time try to reduce their environmental impact.

In this review paper the military-environment conundrum is considered by investigating the issues surrounding military-environmental interaction. Even though considerable research effort has been spent on interrogating military actions and their effects on the environment, several issues regarding the military-environment relationship remain ambiguous. In this paper, the term ‘green’ military is used to refer to the construct of military environmental literacy that focuses on the attitude, behaviour, and knowledge necessary to enable militaries to effectively avoid, reduce, or mitigate their impact on the environment, given their unique activities. Not only will this reduce the environmental footprint of the military, but at the same time, an environmentally literate military will accrue benefits in terms of legal compliance, improved mission success and an enhanced image.

From the review of the available literature, only an environmentally literate military can successfully reduce their environmental footprint and reap the benefits associated with an improved relationship with the environment in which they must conduct their diverse missions.

Keywords: Military activities, military environment, military environmental literacy, military geosciences, green military, military missions.

Introduction

Traditionally, the relationship between military activities and the physical and cultural environment in which it plays out was – and still is – somewhat an uneasy one. Most militaries recognise the importance of the environment in which the military conducts its missions. The environment provides cover, sustenance, realistic training facilities and ultimately the battle arena itself. Contrarily, traditional military activities focused on winning wars – ideally with the least number of own casualties as possible. In such a scenario, caring for the environment was considered a liability that could not be entertained without jeopardising the mission.

Over the last four to five decades, two substantial transformations in this relationship took place. In the first place, a growing recognition of the harm done to the environment by human activities spawned a global environmental movement demanding action against individuals, organisations, and even nations that engage in harmful environmental practices. The yardstick of environmentally responsible conduct is increasingly also applied to militaries – and rightly so. In the second place, growing military mission diversity enables a more nuanced approach to the protection and care of the physical and cultural environment by the military.

This paper investigates the relationship between the military and the physical and socio-cultural environment. The purpose is to explain the impact of military actions on the environment and highlights the importance of an environmentally responsible military. In achieving the aim of this paper, available literature in military environmental management and related fields such as military geography, military geosciences, security and the environment were reviewed. The significance of this paper is that an environmentally responsible military will most likely significantly reduce their environmental footprint in the areas in which they operate.

Materials and Methods

Given the conundrum of a military that relies on the environment, is held accountable for irresponsible military conduct, but must still successfully complete a range of military missions, this paper seeks to address the following five questions: *What is the mission of the military? What do we mean when we debate ‘the military environment’? What constitutes an environmentally literate (green) military? Is it necessary – and possible – for the military to take care of the environment in the execution of its duties? What benefits are there to be gained by the military for being environmentally literate?*

This paper followed a systematic review of published research by academics and professionals to seek the answers to the research questions posed above. Sixty-seven outputs were elicited from various sources, including websites, published articles, books, operational manuals, government documents and national policies between 1983 and 2021. The review focusses firstly on the military mission diversity; then the military environment and the literacy required to respond to environmental issues; next, the focus shifts to the military’s attitude and behaviour towards caring for the environment; and lastly, the benefits of being an environmentally literate or green military are highlighted.

Military mission diversity

In the popular media and public imagination, it seems as if the perception exists that ‘*the military*’ is equal only to damage and destruction. When militaries prepare for, or execute, their missions, bombs explode, and destruction of the environment is inevitable. Contrarily, ‘*the environment*’, is most often associated with flowers, streams, wild animals, solitude, and beauty (Figure 1).



Figure 1. *The military-environment conundrum.* Adapted from [GRL Admin \(2015\)](#) and <https://www.pexels.com/photo/bloom-blossom-field-flora-36032/>, under the Pexels licence].

In both cases these perceptions are gross oversimplifications. While globally the core function of defence forces remains the same – to fight and win nations’ wars – contemporary defence forces spend most of their time training and retraining, taking part in peacekeeping and/or peace-making operations, and performing humanitarian assistance duties. Actual warfighting constitutes a minute part of what modern militaries are expected to do. This increasing mission diversity calls for a more nuanced look at how the military impacts on the environment, and how their impact can be mitigated. Butts (2011, p. 54) contends that *‘the security milieu and the role of the military changed dramatically...’*, while the expanding military mission diversity is further highlighted by Galgano (2011) when he lists no less than 13 types of stability operations, and three types of support operations militaries engage in. Authors such as Singer and Keating (1999), and Lawrence et al. (2015) catalogue operational domains such as land use, testing and development of new weapons (especially chemical and biological), manufacturing and production of armaments, training and practice exercises, maintenance of hardware and infrastructural facilities and disposal of old or used weaponry all as important environmentally impacting military actions. Link this to the vast areas used by militaries for training and housing (Quist et al. 2003; Zentalis et al. 2017; Harabis & Dolny 2018) and the even larger spaces impacted upon by other military activities, and it is clear that we are dealing with organisations that can negatively impact a wide range of ecosystems. At the same time, if the adverse impact of military activities on the environment can be effectively avoided, reduced, or mitigated, this can meaningfully contribute to a more environmentally sustainable world.

Although it is incontestable that most military activities possess an inherent ability to impact negatively on both the physical and cultural environment, this is not equally true for all military missions. The mission diversity characterising modern militaries necessitates a reappraisal of their impact on the environment. Fortunately, for environmental protection, militaries spent large amounts of time and resources on activities that can be managed relatively easily to be less environmentally harmful. These activities include training and peacekeeping and/or peace-making operations and performing humanitarian assistance duties. It is imperative for the military to actively plan to mitigate their impacts on the environment, starting with the activities where they have more control over their environmental impact.

The military environment

Conceptually, the term *‘environment’* is, at best, elusive to define. As a point of departure, it should always be considered holistically. While the term is widely used, it means disparate things to different users (Nel & Kotzé 2009). According to Hans (2018), the environment is a *‘combination of internal and external factors that influence a company’s operating situation, including employees, customers, management, supply and demand and business regulations.’* Barnett and Casper (2001, p. 465) defines the socio-cultural environment as *‘the immediate physical surroundings, social relationships, and cultural milieus within which defined groups of people function and interact.’* These two definitions are clearly aimed at different audiences and confirm the observation of Nel and Kotzé (2009). Miller and Spoolman (2019, p. G5) describe the environment as *‘all external conditions, factors, matter and energy, living and non-living, that affect any living organism or other specified system.’* A much more comprehensive definition by Peet (2002, p. 860) defines the environment as broadly understood to include *‘natural processes, conditions and materials such as climate, landforms, soils and resources from and within which people continually make their livelihoods; territory or landscape as the ‘stage’ on which life literally ‘takes place’; and earth distance or space which, whether through friction or content, shapes every movement and is socialised by human activity.’*

The National Environmental Management Act – the framework law for South African environmental management – defines the environment as ‘*The surroundings within which humans exist and that are made up of (i) The land, water and atmosphere of the earth; (ii) Micro-organisms, plant and animal life; (iii) Any part or combination of (i) and (ii) and the interrelationships among and between them; and (iv) The physical, chemical, aesthetic and cultural properties and conditions of the foregoing that influence human health and well-being.*’ (South Africa 1998, p. 8). The USA Army field manual dealing with environmental considerations, considers the natural environment as follows: ‘*The natural environment is the human ecosystem (including the physical and biological systems that provide resources [clean air, clean water, healthy surroundings, and sufficient food]) that is necessary to sustain productive human life. The natural environment includes man-made structures (water and waste-water treatment facilities) and natural and cultural resources.*’ (ATP 3-34.5/MCRP 4-11B, 2015, pp. 1-2). Several generic considerations emerge from these definitions. First, the concept is complex in meaning and difficult to encapsulate comprehensively. Second, the environment must be considered holistically, or specified accordingly if only parts are under consideration. Third, it involves a range of interrelationships and systems. Last, the concept affects the lives of living organisms. Implicit in the definitions is the fact that it is difficult to manage such a system and what impacts on any one part can (and probably will) affect the other components as well.

It is clear that, as far as the environment is concerned, all of the above apply to military conduct. The military environment is a multifaceted concept encompassing diverse components of social, cultural and physical or natural domains in which soldiers execute a diverse range of missions. When referring to the environment in a military context, it must equally be considered holistically or specified as the cultural, social or physical environment when used with a distinct focus. The military environment impacts on and is impacted on by the lives of soldiers and other humans, as well as the military activities performed in it. Other living and non-living things share the military environment with humans and form interrelationships important in the understanding of the environment targeted for management (Smit & Van der Merwe 2018). Military activities also impact on all the components, conditions and interrelationships of the environment, both in a negative and positive manner.

The working definition of the concept ‘*military environment*’ used in this paper holistically encompasses the biophysical, sociocultural, and socio-economic environments in which the military conducts its missions. In essence, this implies that the military environment encompasses all areas where the military conduct any of its activities. This definition applies irrespective of which of the typical military activities, routine daily base maintenance and management, training activities, disaster relief and support operations, peace-making and peacekeeping, or any conduct of armed conflict, militaries engage in (Smit 2017).

Having dealt with military mission diversity and the definition of the military environment, attention can now turn to the third question posed at the start of the paper, ‘*what constitutes an environmentally literate or ‘green’ military?*’

An environmentally literate (green) military

‘*Environmental issues are now a major factor in regional stability and an essential component of the global security landscape*’ (Galgano, 2019, p. 13). This observation by Galgano implies that to be able to respond to the challenges posed by environmental issues to the security community, will require environmentally literate citizens, military leaders, and soldiers. In this regard, Stevenson et al. (2013) allege that ‘*direct responses to global environmental crises can slow the tide of environmental degradation but reversing the trend will require an*

environmentally literate citizenry.' Teksoz et al. (2014) concur and consider environmental literacy (EL) a prerequisite to making sound environmental decisions.

The term '*environmental literacy*' has eluded precise definition since it was first coined by Roth in the 1960s (Hsu & Roth 1998). Authors such as Karatekin (2013), and Miller and Spoolman (2019), contend that the concept is complex in nature, difficult to define, and encompasses numerous and diverse meaningful components. Examples of these components of EL are personal attitude toward, knowledge about, behaviour toward, beliefs relating to, opinions about, perceptions of, and social values relating to the environment (Wright 2008). Despite the elusive nature of a precise definition of EL as a concept, a widely accepted working definition provided by Roth (1992) has been adopted, adapted, and widely used by researchers (Pe'er, Goldman & Yavetz 2007; Smit & Van der Merwe 2018). Roth (1992) defined EL as an individual's knowledge about and attitude toward the environment and environmental issues, skills and motivation possessed in working toward the resolution of environmental problems, and active involvement in working toward the maintenance of dynamic equilibrium between the quality of life and the quality of the environment.

While the definition of EL formulated by Roth is aimed at civilian populations, it is postulated here that within militaries a specific military culture, ethos and professional conduct exists (Esterhuyse 2013). This military culture differs significantly from civilian conduct and practice and poses unique problems, offers opportunities, and requires specific skills in managing the environment in the military. Consequently, the military environment requires a unique definition to effectively encompass military environmental literacy (MEL) (Smit 2017). Already in 1998, a distinction was made between Military Integrated Environmental Management (MIEM) as applied in the South African Department of Defence and Integrated Environmental Management adopted and applied by civilian enterprises, due to the different contexts they were used in (Godschalk 1998). It is therefore appropriate to use the term '*military environmental literacy*' when referring to military-specific environmental literacy, as opposed to its civilian counterpart.

To enable such a distinction between civilian and military-specific environmental literacy, the civilian definitions of EL discussed above can be modified to formulate a definition that reflects the military context. Smit, (2018, p. 309) defined military environmental literacy as '*the nature and level of the attitude toward, knowledge about, and behaviour in and toward the environment in which the military operates.*' This was the first time a distinction was drawn between civilian and military environmental literacy. In the literature, environmental literacy is usually associated with several components. Attitude, behaviour, and knowledge are usually included when discussing environmental literacy, but other components, such as beliefs, opinions, perceptions, and social values relating to the environment are sometimes noted as well (Wright 2008). For the purpose of this paper, only attitude, behaviour and knowledge will be considered.

According to Hawker (2001, p. 50), attitude can be defined as '*a way of thinking or feeling about someone or something.*' Environmental attitude is therefore defined by Pe'er, Goldman and Yavetz (2007, p. 47) as '*general feelings toward ecology and the environment, feelings and concerns for specific environmental issues, and feelings toward acting to remedy environmental problems.*' A more comprehensive definition is supplied by Milfont and Duckitt (2010, p. 80), who characterised environmental attitude as '*a psychological tendency expressed by evaluating the natural environment with some degree of favour or disfavour.*' The operational definition of military environmental attitude (MEA) constructed by Smit (2017, p. 4) is that it is '*a general feeling of favour or disfavour toward the military environment, i.e., the environment in which the military operates.*' Kollmus and Agyeman (2002, p. 240) defines

pro-environmental behaviour as *'behavior that consciously seeks to minimize the negative impact of one's actions on the natural and built world.'* Bamberg and Möser (2007, p. 15) expand on this definition and describe pro-environmental behaviour as *'a mixture of self-interest (e.g., to pursue a strategy that minimises one's own health risk) and of concern for other people, the next generation, other species, or whole ecosystems (e.g., preventing air pollution that may cause risks for others' health and/or the global climate).'* Military environmental behaviour (MEB) is therefore defined as a *'demonstration of how one acts toward or in the military environment in which the military operates'* (Smit 2017, p. 5). Knowledge (about something) is the *'information and skills gained through experience or education'* (Hawker 2001, p. 499). From this definition, Smit (2017, p. 5) describes military environmental knowledge (MEK) as being *'the ability to identify a number of concepts and behaviour patterns related to the military environment, i.e., the environment in which the military operates.'*

The construct of military environmental literacy thus consists of military environmental attitude (the affective component), military environmental behaviour (the behavioural component) and military environmental knowledge (the cognitive component). A soldier displaying these attributes can be deemed military environmentally literate. An environmentally literate military therefore displays a positive attitude towards the environment in which it operates, exhibits the correct environmental behaviour while executing their activities, and possess an appropriate degree of knowledge about the military environment and how to engage with it in an environmentally sustainable manner.

A military that cares for the environment in the execution of its duties

According to Section 24 of the Bill of Rights in the South African Constitution, everyone has the right *'to an environment that is not harmful to their health or well-being and to have the environment protected for the benefit of present and future generations, through reasonable legislative and other measures that prevent pollution and ecological degradation; promote conservation; and secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development'* (South Africa 1996).

Similar legal protection of the environment in Namibia is reported by Ruppel and Ruppel-Schlichting (2011) and is the norm globally. This legal dimension is linked to a growing recognition that environmental degradation is morally and ethically wrong and can seriously impact the continued viability of the earth to provide the ecosystem services that humans need to survive.

The impacts of military activity on the environment tend to be multifaceted and a rigorous investigation is crucial to expose all facets. In this regard, Lawrence et al., (2015, p. 444), noted that *'the consequences of warfare generate a continuum of outcomes ranging from highly positive to highly detrimental.'* They compiled a comprehensive inventory of negative impacts military activities have on the environment, as well as a few possible positive impacts. Mosher et al. (2008) explain that the long occupations and post-conflict involvements of the US military necessitated a better appreciation of the importance of environmental considerations during all phases of military conduct. They advance additional reasons for heightened environmental concern in the US military: In conflict zones where the environment may pose a threat to soldiers, the longer timeframe of deployments aggravates the threat. Environmentally insensitive actions of US soldiers in terms of the local environment have also become more crucial because of their more lasting negative effect on the local population. The other side of the coin is that environmentally sensitive actions by US soldiers can generate goodwill among the local population toward the US occupying forces.

It is important to note that poorly handled environmental impacts are not bound by borders and can easily cloud good relations with neighbouring countries. According to Rubin (2012), a group of American soldiers inadvertently burnt copies of the Koran in Muslim Afghanistan. The incident was widely publicised, and the US military suffered severe reprisals, protests and even deaths among its soldiers. It was an expensive lesson that the total local environment, including the cultural environment, must be always respected. More importantly, the achievement of American military objectives in that conflict was compromised and a lot of work had to be done to repair the tarnished image of the United States soldiers among both the Afghan population, and the neighbouring Muslim nations, something any military can ill afford.

Based on lessons learned, Mosher et al. (2008: xvii) recorded seven major findings with a potential impact on mission success during overseas deployments. Four of these are especially relevant to this paper: (1) *Environmental concerns impact operations significantly;* (2) *During the post-conflict phase of operations environmental considerations become critically important for mission success;* (3) *Environmental issues have far-reaching impacts across Army operations, and everywhere in the world;* (4) *Ineffective environmental planning and practices increase current and future operational costs, liabilities, strain diplomatic relations and can pose serious risks to soldiers' health.*

These findings apply to most militaries globally and have significant implications for the way in which environmental issues are addressed by militaries. It also provides a powerful incentive and rationale for militaries to conduct their affairs in environmentally responsible ways. Bonds (2015) reiterates that the actions of environmentally illiterate soldiers not only reflect poorly on the nation conducting the military operation, but it may even jeopardise mission success and endanger the lives of soldiers involved in the operation.

Modern defence forces are increasingly measured against elevated environmental concern, and justly so. This manifests in mounting amounts of national and international environmental legislation that regulate both peacetime and wartime operations. There is also a growing recognition of the environmental dimension of global security, and militaries worldwide are coming under increasing pressure to perform their activities in an environmentally responsible manner and in compliance with national and international environmental legislation, both in times of war and during peacetime (Potgieter 2000; Shrivastava 2001). Wilson (1996) concurred and alleged that poor management practices in the Australian Army may lead to environmental degradation, diminishing the value of training or even limiting the access to training areas. Two decades later, Zentelis et al., (2017a, 2017b; 2017c) published three important papers on the integrated management of military training areas in Australia.

The maintenance of a wide scope of diverse training facilities is a prerequisite for training to be conducted in real-world environmental conditions to effectively prepare them for the diverse missions militaries are called upon to execute. Shaw et al. (2000, p. 68) warned that '*... when no environmentally comparable site exists in the United States, the Army lacks a training resource as fundamental as time, equipment, soldiers or money.*' In 2005 Shaw et al. (2005, p. 379) reiterated this warning by stating that '*from a readiness perspective, these lands and their associated physical attributes (such as terrain, vegetation and climate), can be viewed as operational analogs for areas where the Army may deploy to fight a major theatre war or participate in a stability and support operation.*' Gilewitch et al. (2014), stress the importance of training under similar conditions than that expected on the actual battlefield to effectively prepare soldiers and test the logistical support for missions. Authors such as Hanson (2018) and Smit (2018) concur with these pronouncements.

Although it is widely recognised that the impact of military activities is largely negative, some researchers identified some positive impacts as well (Stein et al., 2008; Lawrence et al., 2015; Busěk & Reif, 2017; Harabiš & Dolný, 2018). Both the negative and possible positive impacts of military activities on the environment, should be drivers for better care of the areas impacted by military activities.

The USA Field manual for environmental considerations alleges that the [USA] military has ‘a new appreciation for the interdependence between military missions, the global community, and the environment.’ Also that ‘lasting victories and successful end states are measured in part by how well the military addresses environmental considerations [including FHP (Force Health Protection); sustainable management of energy, water, and waste; protection and conservation of natural and cultural resources; improvement of living conditions for U.S. personnel and HN (Host Nation) citizens].’ It continues to state that ‘U.S. forces must integrate environmental considerations into initial plans to protect and mitigate damage to natural and cultural resources and minimize the conflicts that are driven by these issues. Failure to do so may have impacts far beyond the initial damage’ (ATP 3-34.5/MCRP 4-11B, 2015, pp. 1-3).

Considering the arguments made in this section, it is concluded that to modern militaries, environmental concerns matter at all levels of military planning and execution. It is important to acknowledge that recognition of the importance of sound environmental conduct varies across militaries globally and can also be mission dependent. Equally important is that the negative consequences of poor environmental conduct will be manifested, whether militaries recognise the importance of responsible military environmental conduct or not.

Benefits of being an environmentally literate or green military

An important question to consider when analysing the military-environment relationship is: ‘*Why should military commanders care about environmental issues?*’ Given the diverse nature of military missions, and the fact that lives depend on the successful execution of most military missions, this is a highly relevant question. Why indeed would a military commander take the environment into consideration when planning and executing their missions? In their book on United States Army environmental considerations for operations, Mosher et al. (2008, p. 3), pose this exact question and answer it by referring to soldier health and safety, mission success, the amplification of environmental issues during long deployments and the importance of ‘*doing the right thing*’ as reasons for taking environmental matters into consideration during all phases of military activity (Mosher et al. 2008: p. 11). Other researchers advance more reasons by stating that ‘*militaries worldwide are under increasing pressure to conduct their operations in an environmentally responsible manner. It is the ethically and morally appropriate way to act and legally imperative, but it also makes sense from a business perspective*’ (Smit 2017, p. 236).

Traditional military activities and modern military activities differ markedly from one another, also in terms of their impact on the environment and their importance (Table 1).

Table 1. Military activities and the environment: Traditional military activities versus modern military activities.

Traditional military activities	Modern military activities
Less diverse missions– focus on waging war	Increasing mission diversity
High inherent potential for environmental destruction	Inherent potential for environmental destruction varying according to mission
Environmental impact largely ignored	Environmental impact considered

Traditional military activities	Modern military activities
Environmental sustainability of training areas not deemed important	Environmental sustainability of training areas imperative
Environmental considerations in military operations seen as liability to mission success	Environmental considerations in military operations can increase mission success
Environmental impact of military operations on health of own forces and civilians ignored/poorly understood	Environmental impact of military operations on health of own forces and civilians well-known and taken into consideration
Legal regime vague	Increasing clarity on what constitutes illegal environmental actions
Legal compliance poor	Legal compliance improving
Image of the military subservient to military mission	Image of military important to success of military mission
Ethical and moral implications vague	Ethical and moral issues more clear and well documented

Even a cursory look at Table 1 reveals several important facts, namely that a modern military must deal with increasing mission diversity, the inherent potential for destruction due to military activities differs but is always present; militaries cannot ignore the environmental impact of their activities due to both external pressure and internal considerations, and that environmental compliance can be beneficial to mission success. A brief look at some of the benefits of being an environmentally literate military will consider training and mission success, health issues, legal compliance, an improved image and ethical and moral obligations.

Training and mission success

‘Sustainability is the ability of earth’s various systems, including human cultural systems and economies, to survive and adapt to changing environmental conditions indefinitely’ (Miller & Spoolman 2019, p. G15). To ensure that future training needs are met is one of the core issues militaries need to deal with (Smit 2017). To be able to do that, viable, diverse training areas used in a sustainable manner are needed to prepare militaries for their missions. Without such facilities, militaries will not be able to adequately prepare for the diverse range of missions expected of them, neither will they be able to optimally operate in the varied environments these missions will be conducted in (Shaw 2000, 2005; Gilewitch et al. 2014; Zentelis et al. 2017a). According to Palka (2011), climate change can put further pressure on areas in which the Army needs to train. He contends that the Army needs to train and equip its soldiers to undertake a wide range of missions under virtually any environmental conditions. For this, comparable training areas are a prerequisite. In research conducted among soldiers in the South African Army (Smit 2018), the soldiers themselves identified the sustainable use of training areas as an important issue.

Military training is an important component of the activities militaries globally engage in and can cause extensive damage to training areas (Henrico et al. 2021). Fortunately, this is also an area where proper planning and mitigation measures can relatively easily impact positively on the military environmental footprint. Authors such as Zentelis et al. (2017c) and Marx and Van der Merwe (2019) reported the development of decision-support systems to aid in the management of military training areas, thus empowering militaries with the means to improve their environmental performance on training areas. Both the United States Department of

Defence and the South African Department of Defence (to name but two) actively engage in the management and mitigation of military impacts in their training areas to try to ensure sustainability of these valuable resources. As part of a bilateral agreement between the USA and South Africa, a handbook on military integrated training range management was developed and is currently in use (Environmental Security Working Group 2000). In targeting the sustainable use of military training areas, the military environmental footprint can be substantially reduced, at least internally in the home country.

Military missions can be compromised by inappropriate environmental conduct and the fallout of poor military environmental practices can remain long after conflicts or interventions are over. Soldiers who have an appropriate degree of military environmental literacy can prevent this from happening (Smit 2017). Soldiers with an appropriate environmental attitude, adequate knowledge and the correct behaviour patterns that allow them to operate effectively in whatever environment they must execute their mission, will not damage religious books, destroy important cultural artefacts, scorn cultural taboos, contravene environmental laws or abuse the physical environment in which they operate. Nor will they tolerate unsustainable environmental practices that may impact adversely on their own health and safety as well as that of the civilian population where they operate.

It is especially important that soldiers deployed to other countries must be environmentally literate. In the host countries, other written and unwritten rules regarding conduct in the environment might apply. Being ignorant about, or ignoring these rules, may adversely affect not only the local environment, but also impact negatively on mission success. Deployment also exports the military environmental footprint of the military to the receiving countries. Soldiers with a high level of MEL are likely to have a smaller military environmental footprint than those without. In any country to which deployment takes place, whether for humanitarian aid missions, peacekeeping missions or for fighting a war, the civilian population is unavoidably under varying levels of pressure. These populations do not want, nor deserve, the additional burden of environmentally illiterate soldiers who leave the host environment, both physical and cultural, in a worse state than before their arrival (Moser et al. 2008). In many instances, relatively intact cultural and physical environments can help the rebuilding of communities in post-conflict or post-disaster scenarios. If that is not the case, the burden may fall on the soldiers deployed to the area to help in this regard, further impacting on scarce military resources.

Environmentally illiterate soldiers and bad environmental practices can render military training areas unsustainable and compromise mission success. Fortunately, this can be prevented or mitigated by proper planning and equipping soldiers with the requisite environmental literacy skills.

Health issues

The influence of environmental factors on the health of soldiers is well documented in military history, and military geography, but not always considered by military planners. Sound military environmental practices should be emphasised by environmental education and training and incorporated into planning to avoid health issues among both own forces and the civilian population of the area where the military activity takes place.

During the battle of Paardeberg in the Anglo-Boer War, British soldiers drank contaminated water from the polluted Modder River and suffered many casualties (Breytenbach 1983). Poor sanitary and other environmental conditions that severely hampered the Buna-Gona campaign during World War II is the focus of investigation by Palka and Galgano (2011). They emphasise, *'Bear in mind that the Buna-Gona campaign is only a representative example. We*

can surely look to virtually any war and discover specific examples of where disease and/or adverse environmental conditions rendered soldiers and units combat ineffective' (Palka & Galgano 2011, p. 170).

Bonds (2016, p. 395) reported on the danger posed by unsustainable waste management practices during the American occupation of Afghanistan and Iraq to the health of soldiers and civilians alike. He claims that the open-air burn pits used by the US military to dispose of solid waste caused serious health problems to soldiers and the local population, calling it '*an important, if unacknowledged, environmental justice issue.*' Incidentally, an environmentally literate soldier with a PhD in Environmental Engineering first blew the whistle on the dangers of this mode of waste management.

These, and other examples of bad environmental practices, will continue to affect the health of soldiers, the success of their missions, and the population of the areas in which they operate. Once again, appropriate planning and correct environmental practices can prevent this from happening.

Legal compliance

Environmentally illiterate soldiers can have wide-ranging detrimental effects with severe legal ramifications, both when operating inside their own country and especially during deployments abroad. Ensuring compliance with both national and international environmental laws and regulations is needed to prevent this. In this regard, pre-deployment education and training is imperative to sensitise soldiers to the legal regime of the areas where they will execute their missions, and environmental considerations should be incorporated into all planning and execution phases of the mission (Smit 2017). Failure to account for environmental contingencies may have legal repercussions that can linger long after the military activity is completed (Bonds 2015). This will further burden the scarce resources of militaries.

Improved image

The large size of military training areas and the large areas impacted by military missions are major drivers of the large military environmental footprint (Lawrence et al. 2015; Zentelis et al. 2017b). However, these same vast areas under military control can also help to improve the image of the military if managed in a sustainable manner.

Authors such as Lawrence et al. (2015) list the restricted access to military training areas as reason for them harbouring endangered species and state that, even during wartime, restricted access to certain areas can allow species to rebound. This view is corroborated by the research of Quist et al. (2003) who identified training areas as untouched by intensive agriculture and urban development. Stein, Scott and Benton (2008) indicate the role military and other federal lands can play in sustaining biodiversity in the United States, while Bušek and Reif (2017) studied the potential of military training areas as spaces for the conservation of birdlife in central Europe, and Arimoro et al., (2018) evaluated military training areas in Brazil in terms of its ability to sustain large mammals. Harabis and Dolny (2018) identified military training areas as potential refuges for threatened dragonfly species in the Czech Republic. Zentelis et al. (2017c) identified eight management principles for managing military training areas. The eighth principle states that the development and fostering of good stakeholder relations with surrounding landowners are important. The military will not only be contributing to a more sustainable environment by doing that but will also be enhancing their own image among the broader civilian population.

The same applies to the sharing of military-developed technology, such as satellites, global positioning systems, remote sensing technologies and remotely operated vehicles (Lawrence et al. 2015) to enhance the capabilities of civilian environmental and conservation researchers.

Doing this will likewise enhance the image of the military and can have important positive impacts on environmental and conservation-related research—clearly a win-win situation.

Ethical and moral implications

More than two decades ago, Lonie and Moloney (1996, p. 44) alleged that environmental responsibility has globally attained the status of a ‘*new morality*.’ According to them, this is evidenced by an emphasis on environmental concerns such as recycling, the use of ‘*green*’ products and a growing corpus of laws dealing with activities that may have possible harmful effects on the environment. This high standard of responsible environmental conduct applies to modern defence forces as well and is now more relevant than ever.

During research on environmental literacy among South African Army soldiers, 30% of the respondents indicated that they see it as their duty to care for the environment in areas where they operate (Smit 2018). Deployed soldiers need to be especially sensitive to take ethical and moral issues into consideration in everything they do. During peacekeeping and/or peace-making operations, and the performing of humanitarian assistance duties in foreign countries, as well as during post-conflict deployments, even environmentally literate soldiers may struggle to navigate unfamiliar cultural and socio-economic practices and taboos. Only thorough preparation and general, as well as targeted, military environmental courses can prevent this and will lead to improved mission success under these circumstances (Smit 2020).

The natural and cultural environments pose threats, constraints and possibilities to the soldier in battle and on any other mission, as well as to those who are responsible for the planning of military missions at higher levels. Ultimately, militaries worldwide will have to produce military practitioners that are aware of their environmental responsibilities and equipped with the necessary skills, tools, and attitudes to deal with any environmental challenges they may face. This will not only benefit all components of the environment impacted upon by military activities, but also the military itself in terms of soldier health and safety, sustainable training areas, mission success, legal compliance, an improved image, and adherence to ethical and moral standards.

Results and Conclusions

To many stakeholders, the military – environment relationship remains a conundrum – difficult to fully comprehend and even more difficult to comprehensively research. While the military recognise the importance of the environment in all military activities, they struggle to effectively conduct their diverse missions while taking due care of the environment in which they operate. To help the military fully fathom the impact of their activities and to prevent environmentally harmful conduct as far as possible, soldiers need to be environmentally literate. Only an environmentally literate military will be able to act in an environmentally responsible manner. In doing so, the military will be able to ensure sustainability of their training areas, enhance mission success, and prevent health issues (among both own forces and civilians) in areas where the military operate. They will also be able to ensure legal compliance with national and international environmental laws and regulations, improve the image of the military and abide by their ethical and moral obligations while executing their missions.

To develop environmentally literate soldiers, a comprehensive, continuous, integrated education and training programme is needed. General and targeted environmental education and training must be integrated into all aspects of military training and execution. While general environmental education and training must be the focus during training, targeted, environment-specific education and training must be considered for the pre-deployment phase of all operations.

Although the military-environment conundrum is not going to be solved any time soon, military environmentally literate soldiers can make a substantial contribution towards a better appreciation of this uneasy, but potentially mutually beneficial relationship. This will be to the benefit of not only the military and the environments they operate in, but also to the civilians and the wider environment impacted upon by military activities.

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Exploring determinants of aardvark burrow locations at Rietvlei Nature Reserve, South Africa

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Abstract

Burrowing mammals, *i.e.*, mammals that dig in the ground for shelter creation, food, and nesting, play an important role in the ecosystem, since their burrows support plant and animal assemblages that differ from that of the surrounding environment. Previous research suggests that environmental parameters, such as soil type and vegetation, influence the distribution of burrows in the landscape. The current study investigated the distribution of 250 aardvark (*Orycteropus afer*) burrows, found within 45 1-ha quadrats, within Rietvlei Nature Reserve, South Africa. First, spatial clustering of aardvark burrows was explored using *Average Nearest Neighbour Analysis*, *Multi-distance Spatial Cluster Analysis*, and *Optimized Hot Spot Analysis* in ArcGIS Pro. Next, soil type, geology, rockiness, vegetation, distance to water lines and distance to roads were explored as potential determinants, both of burrow presence (using Fisher exact tests), as well as burrow density (using Generalized Linear Models (GLZs)) in quadrats. Results show dispersion of burrows in two of the three quadrats used for spatial clustering, whereas the third quadrat shows clustering at distances less than 28 m, and dispersion at distances greater than 43 m. There was no association between burrow presence in a quadrat and any of the environmental determinants investigated. In addition, none of the potential determinants was a significant predictor of burrow density within quadrats. The results suggest that other factors, instead of the environmental parameters explored here, are driving aardvark distributions.

Keywords: aardvark; burrow distribution; cluster analysis; *Orycteropus afer*

Introduction

Burrowing mammals are mammal species that dig in the ground for shelter creation, food, and nesting. Many burrowing mammal species are referred to as ecosystem engineers, as they change the structural composition of the physical environment through their digging behaviour (Davis & Kalisz, 1992; Jackson, 2000; Planillo & Malo, 2013; Palmer *et al.*, 2021). Thus, the burrows and mounds of burrowing mammals play an important ecological role in the ecosystem by providing habitats that support plant and animal assemblages that differ from that of the surrounding environment (Wesche, Nadrowski & Retzer, 2007; Kurek, Kapusta & Holeska, 2014).

Many biotic and abiotic environmental parameters within the ecosystem influence the occurrence and distribution of burrows across the landscape (Taylor & Skinner, 2004; Ward-Fear *et al.*, 2021). These environmental parameters include soil type (Van Aarde *et al.*, 1992), topography, geology, slope, infrastructure, vegetation, water bodies (Sharma & Singh, 2018), and rainfall patterns (Romañach, Reichman & Seabloom, 2005). For example, Dentzien-Dias and Figueiredo (2015) found that tuco-tuco (*Ctenomys sp*) prefer to inhabit sandy soils in South America, while Bobak marmot (*Rodentia sciuridae*) of Eastern Europe and Central Asia prefer

mostly arable cropland, dark kastanozems, as well as southern chernozem soil types and grassland environments. Cape porcupines in South Africa, in turn, burrow where geophytes (their food source) occur and they prefer to burrow in mesic environments (Bragg, Donaldson & Ryan, 2005). Davis and Kalisz (1992) showed that prairie vole (*Microtus ochrogaster*) in central Kentucky, USA, burrow on lush and dark green vegetation, where the soil is easy to excavate. In contrast, southern hairy-nosed wombat (*Lasiorhinus lotifrons*) from Australia, burrow in both hard and soft soil (Shimmin, Skinner & Baudinette, 2002). Lastly, Jackson (2000) examined the adaptation ability of southern African whistling rats (*Paratomys brantsii* and *P. littledalei*) to live in an open arid environment. Although both rodents are endemic to arid regions, *P. littledalei* burrows are restricted to areas with good plant cover, while *P. brantsii* burrows are situated in open locations with limited plant cover.

The biotic and abiotic components of the terrestrial environment also seem to play a role in the distribution of burrows of the aardvark (*Orycteropus afer*), a medium-sized (approximately 50-80 kg) burrowing mammal species restricted to sub-Saharan Africa (Melton, 1976). Although they reside in a diverse range of habitats, including all varieties of savanna, open woodland, scrub, and grassland (Skinner & Smithers, 1990), studies suggest that they favour areas with sandy soils and generally tend to avoid true forests and very arid areas (Skinner & Smithers, 1990; Van Aarde *et al.*, 1992). They may also be absent in rocky and mountainous regions because the soil is too shallow and hard to excavate (Skinner & Smithers, 1990), or where their food source, mainly termites, is scarce (Taylor and Skinner, 2003).

Aardvark are nocturnal, although during the colder winter season they forage in the afternoon. Furthermore, aardvark hardly interact with other individuals of the same species, except during the mating season, which in southern Africa occurs in early summer (Taylor and Skinner, 2003, 2004). They are adapted to dig and push back the soil with their hind feet and tail (Melton, 1976), usually excavating three types of burrows. These are: 1) shallow foraging burrows for food searching, 2) large temporary shelters, and 3) more complex burrows for permanent residence (Oduro & Boateng, 2009). Aardvark burrows are also used by many animals for refuge (Melton, 1976), since they ameliorate temperatures and moisture content to the outside environment (Whittington-Jones, Bernard & Parker, 2011).

The spatial clustering of burrows can be evaluated using cluster analyses. Identifying clusters of burrows in high-burrow quadrats offers insight into burrow distribution in the landscape. Cluster analysis tools analyse the spatial patterns of incident point data, summarising spatial dependence (feature clustering or dispersion) over a range of distances (Mitchell, 2005) by illustrating how the spatial clustering or dispersion of feature centroids changes when neighbourhood size changes (Bailey & Gatrell, 1995). This can also be applied to potential burrow clustering. For example, Fisher *et al.* (2007) assessed the ability of Ripley's K-function to determine changes in burrowing owl (*Speotyto cunicularia*) nest clustering and Wilschut *et al.* (2015) investigated the spatial distribution patterns of burrows of great gerbils (*Rhombomys opimus*) in Kazakhstan using the same method. Average nearest neighbour analyses were also successfully used to study spatial patterns of burrowing owl nests within black-tailed prairie dog (*Cynomys ludovicianus*) towns (Desmond, Savidge & Seibert, 1995).

Although previous studies show that the distribution and occurrence of aardvark burrows are driven by the distribution of biotic and abiotic determinants at a broad spatial scale, knowledge about which of these components influence the distribution of aardvark burrows at finer spatial scales lacks scientific documentation. Therefore, the current study aimed at investigating the distribution of aardvark burrows in the surrounding landscape at Rietvlei Nature Reserve, Gauteng, South Africa. To achieve this aim, three objectives were set, namely: 1) to explore spatial clustering of aardvark burrows; 2) to identify potential determinants of aardvark burrow

presence in quadrats at Rietvlei, and 3) to identify potential determinants of aardvark burrow density within these quadrats.

Materials and Methods

Rietvlei Nature Reserve is situated in the southern portion of the City of Tshwane Metropolitan Municipality (CTMM) in the Gauteng Province of South Africa (Figure 1). The reserve is approximately 3,800 ha in size (Marais, 2004) and the geology is characterized by dolomite (to the east), andesitic lava (central part), and shale (on the west), while the soil type is a mixture of avalon, rensburg, hutton, mispah and dundee (Republic of South Africa, 1973). The reserve is characterized as a grassland biome (Mucina & Rutherford, 2006), with a relatively flat topographical landscape, interspersed with water bodies (dams and streams), buildings, and roads. A distinction is made in the reserve between grassland and low-lying grassland, with grassland being, on average, richer and shorter grass assemblages than low-lying grassland. The area receives summer rainfall, with an annual mean of approximately 720 mm (Marais, 2004) with the mean average temperatures ranging from a minimum of 4°C in winter to a maximum of 27°C in summer (Marais, 2004). Approximately 80 mammal species are known to occur in the reserve, with aardvark (*Orycteropus afer*) the largest of the burrowing mammals (Marais, 2004). Visitors use the reserve for leisure activities such as braais (barbeque), holidaying, and viewing wildlife that occur in the reserve.

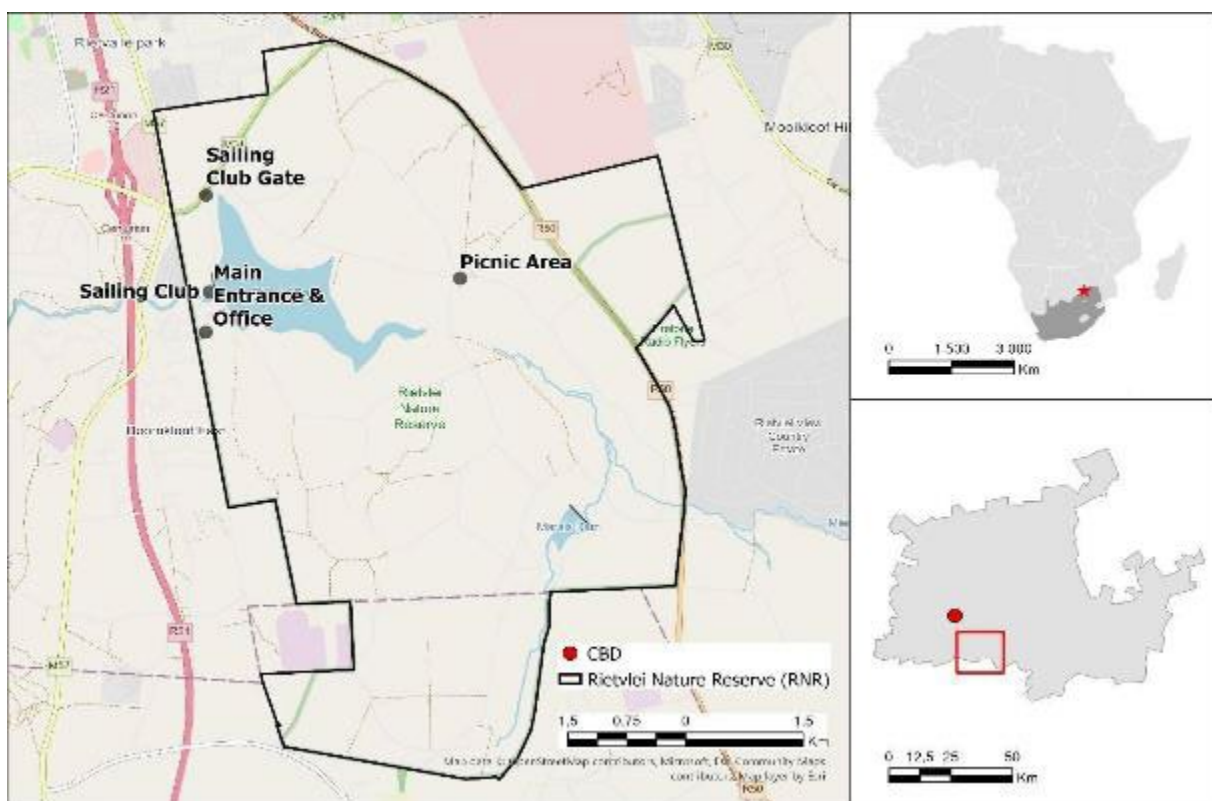


Figure 1: Rietvlei Nature Reserve and its location in the City of Tshwane Metropolitan Municipality (CTMM) and South Africa.

In April 2015 a stratified random sampling approach was used to search for burrows in Rietvlei (see Haussmann *et al.*, 2018). During this survey, a team of eight to 14 people was deployed to systematically search for burrows in randomly chosen 1-ha quadrats within each of the reserve's management blocks (the strata). This approach was used to search for burrows within

approximately 1% (with a total of 45 1-ha quadrats) of the reserve (Figure 2). To ensure that natural depressions and feeding scrapes were not recorded as burrows, only diggings with tunnel-like structures and roofs were recorded. The excavations that were large enough to shelter an armadillo were then considered as its burrows. Using this method, GPS coordinates of 250 burrows were recorded within the reserve. In addition to recording the GPS coordinates, each burrow was also categorised as either complex or simple, with complex burrows having more than one entrance. Due to accessibility, all quadrats were situated on grassland vegetation, avoiding reeds.

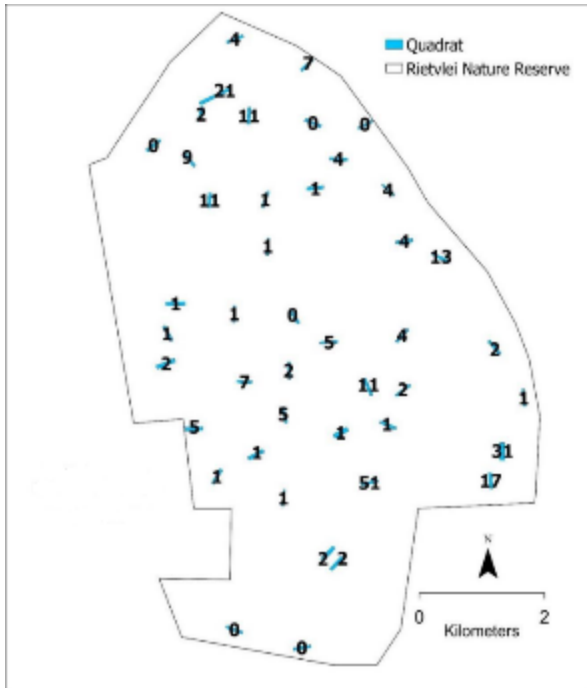


Figure 2: The 45 1-ha quadrats that were searched in 2015 for armadillo burrows. The number on the quadrat refers to the number of burrows found within the quadrat.

distance Spatial Cluster Analysis using Ripley's K function (30 distance bands, 99 permutations) (Equation 2) was run to identify potential clusters. The *Optimized Hot Spot* tool was further used to identify hot or cold spots for burrow type (complex; simple).

Geospatial layers for the following environmental variables were created through digitizing maps received from Rietvlei Nature Reserve: geology, vegetation, soil, rockiness, as well as proximity to water bodies and roads. Subsequently, the *Identity* tool was used to extract these variables per quadrat. To determine potential clustering or dispersion of burrows within quadrats, cluster analyses were conducted using ArcGIS Pro 2.7 for the three quadrats with the highest number of burrows (Quadrats 2, 3, and 28 with 51, 31, and 21 burrows respectively). *Average Nearest Neighbour Analysis* (Equation 1) was used to determine the observed mean distance between neighbours and *Multi-*

$$ANN = \frac{DO}{DE} \quad [1]$$

where DO is the observed mean distance between each feature and its nearest neighbour and DE is the expected mean distance for the features given a random pattern.

$$L(d) = \sqrt{\frac{A \sum_{i=1}^n \sum_{j=1, j \neq i}^n k_{i,j}}{\pi n(n-1)}} \quad [2]$$

where d is the distance, n is equal to the total number of features, A represents the total area of the features and $k_{i,j}$ is weight. If there is no edge correction, then the weight will be equal to one when the distance between i and j is less than d and will equate to zero otherwise.

Apart from cluster analyses, which were performed in ArcGIS Pro, all statistical analyses were performed in the R programming environment (Barton, 2020). First, Fisher exact tests of association (MASS package) were used to determine whether associations exist between aardvark burrow presence/absence in a quadrat and the categorical environmental variables, namely 1) vegetation type (two categories: grassland, low-lying grassland), 2) soil type (two categories: hutton, mispah), 3) soil rockiness (two categories: <40%, >40%), and 4) geology (three categories: shale, dolomite, andesitic lava). Next, Generalized Linear Models (GLZs) were used to model the relationship between the environmental parameters and aardvark burrow density (number/ha) per quadrat. To account for data being over-dispersed, a negative binomial distribution was used. All possible combinations of fixed variables were then compared using the ‘dredge’ function in the MuMIn package (Barton, 2020). Model selection was undertaken based on maximum likelihood and using second-order AIC (AICc) scores and corresponding AIC weights to select the most parsimonious models (Burnham & Anderson, 2002). Statistical significance was set at $P \leq 0.05$.

Results

Burrows in Rietvlei Nature Reserve were found on all searched vegetation types, soil types, rockiness levels and geologies, with burrow numbers per 1-ha quadrat ranging from zero to 51 (Figure 2). No overall spatial pattern was apparent using *Average Nearest Neighbour Analysis* for Quadrat 2 (Table 1). However, Ripley’s K function shows that for this quadrat clustering occurred at distances up to 28 m between burrows, whereas dispersion occurred at distances from 43 m between burrows. Cluster analyses further show that the overall pattern for Quadrats 3 and 28 was dispersion, with observed mean distances to neighbours of 10.7 m and 13.2 m respectively (Table 1). At distances exceeding 21 m, burrows followed a dispersed pattern for Quadrat 3; for Quadrat 28 the distance was 40 m. Neither of these quadrats displayed clustering of burrows. *Optimized Hot Spot* analyses on the type of burrow (complex burrows, simple burrows) further shows that no significant ($P \leq 0.05$) hot or cold spots were present in any of the quadrats.

Table 1. Clustering analyses for Quadrat 2, 3, and 28.

Quadrat	Number of burrows	Average Nearest Neighbour (NN)	Observed Mean Distance (m)	Multi-distance Spatial Clustering
2	51	1.0; random, P = 0.72	7.1	<u>Significant clustering</u> up to 28 m, most pronounced clustering at 7 m; <u>significant dispersion</u> from 43 m, most pronounced dispersion at 213 m

3	31	1.2; significant dispersion, P= 0.04	10.7	No clustering; <u>significant dispersion</u> from 21 m, most pronounced dispersion at 321 m
28	21	1.5; significant dispersion, P ~ 0.0	13.2	No clustering; <u>significant dispersion</u> from 40 m, most pronounced dispersion at 396 m

The Fisher exact test results showed no associations between burrow presence/absence in quadrats and any of the potential environmental determinants (Table 2).

Table 2. Fisher exact test results of associations between burrow presence/absence and vegetation, soil types, rockiness, and geology. Note that two of the quadrats were on soil types other than hutton or mispah, and six of the quadrats were on geologies other than shale, dolomite or andesitic lava. Due to their low numbers, these were excluded from the soil and geology analyses respectively.

Environmental Parameter		Burrow Presence		p-value
		Yes	No	
Vegetation	Low-lying grassland	27	7	0.08
	Grassland	11	0	
Soil type	Hutton	16	4	0.06
	Mispah	20	3	
Rockiness	<40% rock	15	3	1.00
	>40% rock	23	4	
Geology	Shale	10	2	0.84
	Dolomite	9	1	
	Andesitic lava	14	3	

Only 21% of the variation in burrow density was explained by the predictor variables. Furthermore, none of the potential determinants were significant predictors of aardvark burrow density (Table 3) and the best model included none of the predictor variables.

Table 3. Results from the Generalized Linear Model on the effects of potential determinants on aardvark burrow densities.

Predictor variable	Chi ²	df	p-value
Vegetation	0.049	1	0.82
Soil type	4.933	3	0.18
Rockiness	0.008	1	0.93
Geology	1.399	2	0.50
Distance to roads	1.229	1	0.27

Distance to waterlines	0.141	1	0.71
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Discussion

Animal burrows are not static features in the landscape, but instead their locations change over time (Holmes *et al.*, 2016; Goodman *et al.*, 2018). As old burrows fill up, new burrows are created in new locations. Porcupine diggings in the Northern Cape, for example, have a lifespan of between approximately one and three years (Bragg, Donaldson & Ryan, 2005). Similarly, in our study, the 250 aardvark burrows recorded in 2015 had deteriorated to such an extent, that they could not be located again in 2020. From a burrow perspective, the Rietvlei landscape is, therefore, quite dynamic and we realise that the distribution of aardvark burrows in 2015 is not a fixed distribution but had changed by 2020. Nevertheless, there is no reason to suspect that the 2015 distribution is not representative of aardvark burrowing in general and would, therefore, reflect patterns in burrow behaviour, if these existed. In general, our results suggest that patterns in aardvark burrow distribution are not consistent across all spatial scales and within all quadrats. Whereas burrows in general appear to be dispersed across the Rietvlei landscape, at smaller spatial scales, burrows sometimes seem to occur in clusters.

Aardvark are solitary species that do not live in groups. This explains the general dispersed nature of their burrows throughout the landscape. We propose two potential explanations for burrow clusters at smaller spatial scales. First, given that aardvark construct a new burrow every few days (Melton, 1976), and construct complex burrows with multiple entrances (personal observation), it is possible that these burrows were created by a single aardvark. It is, however, also possible that burrow clusters observed at smaller spatial scales were constructed by multiple burrowers, but that they differed in construction age and were therefore either not occupied at the same time or were being used by other species (Whittington-Jones, Bernard & Parker, 2011).

Previous studies have shown that several environmental parameters influence aardvark burrowing. For example, aardvark avoid rocky surfaces when constructing burrows, presumably because of excavation difficulties and, as such, aardvark tend to be absent in mountain environments (Skinner & Smithers, 1990). Surprisingly, burrows occur on both rocky (>40% rock content) and less rocky (<40% rock content) soils within Rietvlei, and more rocky quadrats also did not have lower burrow densities. Although the soils of Rietvlei vary in terms of rockiness, the landscape is by no means mountainous, and the rock content of Rietvlei soils is, therefore, presumably not high enough to limit aardvark digging. In terms of vegetation, and at a broad, southern African spatial scale, aardvark occur on most vegetation types, but are absent from true forests (Skinner & Smithers, 1990). However, at the far smaller, local scale of Rietvlei Nature Reserve, the differences in the two types of grassland in the reserve are apparently not large enough to affect aardvark digging behaviour.

Aardvark tend to avoid digging where the groundwater level is high (Knöthig, 2005). We, therefore, expected to find a positive relationship between distance to water lines and aardvark densities, with quadrats that were further from the reserve's streams and dams, expected to have higher burrow densities. However, because the original 2015 burrow survey was limited to grassland vegetation, none of the quadrats in our study were very close to water lines, where the vegetation type tends to transition into reeds. Thus, the edge of the closest quadrat was still over 100 m from the water edge. This probably explains why distance to water lines was not a significant predictor of aardvark burrow densities. Similarly, distance to roads also did not affect aardvark burrowing, with quadrats closer to roads having similar aardvark densities to quadrats further from roads. Because of the disturbance that roads cause for many animals (Hill,

DeVault & Belant, 2021; Shannon et al, 2014), we expected to find fewer aardvark burrows in quadrats closer to roads, compared to those located further away. Contrary to our expectation, however, aardvark appear comfortable with constructing burrows close to roads, with burrows observed as close as a few meters from the road's edge. This suggests a certain extent of habituation of aardvark to human infrastructure at Rietvlei Nature Reserve. Similarly, Planillo and Malo (2013) reported that European rabbits (*Oryctolagus cuniculus*) also construct their burrows near roads, albeit at lower abundances.

The 2015 aardvark burrow survey did not include the whole of Rietvlei Nature Reserve. Instead, 1% of the reserve was surveyed for burrows, totalling 45 1-ha plots throughout the reserve. Thus, we could not assess clustering for the reserve, but instead clustering was assessed per quadrat, using the three historically most densely populated quadrats (2, 3 and 28). However, within the 45 quadrats, burrow numbers varied greatly, with some quadrats having no burrows, and others over 50 burrows. This suggests that, at the larger spatial scale of the reserve, clusters, *i.e.*, areas of localised higher burrow numbers, potentially do occur. However, reasons for some quadrats containing such high burrow densities, while others contain no burrows at all, still evade us. Given that burrows often occur some distance from their foraging areas (Knöthig, 2005) and Rietvlei is a small nature reserve, with termite mounds regularly seen interspersed throughout the landscape, it seems unlikely that termite distributions are driving burrow locations. Other potential drivers that were not explored here include more nuanced differences in plant cover and grass height between quadrats. Quadrats are, for example, rotated when it comes to managed veld burning. This influences grass cover, which in turn may affect aardvark burrowing. In addition, although Rietvlei is relatively flat from a topographical perspective and none of the burrows were recorded on steep slopes, small-scale topography could possibly play a role in determining burrow locations. Such reasons, however, remain speculative and, in general, aardvark at Rietvlei appear to be largely unrestricted in terms of burrowing locations.

Conclusions

The aardvark is a well-adapted digger, occurring in almost all habitat types in southern Africa (Skinner & Smithers, 1990), and this research supports this. At Rietvlei Nature Reserve, aardvark burrows were dispersed throughout the landscape, with burrowing seemingly unrestricted by the environmental parameters studied. In addition, aardvark are classified as “least concern” on the IUCN red list (Taylor & Lehmann, 2015) and no declines in numbers have been reported from Rietvlei Nature Reserve. From a conservation perspective, the importance of understanding their burrowing behaviour is therefore not immediately apparent. However, aardvark burrows play an important role in providing shelter to several other species. Whittington-Jones, Bernard and Parker (2011) recorded 21 mammal species making use of aardvark burrows over a 12-month period, presumably to avoid climatic extremes and predators. Such climate refugia, provided by burrowing mammals, will potentially become more important in a changing climate, with increasing temperatures. Therefore, understanding the distribution of animal burrows is important, not only for conserving the burrower itself, but potentially also for a host of other species.

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Flood risk analysis in the Limpopo River basin using the Gumbel distribution method

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Abstract

The study employed flood risk analysis as a flood risk reduction strategy in the Mzingwane Catchment of the Limpopo River basin. The flood risk analysis study was conducted using the B35 hydrological gauging station on the Limpopo River. In this paper, the focus is on flood risk to Zimbabweans in the lower parts of Beitbridge and Chiredzi districts, along the borders of Zimbabwe and South Africa and Mozambique. The Gumbel distribution method was used to model flood events since it is a widely used statistical method for predicting flooding and highly volatile and extreme weather events. Daily maximum instantaneous runoff data for B35 hydrological gauging station used for the study covered the period 1959 to 2013. The method successfully predicted flows for the station for 0.5, 0.2, 0.1, 0.05, 0.04, 0.02, 0.01 and 0.005 exceedance probabilities. A Chi-Square test conducted on observed and predicted data produced a value of $\chi^2_{(49)} = 13.49$, $p < 0.05$ against the critical value of 67.50. Therefore, it was observed that peak discharges at the B35 gauging station followed the Gumbel distribution. Results of the study are important in flood risk reduction activities, and flood hazard assessment as it informs flood risk reduction legislation/policy and general decision-making. Similar studies elsewhere should however make use of long-term data to reduce errors from the extrapolation during the detection of flood magnitudes with higher return periods.

Keywords: Flood risk, Flood return, Exceedance, Return period, Gumbel distribution

Introduction

One thousand disasters have hit southern Africa in a space of about 40 years (Dingel & Tiwari, 2010). The recurrence and consequences of these disasters will escalate due to climate change as most of these disasters are hydro-meteorological. The cost of replacing infrastructure after a disaster is quite heavy on developing countries. Recent studies revealed that Namibia required US\$622 million for reconstruction or recovery assistance after being hit by floods in 2009 (Dingel & Tiwari, 2010).

Low lying areas of Zimbabwe, particularly the Save Valley in Manicaland Province and Limpopo River basin in Matabeleland South Province are often affected by disasters such as the tropical cyclones (TCs) (e.g., TC Eline of the year 2000 (UN, 2010). Dingel and Tiwari (2010) also observed that in Zimbabwe, especially in the Zambezi and Limpopo River basins people are vulnerable to severe and devastating floods and droughts. On the other hand, climate change is likely to increase the intensity and frequency of disasters in these low-lying areas. Climate change shall bring with it even more devastating disasters due to the envisaged extreme weather events (ISDR, 2008). Therefore, there is great need to understand the present and future flooding dynamics in these flood prone areas.

Researchers agree that climate change is set to increase the risk of flooding to people especially those living in low lying areas (Ncube-Phiri et al., 2014; Nhemachena, 2014). On the other hand, studies carried out in Zimbabwe mainly on exposure and vulnerability revealed that communities acknowledge the existence and impact of climate change on food security (Bongo et al., 2013). The lack of information about localised climate change magnitude however compromises the quality of risk reduction strategies employed in some areas (Bongo et al., 2013). Ncube-Phiri et al. (2014) lamented that as a result, communities in Muzarabani along the Zambezi River basin have taken too long to adapt and devise coping mechanisms for flood risk.

Flood risk analysis is commonly used as a flood risk adaptation measure (Beullac et al., 2016). Hence, these measures can be used in the planning, design and management of settlement and water resources to avert risk to flooding. It should be noted that flood risk reduction normally relates to measures that can be put in place to reduce the impact of floods or rather to allow for adequate preparations before flooding (Eleuterio, 2012). However, in a study by Merz et al. (2014), it is evident that different catchments respond differently to changes in climatic variability. Results of flood risk management and climate change are therefore difficult to apply in a different catchment even if it's the same country.

In the Limpopo River basin, disaster risk reduction studies have been primarily focused on food security, livestock production and vulnerability of marginalised groups (Muhonda, 2011; Bongo et al., 2013; Nhemachena et al., 2014). Studies by Bongo et al., (2013) examined the country's disaster risk reduction framework with a major interest on how it responded to the needs of vulnerable groups like the poor, elders, sick and disabled. Muhonda (2011) looked at the institutional arrangements for flood and drought management with a greater focus on crop and livestock production in the Kanyemba area of the Zambezi River basin. These studies observed that communities and institutions lack adequate knowledge and technology on how to deal with natural disasters. However, there is need to devote much effort towards unravelling the country's flooding problem and proffering science-based solutions for the benefit of low-lying areas. Hydro-meteorological data are vital inputs towards decision making pertaining to flood risk reduction (Golnaraghi & Power, 2012). Hydrological instruments and models can thus be used to identify the flood prone zones as recommended by Tiepolo (2014). These areas can then be mapped using GIS for use in flood risk reduction and response mechanisms (Madamombe, 2004; Selvakumar and Ramasamy, 2014). This study endeavours to fill in the research gap by making use of hydrological data to analyse the flood risk situation in the study area. The study shall make use of data from a hydrological gauging station to estimate the flood return periods and the corresponding magnitudes in the Limpopo River basin. The results of the study are critical inputs in the development of disaster management and settlement plans (Vivekanandan, 2015). The main objective of the study was to employ flood frequency analysis as a flood risk reduction strategy for low lying areas of Beitbridge and Chiredzi districts within the context of climate change.

Materials and Methods

Study area

The study focuses on the lower part of Mzingwane Catchment, south of Zimbabwe. Note, the Mzingwane Catchment is a sub-basin of the Limpopo River which is shared by Botswana, Mozambique, South Africa and Zimbabwe. Zimbabwe is a country in -southern Africa which share boundaries with Zambia in the north, South Africa in the south, Botswana in the west and Mozambique to the east. The country receives highly variable rainfall, which is well below 400 mm/year in the lowveld and above 1000 mm/year in the highveld regions (Chidavaenzi et al.,

2010). Low lying areas in the west and south of the country receive rainfall of about 350-450 mm/year (Brazier, 2015).

The study area spans from Beitbridge District to the Chiredzi District as shown on Figure 1 below. Beitbridge district is one of the seven administrative districts in Matabeleland South Province (Mtetwa *et al.*, 2013), and has a total population of 122 220 people. The population is further distributed as 80 083 for rural Beitbridge and 42 137 for Beitbridge urban (ZimStat, 2012). Previous socio-economic studies in the Limpopo River basin have shown that poverty prevalence rates in both Beitbridge rural and urban were around 68% (ZimStat, 2015). Chiredzi District is characterised by sugarcane estates of the small-scale farmers who chiefly rely on rainfed agriculture (CASS, 2008). The study area therefore falls within a very arid part of the catchment with little rainfall.

The B35 hydrological gauging station is the last Zimbabwean station on the Limpopo River, which is on the boundary between Zimbabwe and South Africa. B35 is a broad crest weir with a six-meter-high tower fitted with a digital water level recorder. It is the last hydrological gauging station upstream of the study area. The station measures all runoff from the upstream catchments and there are also several dams on the Mzingwane River upstream of the gauging station (Figure 1). The major dams in the Mzingwane River upstream, include the Insiza and Zhovhe dams. These dams are the second and third largest dams in Mzingwane Catchment, respectively (Love *et al.*, 2010). The Mean Annual Runoff (MAR) ranges between 12 mm - 84 mm while the Coefficient of Variation of Runoff (Cv) is between 100% and 225% (Mazvimavi & Associates, 2007). Therefore, all rivers in the study area are seasonal with natural runoff being recorded during or immediately after the rainfall season.

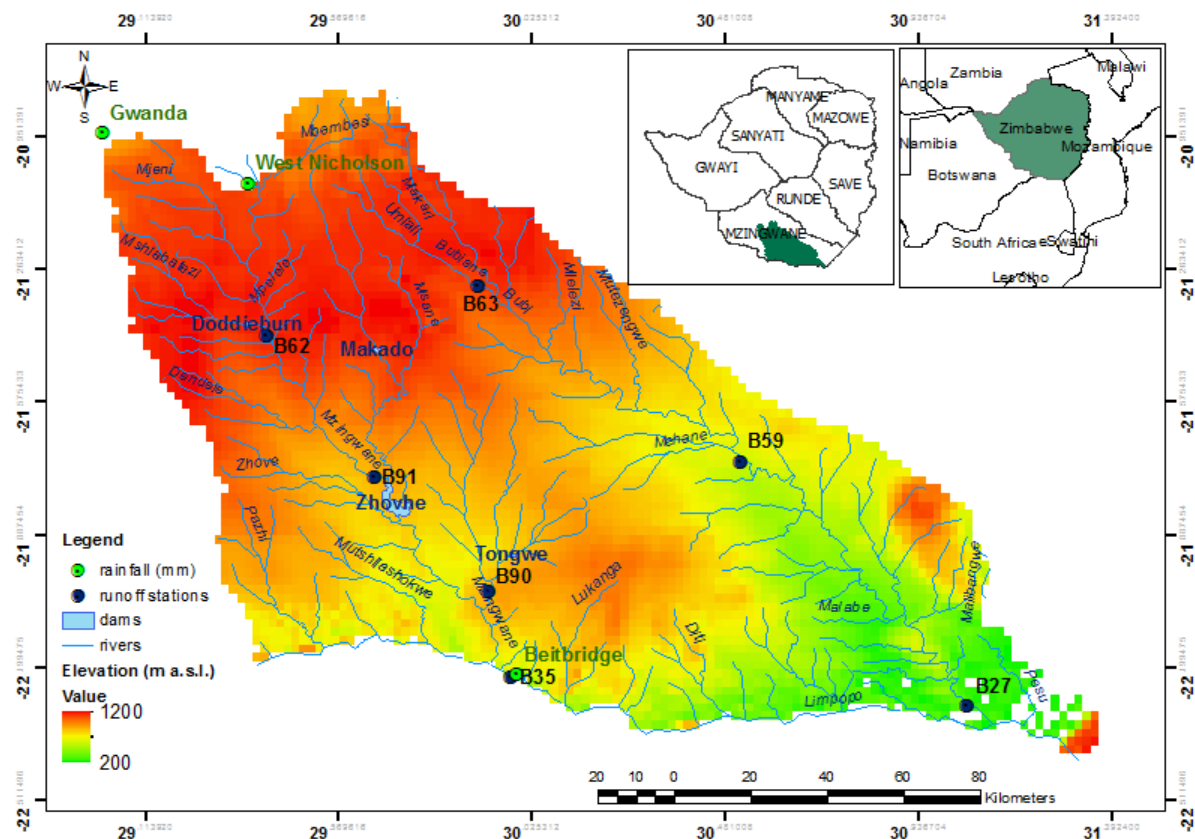


Figure 1: Study area.

Methods

The Generalised Extreme Value (GEV) distributions including Weibull, Log-Normal and Gumbel distribution methods are the most used distribution methods in flood frequency analysis (Beskow et al., 2015; Machado et al., 2015). However, the Pearson and L-moments distribution methods have often been used in data scarce regions (England et al., 2008; Hailegeorgis & Alfredsen, 2017). In this study, the Gumbel distribution method was used for flood frequency analysis using peak river flows data provided by the Zimbabwe National Water Authority (ZINWA). The Gumbel distribution is a widely used statistical method for predicting flooding and highly variable and extreme weather events (Mujere, 2011). Earlier studies (Mujere, 2011; Bhagat, 2017) have revealed that the Gumbel distribution method can be used in flood risk analysis in various regions. Flood frequency analysis study conducted for 11 southern African countries by Mkhanda et al. (2000) using the regional analysis approach identified Pearson or Log-Normal distributions as suitable for the southern parts of Zimbabwe. In delineating the region, Mkhanda et al. (2000) used seven gauging stations in the upper parts of the region and none on the Limpopo River which is the focus of this study. In that instance, the regional approach tended to bury large deviations such that standard errors got smaller when data was pooled together under the regional analysis approach. Therefore, this study employed at 'site analyses' within one of the six regions identified by Mkhanda et al. (2000) through the use of the B35 gauging station while adopting the recommendation by Mujere (2011) of employing the Gumbel distribution on major rivers especially when maximum instantaneous river flows data is available (Mkhanda et al., 2000; Mujere, 2011). Flood magnitudes and frequencies were produced using B35 runoff data for the period 1959-2013. The Gumbel distribution method was applicable to this study as the hydrological station contained long term data of over 20 years (Beskow et al., 2015). The method was also selected as it has satisfactorily been applied in India by Bhagat (2017) and in Zimbabwe by Mujere (2011) in the eastern parts of the country. The two studies identified the Gumbel distribution as appropriate for flood modelling with the use of daily maximum instantaneous data. The authors recommended other researchers to apply the method in different regions since the formula was spatially consistent.

Testing for trends in peak flows data

Flood frequency analysis assumes that peak flow data is independent and identically distributed (England et al., 2018). Visual inspection of data plots and autocorrelation were used to check for these assumptions in the data (England et al., 2018). The time series plot and the Pearson correlation coefficient (r) were thus employed in the study.

Time series plot of peak flows data

The histogram was used to show the trend of peak flows at the B35 gauging station. Figure 2 indicates a general increase in the occurrence of peak flows with time at the station.

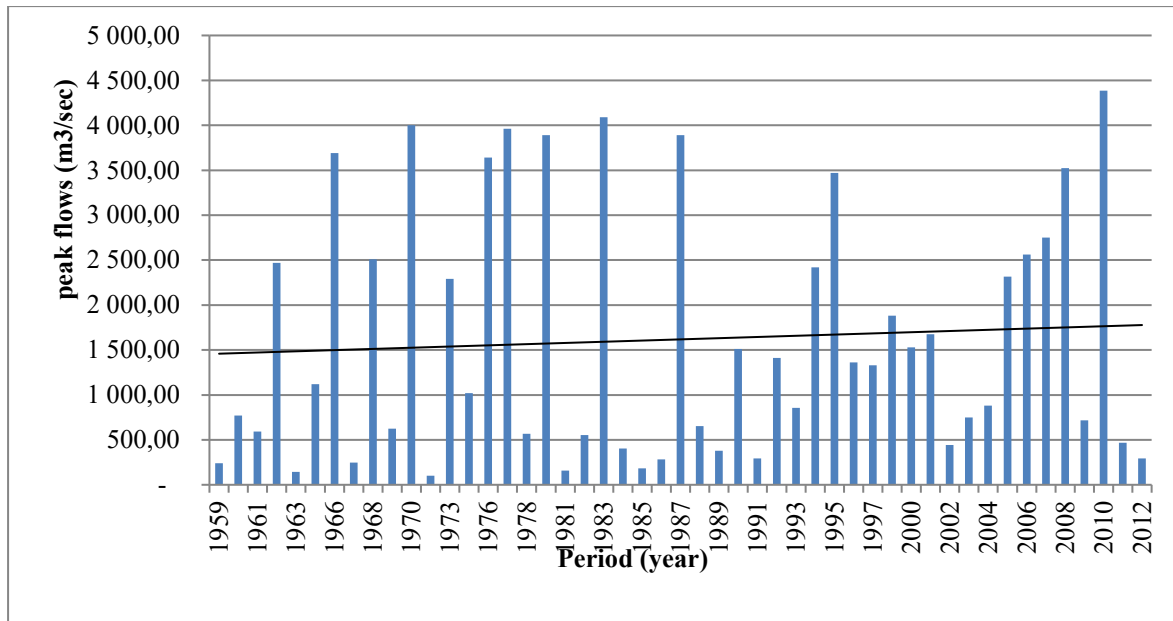


Figure 2: Time series plot of peak flows at B35 station.

Correlation

The Pearson correlation coefficient (r) was calculated from the following formula:

$$r_{xy} = \frac{n \sum x_i y_i - \sum x_i \sum y_i}{\sqrt{n \sum x_i^2 - (\sum x_i)^2} \sqrt{n \sum y_i^2 - (\sum y_i)^2}} \quad [1]$$

where r_{xy} = Pearson r correlation coefficient between x and y
 n = number of observations
 x_i = value of x (for ith observation)
 y_i = value of y (for ith observation)

A Pearson correlation coefficient (r) of 0.071 was obtained. The result showed that the occurrence of peak annual flows was increasing with time. Figure 3 indicates a persistent long-term relationship of peak flows and time in the data series.

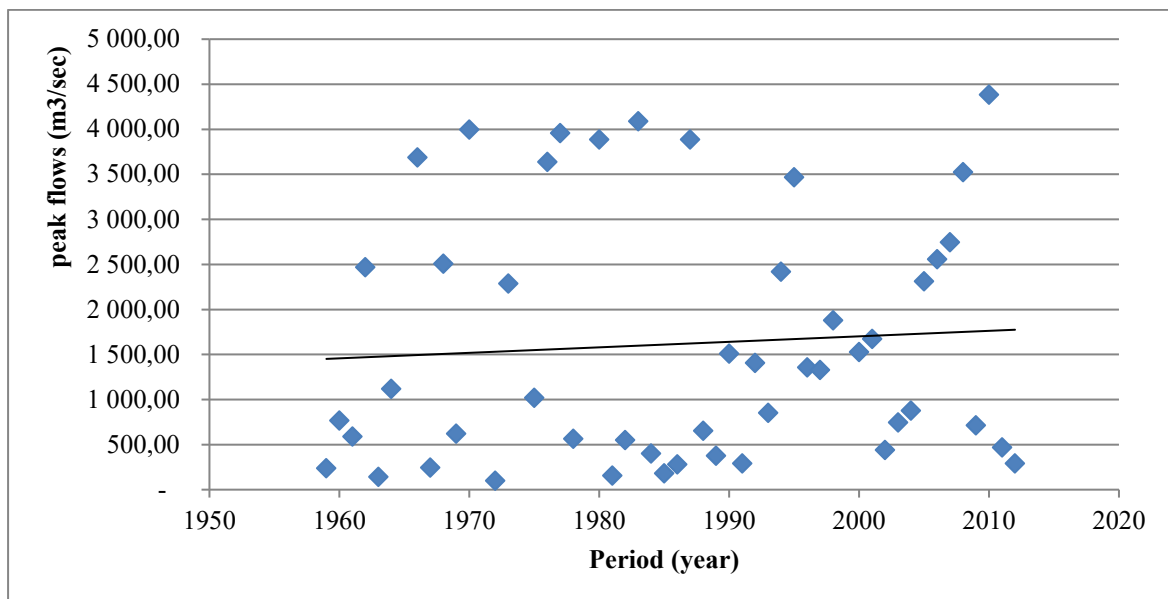


Figure 3: Correlation of peak flows with time ($r=0.071$).

The daily maximum instantaneous flows or peak flow data and their date of occurrence were extracted from the B35 daily flows dataset. The data were then arranged in terms of magnitude of flow from the highest to the lowest figure with the highest figure on top. The data was ranked from m_1 to m_{49} with the highest peak flow figure being ranked m_1 and the lowest peak flow being ranked m_{49} . The plotting positions for the Probability of Exceedance (P) and Average Recurrence Interval or Return Period (T) were calculated using the Gringorten formulae shown in equations [2] and [3] (Selaman et al., 2007);

$$P = \frac{(m-0.44)}{(n+0.12)} \quad [2]$$

$$T = \frac{(n+0.12)}{(m-0.44)} \quad [3]$$

where m = rank of extreme value
 n = total number of flow values

To calculate the flood magnitude (Q) at return period (T) to fit the Gumbel distribution to observed data, the equation shown below was used (Mujere, 2011):

$$Q_t = Q_{av} + k\sigma \quad [4]$$

where Q_t represents magnitude of (T) year flood event
 Q_{av} is the maximum daily instantaneous flow
 σ represents standard deviation of maximum daily instantaneous flow
 k represents the frequency factor

Frequency factors for each flood return period were calculated from equation below (Mujere 2011);

$$K_T = \frac{\sqrt{6}}{\pi} \left\{ \lambda + \ln \left[\ln \left(\frac{T}{T-1} \right) \right] \right\} \quad [5]$$

where $\pi = 3.14$
 $\lambda = 0.5772$ (Euler constant)
 \ln = natural logarithm
 K_T = frequency factor for (T) year flood event

Expected flood magnitude and return periods for the 2-year to 200-year flood events were calculated. The flood frequency curves were then drawn with peak flows on the y-axis and flood return period on the x-axis. The results of the model produced from observed data and those from the Gumbel distribution were then compared. The Chi-Square test was used to evaluate how closely related the results were. Flood magnitudes for 0.5, 0.2, 0.1, 0.05, 0.04, 0.02, 0.01 and 0.005 exceedance probabilities were finally established for the B35 hydrological gauging station.

Results

The B35 station recorded a highest maximum instantaneous flow of 4,386.93m³/sec during the 2010-11 season while a minimum flow of 102m³/sec passed through the station during the 1972-73 hydrological season. The mean flow for the 49 years of data was calculated as

1,618.11m³/sec while the standard deviation was 1,361.30m³/sec. Table 1 presents the results of the descriptive statistical analysis conducted at the station.

Table 1: Descriptive statistics for B35 daily maximum instantaneous flow data.

Statistic	Result
Mean	1,618.11 m ³ /sec
Median	1,120.00 m ³ /sec
Mode	3,890.00 m ³ /sec
Standard Deviation	1,361.30 m ³ /sec
Skewness	0.7
Range	4,284.93 m ³ /sec
Minimum	102.00 m ³ /sec
Maximum	4,386.93 m ³ /sec
Count	49 years

The flood return periods and magnitudes calculated using the Gringorten formulae produced return periods of 1.01 years and 87.71 years for the lowest and highest observed daily maximum instantaneous flows, respectively.

It was observed that a flood event of 1,394.48m³/sec had a return period of 2 years while a 6,626.43m³/sec flood event had a 200-year return period. The small difference between the expected 2 year and 200-year flood magnitudes emanated from the little variation of daily maximum instantaneous flows in the observed data.

A graph of the two datasets of peak discharges and flood return periods was drawn from the observed flows and flows predicted from the Gumbel distribution. Logarithmic *trendlines* were then added to both the observed and expected flow data as shown in Figure 4 below.

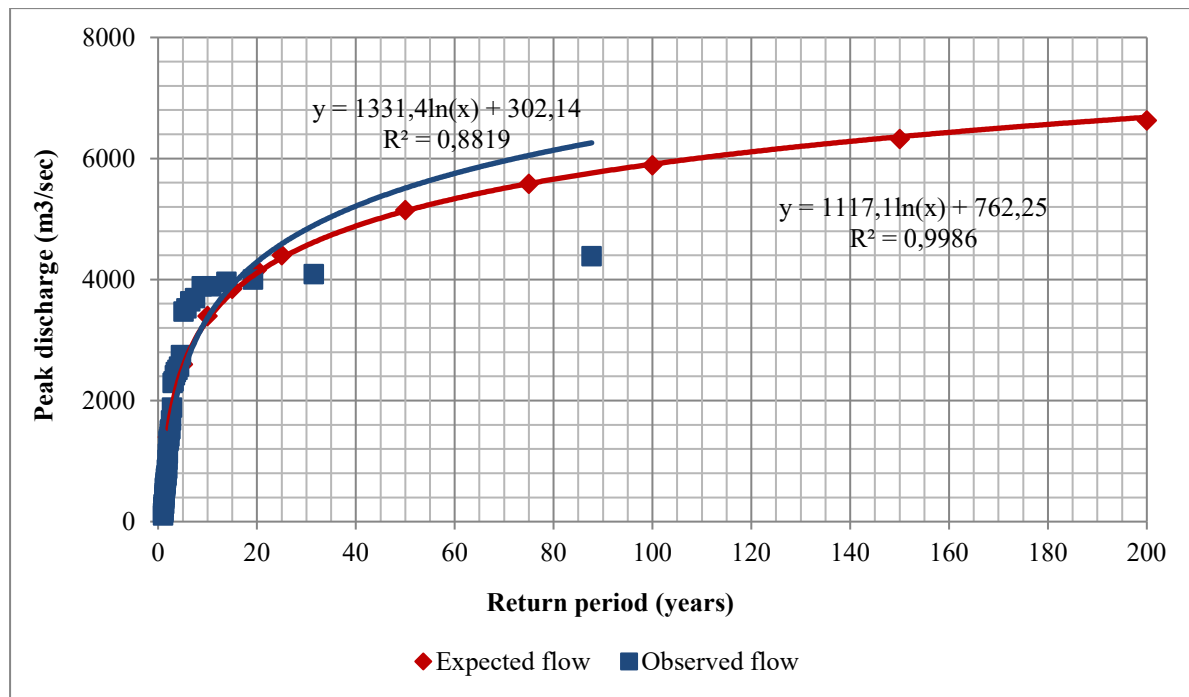


Figure 4: Flood return curve from observed and expected flow data.

The observed and expected data were closely related on discharges of up to 3,000m³/sec. There were higher differences between observed and expected flows at higher discharge levels of above 4,000.00m³/sec. The coefficients of determination of the observed and measured flows were 0.8819 and 0.9986 respectively. The following models were produced from the data:

$$\gamma = 1331.4 \ln(x) + 302.14 \quad R^2 = 0.8819 \text{ for observed flows} \quad [6]$$

$$\gamma = 1117.1 \ln(x) + 762.5 \quad R^2 = 0.9986 \text{ for expected flows} \quad [7]$$

where γ = peak discharge (m³/sec) and x = flood return period (years)

Validation of the model

Goodness of fit tests were carried out to establish how closely related the expected data was to observed data. A Chi-square test was conducted on the two sets of data.

The Chi-Square test was conducted using the formula below:

$$\chi^2 = \sum \frac{(O-E)^2}{E} \quad [8]$$

where O = observed flow and E = expected flow

The Chi-Square test can only be conducted on data that has the same units. The observed and expected data were both in m³/sec, and the test was applicable. A Chi-Square test value of $\chi^2_{(49)} = 13.49$, $p < 0.05$ was obtained against the critical value of 67.50. Since $\chi^2 < \text{critical value}$, it was observed that peak discharges at the B35 gauging station followed the Gumbel distribution. The Gumbel distribution was finally used to predict magnitudes of flood events in the Limpopo River at the B35 hydrological gauging station as shown in Table 2.

Table 2: Flood magnitude prediction using the Gumbel distribution.

Flood exceedance probability	Flood return period (years)	Flood magnitude (m ³ /sec)
0.5	2	1,537.12
0.2	5	2,556.22
0.1	10	3,327.14
0.05	20	4,098.05
0.04	25	4,346.23
0.02	50	5,117.15
0.01	100	5,888.07
0.005	200	6,658.99

Discussion

The study used maximum instantaneous flow data for the B35 hydrological gauging station covering the period 1959 to 2013. It was imperative to use long-term data in order to separate natural variations from trends (Hailegeorgis & Alfredsen, 2017). According to Machado et al. (2015), datasets with 30 to 40 years of runoff data must however not contain extraordinary events as this creates outliers in the data. The use of such long-term data for flood frequency analysis also caters for the stationary assumption since flood magnitudes and their frequencies keeps changing (Machado et al., 2015). This therefore validates the size of the dataset used as the data covered 49 years.

The study's use of maximum instantaneous or peak river discharge values for flood frequency analysis conforms with previous local, regional and global studies of a similar nature (Mujere 2011; Ahn et al., 2014; Machado et al., 2015; Bhagat 2017; Hailegeorgis & Alfredsen, 2017; Engeland et al., 2018). Engeland et al. (2018) in a study conducted in Norway attempted to fuse in historical flood information into the annual peak river discharge data to improve data length and improve reliability of results. They observed that historical information was valuable to flood design but must be converted to flood magnitudes first. Aano (2017) used historical information and paleo-hydrological data to extend the length of streamflow data for flood frequency analysis. It was agreed that the annual peak river discharge data, especially for the long-term data could be used for flood frequency analysis as they contain most streamflow events (Machado et al., 2015).

The Gumbel distribution applied in the study was also well suited to the data since the distribution method was also used for the Nyanyadzi River in Zimbabwe and produced acceptable results (Mujere, 2011). The Gumbel distribution method was used in similar studies by Beskow et al. (2015) and Aano (2017) on annual peak river discharge data to model extreme runoff and predict flood return intervals. Being a two-parameter model, the Gumbel distribution has often been applied in flood frequency analysis for its simplicity and reliability (Beskow et al., 2015). Ahn et al. (2014) observed that the Gumbel distribution produces better results when applied to observed annual maximum instantaneous data than peak flows simulated from rainfall.

The effect of dams or reservoirs of delayed peaks and consistent runoff during the dry season on the results is well noted especially on the flood magnitudes for the different flood return periods. The flood magnitudes were all clustered between 1,394.48m³/sec and 6,626.43m³/sec for the 2-year and 200-year floods predicted using the Gumbel distribution method. That finding is supported by Machado et al. (2015) who noted that flood magnitudes for various return periods tend to be moderate post-dam construction.

Conclusions

The Gumbel distribution method was applied to the B35 hydrological gauging station for the period 1959 to 2013, $n = 49$. The method predicted flows for the station for 0.5, 0.2, 0.1, 0.05, 0.04, 0.02, 0.01 and 0.005 exceedance probabilities. A Chi-Square test performed for observed and predicted data, produced a value of $\chi^2_{(49)} = 13.49$, $p < 0.05$ against the critical value of 67.50. Since $\chi^2 < \text{critical value}$, it was observed that peak discharges at the B35 gauging station followed the Gumbel distribution. Results of the study are important in flood risk reduction activities, planning as well as informing flood risk reduction legislation. The major limitation in this study was that the data did not have major variations and some key dates had missing data especially between years 1999 and 2000. A lot of the data points tended to be clustered around one area. Therefore, this impedes or limits the prediction of high flows. It is therefore recommended to make use of long-term data to reduce errors emanating from extrapolation when trying to get flood magnitudes for higher return periods.

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Runoff forecasting for large rivers using the Linear Regression Model: Case of the Limpopo River

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Abstract

There is no perfect runoff forecasting model as all models are inherent with errors emanating from reality uncertainties. However, effort should be made in selecting a model that forecasts well and reduces the margin of error between observed and predicted values. Regression analysis was used to predict the discharge at the B35 hydrological gauging station on the Limpopo River using Beitbridge, Gwanda and West Nicholson rainfall as well as Zhovhe dam water level data. Data for the same period of observation were used to develop a regression model. Goodness of fit tests which include RMSE, MAE, MAPE and MPE were conducted on the developed models to establish how well they simulated runoff from given rainfall values. The models had high predictive errors between 62.20 m³/sec and 1,080 m³/sec even after removing the effect of water impoundment by the Zhovhe dam by using data when the dam was spilling. It therefore can be concluded that runoff in the Limpopo River at B35 cannot be accurately predicted from upstream rainfall-derived runoff from the Mzingwane River system alone. The forecasting model would therefore require input from Thuli River; a tributary of the Limpopo River coming from the Botswana side upstream of B35.

Keywords: Runoff, rainfall, forecasting, regression model, prediction

Introduction

Water managers (mainly hydrologists and engineers) have always desired to accurately predict within a particular river basin the resultant runoff from a given rainfall threshold (Khopade & Oak, 2014). Runoff prediction is regarded as an essential input in the effective and efficient planning and management of river catchments (Li et al., 2015). Lumped Conceptual Rainfall-Runoff Models, Distributed Hydrological Models and Global Hydrological and Land Surface Models are often used for runoff forecasting depending on the purpose and available data (Li et al., 2015). However simpler mathematical modelling techniques which include Regression Analysis can be applied to simulate the complicated reality within a catchment (Ramana, 2014). Regression analysis is commonly used in modelling relationships between sediment concentration and stream discharge as well as rainfall and runoff in hydrological studies (Helsel & Hirsch, 2002). Simple linear regression analysis provides guidance on the rainfall volume and peak discharge dynamics and these often produce credible predictions (McIntyre et al., 2007). Multi-regression analysis can however make good predictions of runoff using mostly rainfall and antecedent wetness as well as input data (Qin et al., 2017). Shaw (2005) adds that a relationship between rainfall and runoff in a river basin can be derived from the monthly and annual sums of rainfall and runoff respectively. The rainfall and runoff data should however be converted to the same units e.g., cubic metres (m³). Khopade and Oak (2014) in a study of the Nira River basin; applied several empirical formulae to estimate runoff using two datasets of

18 years and 31 years long. Formulae which include rational method, time-area method and hydrograph analysis can be used to characterise such rainfall-runoff relationship in a river catchment (Shaw, 2015). Nawaz and Adeloye (1999) employed the rainfall-runoff regression model to simulate monthly runoff for England and Wales. They recommended that the model could be used for checking the performance of other rainfall-runoff models especially where low flows are crucial. The Multiple Linear Technique has also been successfully applied to model rainfall-runoff relationships in India (Dar, 2017). The study produced satisfactory results; however, the researcher used short term data covering the period 2001-2013.

Runoff forecasting studies in the Limpopo River basin are mostly concentrated in the upper parts of the river in South Africa. Graham et al. (2022) employed the Conformal-Cubic Atmospheric Model; a global rainfall forecast model to estimate rainfall for two subbasins of the Limpopo River basin in South Africa. The resultant rainfall was then used to estimate runoff response for a 3-year forecast period. Trambauer et al. (2014) used three hydrological systems and forecasted-meteorological data to predict the seasonal drought conditions in a South African catchment of the Limpopo River basin. Seibert et al. (2016) however tried to cover a larger part of the basin in their study which they conducted at 16 hydrometric stations covering South Africa, Botswana, and Mozambique. Atmospheric indices obtained from the National Oceanic and Atmospheric Administration satellites (NOAA) were used as predictors. Results of all studies conducted in some parts of the Limpopo River basin shows great potential of statistical methods and hydrological models in forecasting runoff. However, in all the studies conducted, mostly satellite derived data was used and no study focused on addressing challenges on the Zimbabwean part of the basin.

Materials and Methods

Study area

The study focused on the lower part of Mzingwane Catchment which is to the south of Zimbabwe. The Mzingwane Catchment is a sub-basin of the Limpopo River which is shared by Botswana, Mozambique, South Africa and Zimbabwe. Zimbabwe share international boundaries with Zambia to the North, South Africa to the South, Botswana to the West and Mozambique to the East (Figure 1). Generally low-lying areas to the west and south of the country receive the least rainfall between 350 mm and 450 mm per annum (Brazier, 2015). Areas in the Limpopo River basin receive an average of 530mm of rainfall per annum varying spatially from 200mm to 1200mm (Trambauer et al., 2014)

There are three rainfall stations namely, Gwanda, West Nicholson and Beitbridge as well as one major dam i.e., Zhovhe in the area of interest. There are also three gauging stations which include B62, B90 and B91 on the Mzingwane River and B35 on the Limpopo River (Figure 1). The B35 hydrological gauging station is the last Zimbabwean station on the Limpopo River sitting on the boundary between Zimbabwe and South Africa. The station measures all runoff from the upstream catchments. Dams including Zhovhe are located further upstream on the Mzingwane River system and none on the Limpopo River. With a net capacity of 130 million m³, Zhovhe dam is the third largest dam in Mzingwane Catchment (Nyikadzino et al., 2020). Altitude in the study area drops from 1200 m at West Nicholson to 200 m above sea level at the point when Limpopo River exits Zimbabwe into Mozambique. Therefore, the lower part of Mzingwane Catchment especially along the Limpopo River is low lying hence susceptible to flooding.

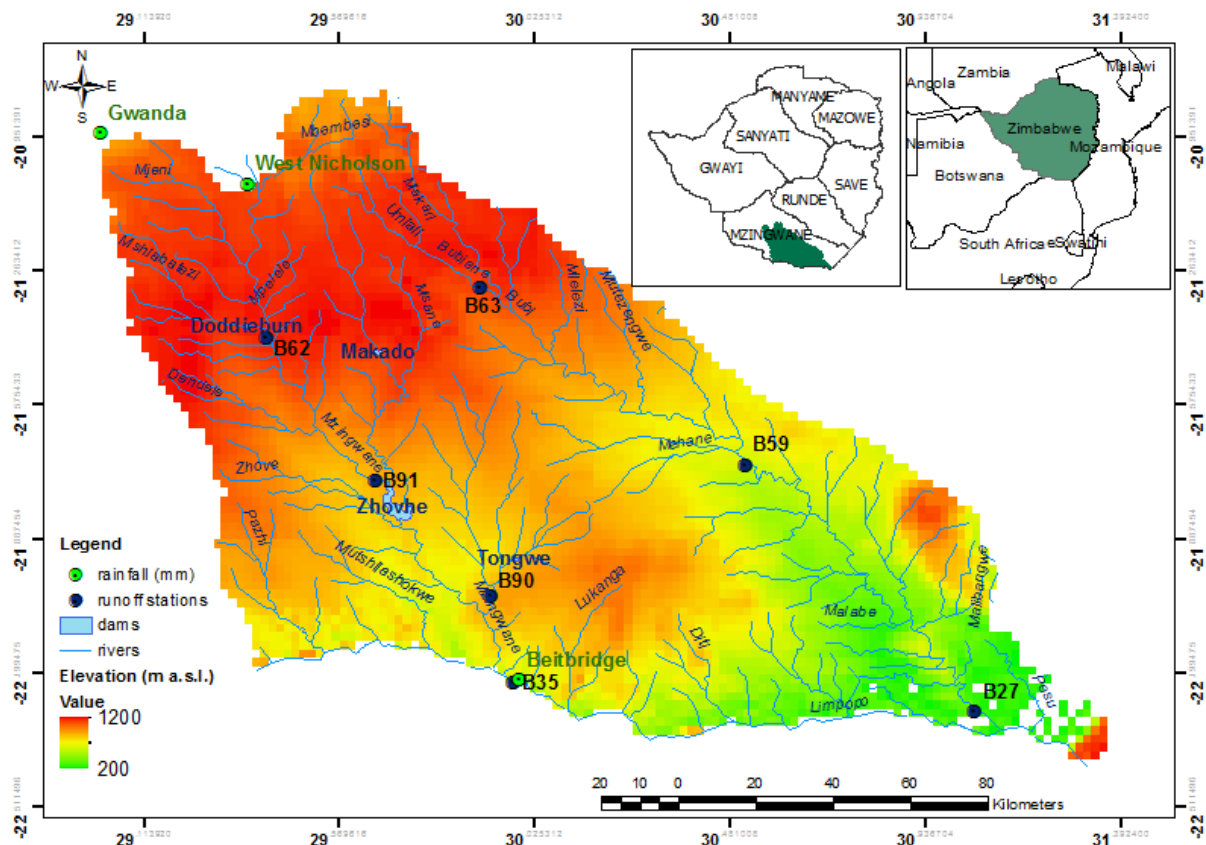


Figure 1: Study area.

Data profile

Monthly runoff data (m^3/hr) for the B35 and B62 hydrological gauging stations; rainfall data (mm) for Gwanda, West Nicholson and Beitbridge rainfall station as well as water storage data for Zhovhe dam (Mm^3) were used in the study. The shortest period of dataset was for Zhovhe dam since it was completed in 1995 (See Table 1).

Table 1: Overview of hydro-meteorological data.

Station	Data Type	Month	Period	Length (years)
B35	Runoff	Month	1959-2013	54
B62	Runoff	Month	1962-2013	51
Zhovhe Dam	Dam level	Month	1995-2019	24
Gwanda	Rainfall	Month	1951-2015	64
West Nicholson	Rainfall	Month	1951-2015	64
Beitbridge	Rainfall	Month	1950-2014	64

Tests of data for normality and heterogeneity

It is believed that there is no perfect forecasting model as all models are inherent with errors emanating from reality uncertainties (Kostenko & Hyndman, 2008). However, effort should be made in selecting a model that forecasts well and reduces the margin of error between observed and predicted values. As part of the model selection process, the data, assumptions and outputs

should be tested to evaluate whether the model is ideal for the task (Armstrong, 2001). Graphical and numerical methods can be used for testing data normality. Most commonly used graphical methods include histograms and QQ plots while numerical methods include Shapiro-Wilk and Kolmogorov-Smirnov tests (Mishra et al., 2019). The authors added that the Shapiro-Wilk test is most ideal for samples of between 20 and 50 while the Kolmogorov-Smirnov test can be applied to samples of over 50. A smaller value of Kolmogorov-Smirnov or a Shapiro-Wilk test statistic indicates normality in the data series (Javari, 2016). However, Mishra et al. (2019) argues that for sample sizes of 100 and above there is no major discrepancy that arises from nonconformity. The rainfall and runoff data should also be tested for data consistency against each other to make sure that there are no major abrupt changes.

In this study, the data was tested for normality using the Kolmogorov-Smirnov ($p>0.05$), Shapiro-Wilk ($p>0.05$), skewness and kurtosis tests. All results for B35, B62, Beitbridge rainfall, Gwanda rainfall and West Nicholson rainfall datasets indicated that the data was not normally distributed (Table 2). Skewness and kurtosis' z-values outside the -1.96 to +1.96 range revealed that the data was rather skewed to the right side. Kolmogorov-Smirnov and Shapiro-Wilk values below 0.05 also proved that indeed all the data was not normally distributed (Table 2).

Table 2: Data normality test results.

Station	Kolmogorov-Smirnov ($p>0.05$)	Shapiro-Wilk ($p>0.05$)	Skewness		Kurtosis	
			Statistic	z	statistic	Z
B35	0.000	0.000	2.289	22.441	7.053	34.744
B62	0.000	0.000	17.733	141.864	333.110	1343.186
Beitbridge	0.000	0.000	2.972	29.137	13.890	68.424
Gwanda	0.000	0.000	2.013	19.735	4.362	21.488
West Nicholson	0.000	0.000	2.105	16.840	4.857	19.585

Regression analysis

The regression model was used to predict the runoff threshold that would be generated by a particular amount of rainfall within the Limpopo River. Runoff or river discharge passing through the B35 hydrological gauging station is influenced by a number of some other factors that include evaporation, soil type and soil cover. However, since rainfall is the most direct and most important input, the following rainfall-runoff correlation was developed (Qin et al., 2017);

$$R_i = \alpha_1 r_j + \alpha_2 r_{j+1} + \dots + \alpha_n r_{j+n+1} + e \quad [1]$$

- where
- R_i = monthly runoff (m^3)
 - r_j = monthly rainfall (mm)
 - α = correlation coefficient
 - e = accidental error

Six scenarios were considered in developing regression models for the study. Regression models for the B35 station were first developed using the whole rainfall datasets for the period 1959 to 2013 according to the following three scenarios;

- a) Multiple linear regression using Beitbridge, West Nicholson and Gwanda rainfall data
- b) Multiple linear regression using Beitbridge and West Nicholson rainfall data
- c) Simple linear regression using Beitbridge rainfall data

Regression models for the B35 station were also developed using datasets corresponding to days when Zhovhe dam was spilling (during the period 1996 – 2011) according to two scenarios below;

- a) Multiple linear regression using Beitbridge, West Nicholson and Gwanda rainfall data
- b) Simple linear regression using Beitbridge rainfall data

As a control, a regression model was developed for the B62 station which is upstream of Zhovhe dam using the scenario below;

- Multiple linear regression using West Nicholson and Gwanda rainfall data

Goodness of fit tests which include Root Mean Square Error (RMSE), Mean Absolute Error (MAE), Mean Absolute Percentage Error (MAPE) and Mean Percentage Error (MPE) were conducted on the developed models to establish how well they simulated runoff from given rainfall values.

The RMSE is often frowned upon because of its sensitivity to outliers (Chai & Draxler, 2014). However, in practice, outliers can be removed first before calculating the RMSE. On the other hand, the RMSE does not use absolute values and is also assumed that the errors are unbiased and they do follow a normal distribution (Chai & Draxler, 2014). A model with a lower RMSE value would produce more accurate short-term predictions (Meyer, 2012; Doreswamy & Vastrad, 2013). RMSE is calculated using the following equation:

$$\sqrt{\frac{\sum_{t=1}^n (A_t - F_t)^2}{n}} \quad [2]$$

where A_t = actual value
 F_t = forecast value
 n = number of values

MAE indicates the average deviation of predicted values from observed values. Models with low MAE values produce good long-term predictions (Doreswamy & Vastrad, 2013). MAE is calculated from equation below;

$$\frac{1}{n} \sum_{t=1}^n |A_t - F_t| \quad [3]$$

where A_t = actual value
 F_t = forecast value
 n = number of values

MAPE gives the error as a percentage of the actual value. MAPE helps in showing by how much a forecasting model would have missed the actual value (Khair et al., 2017). Though it is the most widely used and trusted forecast accuracy measurement technique; for very low values or values close to zero, MAPE gives infinite or rather undefined results (Kim & Kim, 2016). MAPE is calculated from formula below:

$$\left\{ \frac{1}{n} \sum \frac{|A_t - F_t|}{|A_t|} \right\} * 100 \quad [4]$$

where A_t = actual value
 F_t = forecast value
 n = number of values

The MPE test is referred to as Mean Percentage Error (Ragnerstam, 2015) or Mean Prediction Error by Steurer & Hill (2000). The MPE error measurement technique is essentially the same as MAPE except that MPE does not measure the errors in absolute form (Ragnerstam, 2015). The MPE is calculated from the following equation;

$$\frac{100\%}{n} \sum \left(\frac{y - \hat{y}}{y} \right) \quad [5]$$

where y = actual value
 \hat{y} = forecast value
 n = number of values

Results

Linear regression forecasting models

Regression analysis was used to predict the discharge at the B35 hydrological gauging station. Rainfall and runoff data for the same period of observation were used to develop the regression models. Linear regression modelling that includes both simple and multi-linear using Beitbridge, Gwanda and West Nicholson rainfall stations was conducted, and the resultant models were tested for the quality of predictions they make.

Regression model for B35 Runoff (1959 - 2013)

Data for Beitbridge, West Nicholson and Gwanda rainfall stations for the period Oct 1959 – Jan 2013 was used to develop a rainfall-runoff relationship at the B35 hydrological gauging station. The datasets were split into training and validation datasets. Training data used to develop the models covered the period 1959-1990 while validation data covered the period 1991 – 2013.

(a) Scenario 1: Multiple linear regression output for B35 using Beitbridge, West Nicholson and Gwanda rainfall data

The maximum observation across the four datasets was 4,566 while the minimum was 0. The regression analysis produced a very low coefficient of correlation ($R^2 = 0.39$) thereby suggesting that around 39% of the 352 sets of values can be explained by the resultant model (Table 3). A standard error of 368.26 obtained was also considered very high. The p-value obtained from the Gwanda rainfall station dataset was 0.05 while those for Beitbridge and West Nicholson were below the 0.05 threshold (Table 4).

Table 3: Summary statistics for scenario 1.

Regression Statistics	
Multiple R	0.621
R Square	0.386
Adjusted R Square	0.381
Standard Error	368.255
Observations	352

Table 4: Regression model coefficients for scenario 1.

	Coefficients	Standard Error	t Stat	P-value
Intercept	-20.032	26.712	-0.750	0.454
Beitbridge	-1.532	0.598	-2.562	0.011
West Nicholson	5.111	0.399	12.811	4.767
Gwanda	0.627	0.364	1.720	0.086

The results were used to create model below;

$$B35 \text{ Runoff} = -20.032 - 1.532r_1 + 5.111r_2 + 0.627r_3 \quad [6]$$

where r_1 = Beitbridge monthly rainfall (mm)
 r_2 = West Nicholson monthly rainfall (mm)
 r_3 = Gwanda monthly rainfall (mm)

(b) Scenario 2: Multiple linear regression output for B35 station using Beitbridge and West Nicholson rainfall data

The regression analysis was run again without the Gwanda rainfall data since it was deemed not to have any significant effect on the runoff recorded at the B35 hydrological gauging station. There was no improvement in the coefficient of correlation after omission of the Gwanda rainfall dataset (Table 5). There was also a weak relationship of the values in the three datasets ($R^2=0.38$). The standard error also increased to 369.29.

Table 5: Summary statistics for scenario 2.

Regression Statistics	
Multiple R	0.617
R Square	0.381
Adjusted R Square	0.377
Standard Error	369.286
Observations	352

The regression model coefficients for the intercept, Beitbridge and West Nicholson were approximately -7.683, -1.340 and 5.295, respectively (Table 6).

Table 6: Regression model coefficients for scenario 2

	Coefficients	Standard Error	t Stat	P-value
Intercept	-7.683	25.800	-0.298	0.766
Beitbridge	-1.340	0.589	-2.274	0.024
West Nich	5.295	0.385	13.737	0.000

The following regression model was developed:

$$B35 \text{ Runoff} = -7.683 - 1.340r_1 + 5.295r_2 \quad [7]$$

where r_1 = Beitbridge monthly rainfall (mm)
 r_2 = West Nicholson monthly rainfall (mm)

(c) Scenario 3: Simple linear regression output for B35 station using Beitbridge rainfall data

The B35 hydrological gauging station is located downstream of the catchment's largest dam (i.e., Zhovhe dam). As such, a simple linear regression analysis to model runoff at the B35 station was done using Beitbridge rainfall only. This was done to remove the effect of water impoundment by the dam before it starts spilling. The following summary statistics were produced (Table 7). The analysis produced a very low correlation coefficient (R^2) of 0.05 and an adjusted coefficient of correlation (Adjusted R^2) of 0.04.

Table 7: Summary statistics for scenario 3.

Regression Statistics	
Multiple R	0.214
R Square	0.046
Adjusted R Square	0.043
Standard Error	457.719
Observations	352

The p-value for Beitbridge rainfall was 0.000 while the standard error was 0.637 (Table 8).

Table 8: Regression model coefficients for scenario 3.

	Coefficients	Standard Error	t Stat	P-value
Intercept	96.328	30.570	3.151	0.002
Beitbridge	2.616	0.637	4.107	0.000

The following model was produced from the regression coefficients in Table 8.

$$B35 \text{ Runoff} = 96.328 + 2.615r_1 \quad [8]$$

where r_1 = Beitbridge monthly rainfall (mm)

Evaluation of the models for Scenario 1, 2 and 3

The quality of the three regression models developed from B35, Beitbridge, West Nicholson and Gwanda datasets were tested using RMSE, MAE, MAPE and MPE (Feng et al., 2016). RMSE and MAE values were high across all the three models while MAPE and MPE were undefined due to zero runoff values observed at the B35 station (Table 9). Though RMSE and MAE values for scenario 3 were lower than those obtained from models for scenarios 1 and 2, they were quite high at 898.50 and 615.40 respectively.

Table 9: Model evaluation results for scenarios 1, 2 and 3.

Test	Scenario 1	Scenario 2	Scenario 3
RMSE	917.70	921.10	898.50
MAE	703.80	705.10	615.40
MAPE	Undefined	Undefined	Undefined
MPE	Undefined	Undefined	Undefined

Two of the models for predicting B35 runoff simulated values lower than observed values as shown by Figures 2 and 4. However, the model which used Beitbridge, and West Nicholson rainfall data predicted values slightly higher than observed values (Figure 3).

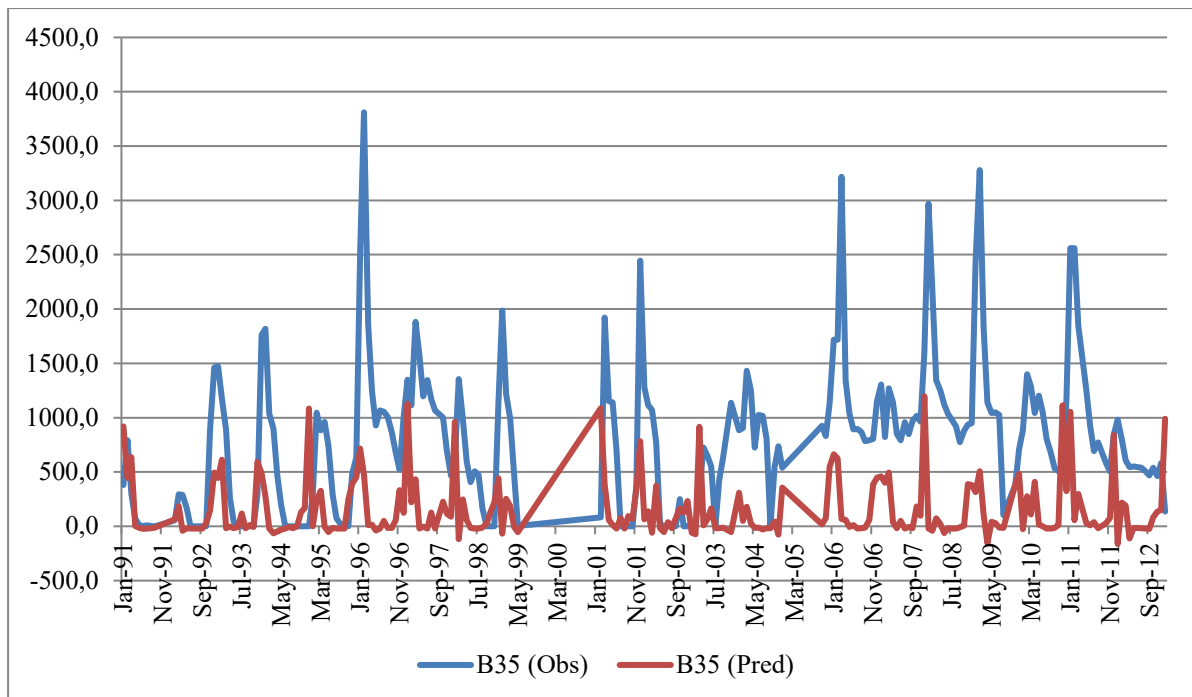


Figure 2: Observed versus predicted runoff at B35 gauging station using Beitbridge, West Nicholson and Gwanda datasets.

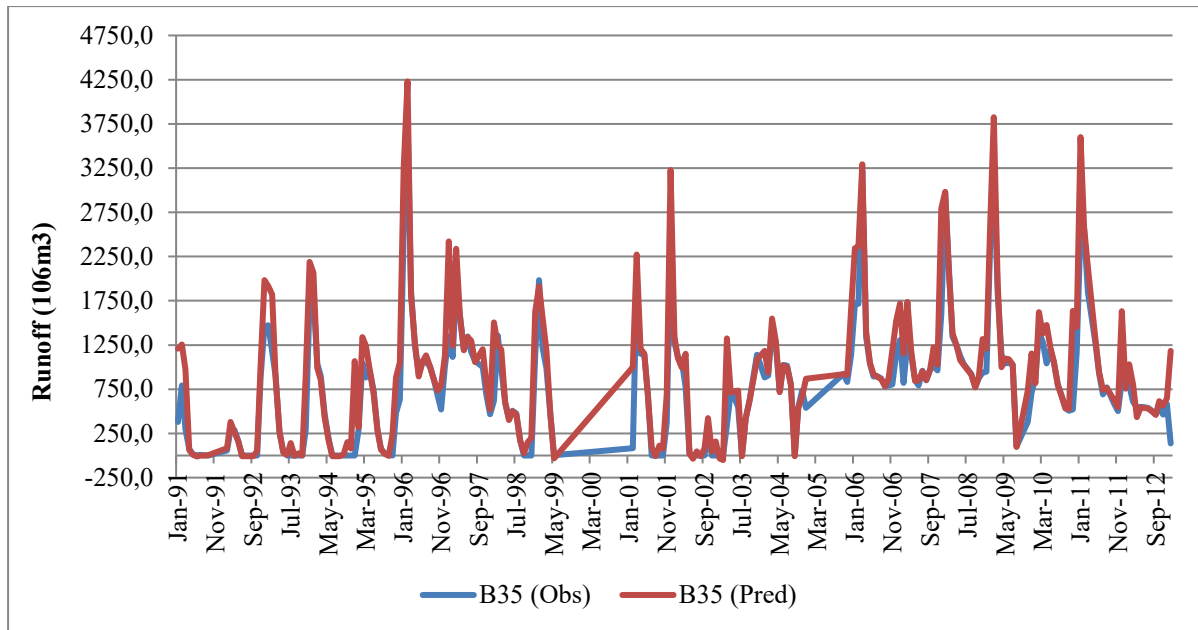


Figure 3: Observed versus predicted runoff at B35 gauging station using Beitbridge and West Nicholson datasets.

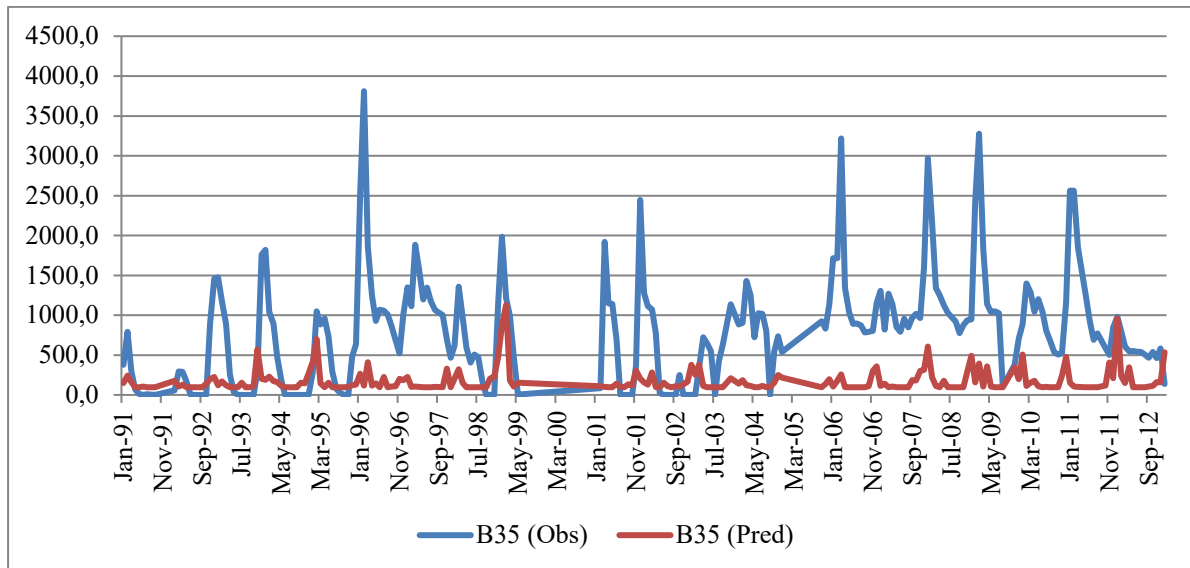


Figure 4: Observed versus predicted runoff at B35 gauging station using Beitbridge dataset.

Regression model for B35 Runoff using datasets corresponding to Zhovhe dam spilling months (1996 -2011).

(a) Scenario 4: Multiple linear regression output for B35 using Beitbridge, West Nicholson and Gwanda rainfall data

An effort was made to reduce the effect of impoundment of upstream runoff by Zhovhe dam during the rainfall season hence runoff at B35 while Zhovhe dam was full was considered. The Zhovhe dam dataset was used to identify months when the dam was spilling. Rainfall recordings corresponding to dam spilling months were selected from the Beitbridge, West Nicholson and Gwanda datasets. Data covering the period 1956-2001 was used for developing the B35 runoff model while data from 2004 to 2011 was used for model validation. The coefficient of correlation for the four datasets was however very low at 0.25 (Table 10). The p-values for Beitbridge, West Nicholson and Gwanda were all above 0.05 (Table 11).

Table 10: Summary statistics for scenario 4.

Regression Statistics	
Multiple R	0.503
R Square	0.253
Adjusted R Square	-0.308
Standard Error	975.746
Observations	8

Table 11: Regression model coefficients for scenario 4.

	Coefficients	Standard Error	t Stat	P-value
Intercept	1918.136	612.873	3.130	0.0352
Beitbridge	-1.902	3.441	-0.552	0.610
West Nicholson	-2.478	8.052	-0.308	0.774
Gwanda	5.677	9.389	0.605	0.578

The following model was produced from the regression coefficients

$$B35 \text{ Runoff} = 1918.136 - 1.902r_1 - 2.478r_2 + 5.677r_3 \quad [9]$$

where r_1 = Beitbridge monthly rainfall (mm)
 r_2 = West Nicholson monthly rainfall (mm)
 r_3 = Gwanda monthly rainfall (mm)

(b) Scenario 5: Simple linear regression output for B35 station using Beitbridge rainfall data

A simple linear regression model was run for the B35 Runoff using Beitbridge rainfall corresponding to Zhovhe dam spilling dates. Data for the period 1956 to 2001 was used as training data while for the period 2004 to 2011 was used for validating the resultant model. Tables 12 and 13 present the results of the regression model.

Table 12: Summary statistics for scenario 5.

Regression Statistics	
Multiple R	0.415
R Square	0.173
Adjusted R Square	0.035
Standard Error	838.305
Observations	8

Table 13: Regression model coefficients for scenario 5.

	Coefficients	Standard Error	t Stat	P-value
Intercept	2141.387	344.344	6.219	0.001
Beitbridge	-2.666	2.383	-1.119	0.306

Using the intercept and Beitbridge rainfall coefficients, the following regression model was developed:

$$B35 \text{ Runoff} = 2141.387 - 2.666r_1 \quad [10]$$

where r_1 = Beitbridge monthly rainfall (mm)

Evaluation of the models for Scenarios 4 and 5

RMSE, MAE, MAPE and MPE tests were all conducted on the model using data covering the period 2004-2011 for both Scenarios 4 and 5. All the tests conducted on the model including RMSE, MAE and MAPE showed very high magnitudes of forecasting errors inherent in the two models (Table 14). The negative MPE values for the two scenarios indicated that the models systematically underestimated runoff.

Table 14: Model evaluation results for scenarios 4 and 5.

Test	Scenario 4	Scenario 5
RMSE	1063.70	1080.03
MAE	922.80	976.20
MAPE	62.20	69.97
MPE	-27.98	-37.01

Regression modelling for B62 Runoff (1966 -2013)

(a) Scenario 6: Multiple linear regression output for B62 using West Nicholson and Gwanda rainfall data

Regression modelling was also done at B62 gauging station which is situated upstream of the B35 gauging station as a control. The analysis used rainfall data for West Nicholson and Gwanda. Data for the period 1966 to 1990 was used for development of the model while data for the period 2000 to 2013 was used for validating the resultant model. Summary statistics that include $R^2 = 0.11$ and standard error = 203.53 were obtained (Table 15). All p-values for West Nicholson and Gwanda data were below the 0.05 level thus relevant for use in the development of the regression model (See Table 16).

Table 15: Summary statistics for scenario 6.

Regression Statistics	
Multiple R	0.332
R Square	0.110
Adjusted R Square	0.102
Standard Error	203.529
Observations	228

Table 16: Regression model coefficients for scenario 6.

	Coefficients	Standard Error	t Stat	P-value
Intercept	-3.381	17.645	-0.192	0.848
West Nich	1.196	0.227	5.279	0.000
Gwanda	-0.470	0.230	-2.042	0.042

The following regression model was developed;

$$B62 \text{ Runoff} = -3.381 + 1.196r_1 - 0.470r_2 \quad [11]$$

where r_1 = West Nicholson monthly rainfall (mm)

r_2 = Gwanda monthly rainfall (mm)

Evaluation of the model for Scenario 6

The values predicted by the model produced lower levels of errors as compared to the B35 model. RMSE and MAE were 57.0 and 35.3 respectively while MAPE and MPE were undefined due to zero magnitude values in the runoff dataset. Generally, the model can predict better results than the B35 model though its level of errors remains high.

The model tends to predict negative flows on low flows as well as overestimate the high flows (Figure 5). That phenomenon could also be the reason for the high predictive error values for the model.

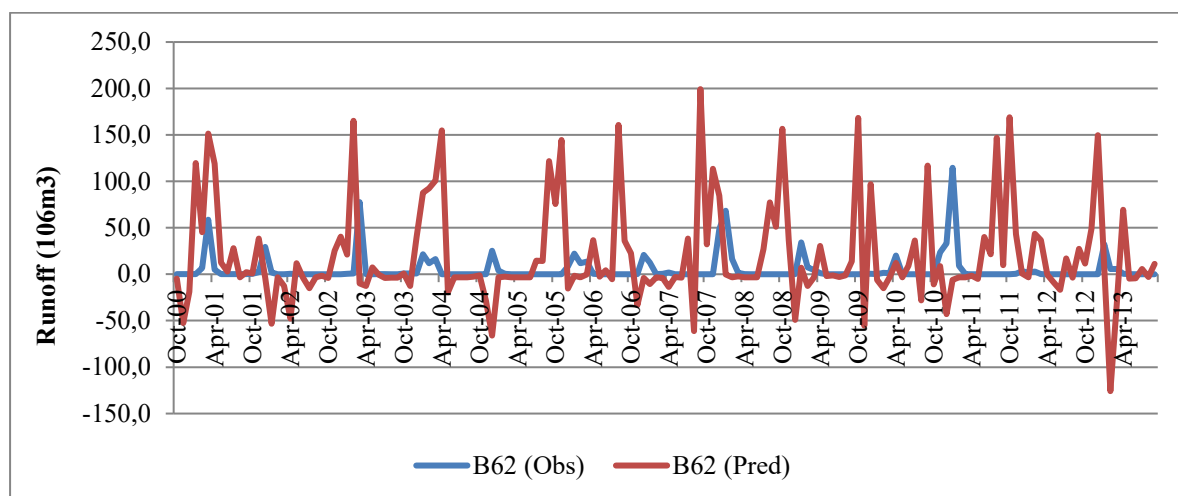


Figure 5: Observed versus predicted runoff at B62 gauging station.

Summary

Both multiple linear and simple linear regression modelling techniques were used to produce predictive equations for runoff at the B35 hydrological gauging station. A control model was also created for the B62 station. Models for the following scenarios were produced:

- (i) Regression model for B35 using Beitbridge, West Nicholson and Gwanda rainfall data

$$B35 \text{ Runoff} = -20.032 - 1.532r_1 + 5.111r_2 + 0.627r_3 \quad [12]$$

where r_1 = Beitbridge monthly rainfall (mm)
 r_2 = West Nicholson monthly rainfall (mm)
 r_3 = Gwanda monthly rainfall (mm)

- (ii) Regression model for B35 using Beitbridge and West Nicholson rainfall data

$$B35 \text{ Runoff} = -7.683 - 1.340r_1 + 5.295r_2 \quad [13]$$

where r_1 = Beitbridge monthly rainfall (mm)
 r_2 = West Nicholson monthly rainfall (mm)

- (iii) Regression model for B35 using Beitbridge rainfall data

$$B35 \text{ Runoff} = 96.328 + 2.615r_1 \quad [14]$$

where r_1 = Beitbridge monthly rainfall (mm)

- (iv) Regression model for B35 using Beitbridge, West Nicholson and Gwanda rainfall data when Zhovhe dam was spilling

$$B35 \text{ Runoff} = 1918.136 - 1.902r_1 - 2.478r_2 + 5.677r_3 \quad [15]$$

where r_1 = Beitbridge monthly rainfall (mm)
 r_2 = West Nicholson monthly rainfall (mm)
 r_3 = Gwanda monthly rainfall (mm)

- (v) Regression model for B35 using Beitbridge rainfall data when Zhovhe dam was spilling

$$B35 \text{ Runoff} = 2141.387 - 2.666r_1 \quad [16]$$

where r_1 = Beitbridge monthly rainfall (mm)

- (vi) Regression model for B62 using West Nicholson and Gwanda rainfall data

$$B62 \text{ Runoff} = -3.381 + 1.196r_1 - 0.470r_2 \quad [17]$$

where r_1 = West Nicholson monthly rainfall (mm)
 r_2 = Gwanda monthly rainfall (mm)

Coefficients of correlation and accuracy test results produced are as shown in Table 17.

Table 17: Coefficients of correlation and accuracy tests for the models.

Scenario	r ²	RMSE	MAE	MAPE	MPE
1	0.39	917.70	703.80	undefined	Undefined
2	0.38	921.10	705.10	undefined	Undefined
3	0.05	898.50	615.40	undefined	Undefined
4	0.25	1063.70	922.80	62.20	-27.98
5	0.17	1080.03	976.20	69.97	-37.01
6	0.11	57.0	35.3	undefined	Undefined

Discussion

A forecasting model is not expected to produce the exact results of true events but something close which can be used for planning purposes (Silitonga et al., 2020). The regression method is one of the commonly used forecasting methods through the use of quantitative data. Simple runoff prediction techniques that include regression and unit hydrograph have widely been applied with rainfall as the major model input and produced acceptable results (Nemati et al., 2014; Ramana, 2014). Dar (2017) applied Multiple Linear Regression modelling to predict runoff in the upper Jhelum catchment and produced acceptable results. It was however noted that unlike in the present study, there were no reservoirs in the Jhelum catchment. Sharifi et al. (2017) compared the linear regression, artificial neural networks, adaptive neural-based fuzzy inference system and support vector machine (SVM) models to predict runoff in the Amameh watershed of Iran. The study produced acceptable results across all models however, the SVM model performed better than the other techniques. In China, Duan et al. (2010) developed a regional regression model for estimating runoff in Halar River of China. The study employed 51 years of runoff, rainfall, and surface evaporation data. The model proved very robust as predicted values compared favourably with observed values.

Hydrological forecasting studies by Trambauer et al. (2014) is one of the attempts to simulate runoff in the Limpopo River basin. Their model results for a forecast period of between three and five months were encouraging however, inaccuracies increased with the lead time. Seibert et al. (2016) attempted a basin wide runoff forecasting study using multiple linear models, artificial neural models, and random forest models. The study results indicated that linear models were more robust at predicting runoff than nonlinear methods i.e., artificial neural networks and random forest methods. It was also observed that hydrological conditions can be forecast using statistical methods. In more recent runoff forecasting studies by Graham et al. (2022) in two sub-basins of the Limpopo in South Africa, the results matched well with observed data for the study period and thus further supported the use of runoff forecasting techniques to aid in decision making purposes.

Linear regression modelling at both small and large scales has proved robust in predicting runoff from upstream catchments. For better results, the models require long term data and input from all upstream tributaries.

Conclusions

The runoff forecasting models using rainfall data upstream of the B35 hydrological gauging station had high predictive errors thus could not accurately model runoff at B35 hydrological gauging station. The model still had high predictive errors even after removing the effect of water impoundment by Zhovhe dam by using data when the dam was spilling. However, the model for scenario 6 produced small margins of error; RMSE and MAE of 57.0 and 35.5 respectively, which proves that with adequate data and less runoff interruptions, regression modelling can satisfactorily predict runoff at B35 with rainfall as input data. It therefore can be concluded that runoff in the Limpopo River at B35 cannot be accurately predicted from upstream rainfall-derived runoff from the Mzingwane River system alone. The forecasting model would therefore require input data for the Thuli River from neighbouring Botswana and major tributaries of the Limpopo River from South Africa. The study further confirms assertions by Trambauer et al. (2014) that any small misalignment in precipitation in the Limpopo River basin often result in large runoff disparities. It is recommended that future studies should include antecedent soil moisture conditions so as to improve modelling results.

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Household hydro-resilience in a middle-class suburb during a water crisis in Cape Town, South Africa

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Abstract

The worst drought in more than a century drastically reduced the supply of water in Cape Town's rain-fed dams. With ninety days' worth of water remaining, the City implemented unprecedented water restrictions as Day Zero drew closer. All citizens were called on to play their part in reducing their potable water demand. This study investigates hydro-resilience practices in middle-class households in a suburb of Cape Town as wealthier residents are said to consume more natural resources than others. Underpinned by disaster resilience theory, the academic gaze shifts to this well-off cohort of urban dwellers. Research instruments used were a questionnaire survey and interviews. Thirty adult respondents, each representing one household in the suburb of Newlands, provided information on their water supply and demand, ownership of water-saving appliances and devices, water-saving behaviour and how they coped with the spectre of Day Zero. Water consumption per household dropped dramatically as the reality of Day Zero hit home and as respondents reported investing in more water-saving appliances and devices. Citizen behaviour regarding water use also changed remarkably. It was only through strategies to stave off the impending Day Zero that respondents felt that they coped with the water crisis. Crucially, the respondents in this middle-class suburb had the financial resources to build household water resilience that benefitted the city.

Keywords: Cape Town, Day Zero, resilience, water crisis, water saving

Introduction

In May 2017 Cape Town was declared a disaster region because of a severe drought that began in 2015. The citizens were warned of their city becoming the first major city in the world to run out of water because of the worst drought to hit Cape Town in over 100 years (Maxmen, 2018). The drought spurred the municipal authorities to implement emergency measures to increase water supplies through water-augmentation schemes. They warned water consumers to radically reduce their water consumption to stretch available water supplies to continue to meet the water demand. In response to the water crisis, gyms closed their steam rooms and saunas, hotels removed bath plugs to encourage guests to shower rather than bathing and restaurants made water-wise changes to their menus (*Bizcommunity*, 2018; De Villiers, 2018; *News24*, 2018). These measures were implemented to avoid the worst-case scenario notoriously known as Day Zero; the day on which most of the city's taps would be turned off once dam storage levels reached a critically low 13.5% (Jacobs-Mata et al., 2018). Residents would then have to queue for a daily allocation of 25 litres per person. With growing uncertainty as to the end of the water crisis, drought-related concerns confronted the city as it was announced in January 2018 that Day Zero was set to arrive within 90 days, on 21 April (*TimesLive*, 2018). Fortunately, winter rains returned in 2018, slowly filling up the city's dams (Bourzac, 2018). Day Zero was averted.

Cape Town was not the only city to experience water scarcity. Across semi-arid South Africa, metropolitan areas like Nelson Mandela Bay, Gauteng and eThekweni as well as some small municipalities have had or are continuing to experience water stress (Ziervogel, 2019). Internationally, in 2014 in the city of São Paulo, Brazil, experienced its worst water crisis in over 80 years which affected around 20 million people (Cathala et al., 2018). The myth that water was an infinite resource that would always be readily available was debunked (Watkins, 2006). Occurrences of urban water crises are increasing. When cities experience water shortages, human comfort and well-being are compromised. Citizens become more susceptible to disease through poor hygiene practices, to poverty through job losses and to hunger because of increased food prices. The economic development of cities is affected negatively, inequalities between the rich and poor are reinforced, or worse, anarchy could erupt as citizens compete for remaining water supplies when water crises strike (Watkins, 2006).

City authorities can warn citizens about a water crisis and looming disaster by implementing punitive measures for excessive water use, launch water-saving awareness campaigns and reduce water supply to individual properties. However, without the buy-in and cooperation of the citizenry a water crisis cannot be overcome. Thus, it is up to citizens to heed the warnings and avert the crisis by changing their water-consumption behaviour. This paper investigates the practices implemented by middle-class households in Newlands, Cape Town, to give effect to their hydro-resilience during the water crisis. The section after this introduction scaffolds the research in the theory of disaster resilience. An overview of the relevant literature is followed by a description of the study area and methods used. The findings of the research are discussed, and the paper ends with some concluding thoughts.

Conceptualising disaster resilience

When water consumers find themselves at a high risk of receiving limited water supplies, they may resort to a range of behavioural and/or structural solutions in order to cope. In the 1960s Canadian ecologist Crawford Stanley Holling introduced the concept of resilience which was initially described as the persistence of natural systems when experiencing disturbances, how they adjust and how they return to their original state (Seeliger & Turok, 2013). Head (2014) has noted that being resilient does not merely imply a return to an original or equilibrium state but also finding and incorporating appropriate adaptive responses to shocks. Ghoneem (2016) recognises that resilience is not necessarily an immediate reaction to disaster but should be viewed as a long-term transformative process that identifies its available resources. Nevertheless, the most widely accepted definition of resilience is: “The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions” (United Nations International Strategy for Disaster Risk Reduction, 2016: 22). In the context of a water crisis this means that instead of merely overcoming drought and returning to business as usual, resilience requires the extra mile of improving processes, legislation, and current infrastructure to ensure freshwater supplies are not depleted. The concept of resilience exists in multiple disciplines where it differs in perspective, scientific background, and context. Consequently, the concept is exposed to many interpretations which can lead to ambiguities in how it is understood. Furthermore, scholars have debated whether resilience is something to be achieved (a goal) or whether it is a work in progress towards an elusive goal. Despite this, frameworks for conceptualising resilience by looking at households’ capacities to respond are explored through understanding disaster and individual household resilience.

Disaster resilience forms part of the broad concept of resilience. It is the ability of households, communities and countries to handle change in response to shocks and stresses⁷ (such as drought and conflict) by either retaining or transforming their standards of living (Department for International Development, 2011). There are four main elements of disaster resilience. First, *context* looks at who is trying to build resilience. This could range from individuals and communities to political systems, institutions, and cities. Resilience should always be put into context as these different entities display disparate levels of resilience to disasters, depending on their available resources. Second, *disturbances* are shocks and stresses like sudden or long-term adverse events towards which a group needs to be resilient. Third, *capacity to respond* is the ability to manage and reduce disturbances through the strength and resources of the entities to reinforce resilience. This depends on the size and frequency of the disturbance (exposure); the degree to which the system will be affected and able to respond to the disturbance (sensitivity); and how well it can adjust to and cope with the effects of the disturbance through anticipating, planning, reacting, and learning (adaptive capacity). Last, *reaction* is the type of responses that a group displays to the disturbance. There are four different types of responses, namely *bouncing back better* where capacities have improved and, as a result, exposure to the shock is smaller and the ability to handle disasters and stresses in the future is better; *bouncing back* where the conditions before the disasters are able to overcome the shock and stress, and return to normal; *recovering but worse than before* meaning that after the disaster capacities have been diminished; and finally, in the worst-case scenario the system *collapses* resulting in massive reductions in abilities to cope (Department for International Development, 2011).

The application of this framework to this study implies that the *context* is respondents in the study area who are trying to build hydro-resilience and the *disturbance* is the drought which caused Cape Town's water crisis. The *size* of the drought is at a water-crisis level, but it is difficult to determine the *frequency* of the drought, and although drought is not an unfamiliar concept to semi-arid Cape Town, a drought at the scale of a water crisis is an uncommon disturbance. Water restrictions, the *exposure* to other punitive measures implemented by the City and how severe the respondents classify the drought all constitute *sensitivity*.

Jones and Samman (2016) see disaster resilience as comprising three core capacities: a household's ability to prepare, recover and adapt. The ability to prepare involves a household anticipating and reducing the impacts of drought through planning and preparation by using the relevant information available and early warnings given to the households. The ability to recover entails the absorbing of the impacts of drought by maintaining core functions and livelihood activities. The ability to adapt implies adjusting and changing the characteristics of a household to lessen potential damage and/or take advantage of new prospects. Clearly, the Jones and Samman (2016) disaster resilience framework is appropriate to the *adaptive capacity* category of the framework of the Department for International Development. In this study both frameworks are considered for exploring hydro-resilience at the household level.

In using Jones and Samman's (2016) disaster resilience framework, information gathered about whether the respondents actively searched for details on the drought; what their responses to public warnings were; and how they prepared for the potential arrival of Day Zero, should help determine how they anticipated, planned, and *prepared* for the drought. Particulars about respondents' purchasing of bottled water and the descriptions of their water-saving actions and their visitation of the local spring provided insight into how respondents absorbed the impacts of drought, and *recovered*, while maintaining core functions in their households. An

⁷ Shocks are sudden disaster-related events. Weather-related shocks include droughts, floods and earthquakes. Stresses, on the other hand, are long-term trends that can increase vulnerabilities and threaten the future, for example climate change, urbanisation and political instability (Department for International Development, 2011).

investigation of the respondents' adoption of water-saving appliances and their water-saving actions will give insight into their ability to *adapt* by changing the characteristics of their households.

The framework element reaction involved four responses, namely, *bouncing back better* implying respondents being in a better position to handle limited water supplies by using their new and established drought-coping strategies. *Bouncing back* and returning to normal refer to households that may have decreased their water consumption to stay within the limits of the water restrictions or had to pay high water tariffs during the water crisis, but once the water crisis had passed, they had returned to their old water-consumptive ways. The paying of hefty water fines or having a water-management device installed to limit household daily water consumption to just 350 litres can both be classified as *recovering but worse off than before*. Finally, respondents' potable water supplies being cut off by the City authorities or their taps running dry can be categorised as *collapse*. A brief review of the literature on drought and urban water supply follows.

Overview of the literature

While Cape Town was said to be the first major global city to almost run out of water, there have been similar water crises in other cities across the globe. In his treatment of the severe water shortage in São Paulo, Brazil, Millington (2018) attributed the shortage to political stubbornness. São Paulo narrowly escaped a city shutdown when the rains returned in 2015. Dam levels were as low as 7% of capacity and full-scale rationing was set to be implemented. Koutiva et al.'s (2017) study of Athenian water users in Greece found that they had little faith in their city's government. Conspiracy theories about political control of water blamed farmers and non-Athenians as the real culprits for the water scarcity. Earlier, a survey among 437 households in Barcelona, Spain, on drought perception by March et al. (2014) had found that 33% rated climate change as the most significant cause of water scarcity, with population growth (22%), lack of public awareness (21%) and inadequate water management (8%) following suit.

Traditional water policies in urban areas involve the development of infrastructure such as dams, pipes and water-transfer schemes. Dwindling water supplies and the cost of infrastructure have pressured changes in water-management policy to include the targeting of citizens (March et al., 2014). Water-awareness initiatives are mostly implemented during times of drought and their success usually depends on the climate, the severity and frequency of droughts, citizens' willingness to change their water-consumption behaviour, type of urban land use as well as how water-saving campaigns are implemented (March et al., 2013). Thus, March et al. (2014) studied household water-use habits in Alicante, Spain, to inform the arranging of effective water-awareness campaigns. Their telephonic survey of 450 households covered ten municipalities in the drought-prone city and they found that most interviewees followed most of the water-conservation practices broadcasted in media campaigns. The messages to reduce water consumption included 'take showers and not baths', 'reuse your pool water' and 'turn off the tap while brushing your teeth', all borrowed from previous water-awareness campaigns.

It was worthwhile for these campaigns to focus on the reduction of outdoor water use through the planting of drought-resistant trees and the use of pool covers to avoid water loss via evaporation, in addition to campaigns aimed at indoor water use which encourage consumers to purchase water-saving appliances such as municipal-subsidised water-flow regulators for taps and showers. For campaigns to have significant impacts, they must take into consideration the heterogeneity of water users because differences in household types and their water-use habits can govern the types of measures to be implemented for curbing water consumption. The Alicante study found that the campaigns were effective in convincing citizens to reduce water

consumption to the degree of a 20% decline in water consumption between 2007 and 2013 (March et al., 2014).

Water-conservation campaigns are vital during a period of drought, but once a drought has ended it is equally vital to evaluate their successfulness (March et al., 2013). In the case of São Paulo, reservoir levels recovered, the end of the crisis was declared, and water-related anxieties were soon forgotten by the public (Millington, 2018). Campaigns in California have successfully, even significantly, reduced water demand by encouraging the use of water-saving appliances in the face of frequent droughts experienced since the 1970s (Mitchell et al., 2017). A significant proportion of California's population can afford to install water-saving devices thereby facilitating resilience to shrunken water supplies. The state's budgets were also not as limited as those in most developing countries so that Californians were even offered free water-saving kits and rebate programmes.

Water restrictions are a universal initiative implemented by water authorities and they usually result in immediate water-saving responses, especially in events of severe water shortage (Millock & Nauges, 2010). Because water restrictions usually involve increased water tariffs, they may place crippling financial burdens on poorer households that are used to consuming large volumes of water. The promotion of water-saving appliances is therefore more likely to be politically and socially acceptable than price increases and the imposition of water restrictions. Although saving water directly impacts consumers' water bills where households are charged for their water use, the installation of water-saving appliances can be costly so that their advocacy can create even larger water-use disparities between the rich and the poor.

Although it seems desirable to apply drought-adaptation techniques that were successful in the developed world to cities in developing countries, it is crucial to be mindful that cities differ in their capacities to respond to the effects of drought. Cities in the developed world have different political, socio-economic, and biophysical contexts to those pertaining in cities of the developing world (Jacobs-Mata et al., 2018). Projects and initiatives for saving water are difficult to implement within the constraints of financial and technological capacities. High levels of poverty, lack of necessary and trained staff, and urgent socio-economic priorities (such as providing housing) are barriers to mitigating severe crises in cities of the developing world. As a result, structural measures, such as the installation of water-saving appliances to reduce water consumption, are seldom named in the literature on drought responses in developing countries. Thus, the responsibility of saving water devolves to the citizens and it is the prerogative of the citizenry to lead the quest to become water resilient. The next section introduces the locale of this study and the research methods used.

Material and Methods

The study was done in the middle-class suburb of Newlands, Cape Town and can see up to 2000 mm of rainfall per year (Watson, 2015). The area is characterised as a green, leafy suburb with lush gardens and private swimming pools being common features of residences. This neighbourhood was chosen because little is known about resilience in middle-class suburbs in the South African context. This is echoed by Pieterse, cited in Visser (2013), who posited that the wealthy classes are often not part of the gaze of urban scholars, despite these classes consuming disproportionately greater amounts of natural resources (Swilling, in Nel, 2016). Hence, the City of Cape Town's water-reduction communication strategy was aimed at middle-class households who could respond rapidly to water restrictions (Cremer, 2020; Ouweneel et al., 2020).

A sample of 30 residents over the age of 21 was chosen with each respondent representing one household. Information was collected through a questionnaire survey and interviews. The survey questions were inspired by surveys reported in the literature, notably those of March et al. (2013) and Jones and Samman (2016). The questionnaires comprised 48 main questions and nine subquestions which were either multiple-choice or of a five-point Likert-scale format. Subquestions allowed respondents to clarify and/or to give reasons for their answers to the main questions. The questionnaires covered household demographics; household water supply; water-related habits; water consumption; ownership of water-related appliances; water resources in the study area; the presence of water resources in Cape Town; and the overall management of domestic water demand. Qualitative, in-depth, semi-structured interviews explored household water demand and supply, the use of water-saving devices, changes in water-saving behaviour and household preparedness for a possible Day Zero. Data collection began in October 2018 after the critical period of the drought had passed and Day Zero had been indefinitely postponed. The questionnaire items catered for valid information to be elicited from the respondents and the interviews allowed for follow-up questions and clarification of answers to the survey questions. The semi-structured interviews added flexibility to the structured questions so contributing to data credibility and trustworthiness (Creswell, 2009). Institutional ethical clearance (ethical clearance project number 7642) was obtained prior to the commencement of data collection.

Results and Discussion

Households are key components in understanding the links between the population of a city and water consumption (Corbella & i Pujol, 2009). In this study households in single-family dwellings were recruited as their water use is individually metered and they are charged for how much water they use, instead of paying a flat fee usually applied to rented apartments. In the absence of water meters, it is impossible to monitor household water consumption, measure the effectiveness of adopting water-saving appliances, incorporate new water-saving actions or determine the impact of punitive measures such as increased water tariffs. The socio-demographic characteristics gender, age, education level and household size were determined in the survey to characterise the type of audience the survey reached. The following subsections provide information on the household demographics, household water supply and demand, the prevalence of water-saving devices in households, respondents' water-saving behaviour and their coping with a potential Day Zero.

Household demographics

Household water use is not necessarily easy to predict. Lifestyles and residential dynamics are complex, and they influence water consumption in a variety of ways (Crouch et al., 2021). There were 17 (57%) female and 13 (43%) male respondents in this survey. Most (73%) respondents considered themselves as the head of the household, the 30 respondents ranged in age between 22 and 90, and 60% had a postgraduate degree. The average household size was five persons. Seventeen per cent of households included at least one infant younger than three, while 27% had at least one person over the age of 60. Older persons tend to use less water while families with young children and teenagers are expected to use more water as they may need to bathe or do laundry more frequently (Corbella & i Pujol, 2009; Lindsay et al., 2017). Forty-seven per cent of the participating households had lived in Newlands for fewer than ten years, whereas 40% had been living there for between 10 and 19 years. It is within this demographic milieu that the potable water supply and demand of the respondent households are examined next.

Household water supply and demand

Although every residence in the suburb is connected to the municipal water supply system, the study aimed to determine how reliant each respondent household were on municipal potable water. The water sources, other than the municipality, mentioned by households were abstraction from boreholes, purchasing of bottled water and the collecting of spring water at a facility in the suburb. Most respondents (80%) relied solely on municipal water. Some 10% relied equally on municipal and bottled water, 7% relied equally on municipal and spring water, while only 3% relied on municipal water and their private borehole supply. Concerning water consumption, 20% of the respondents perceived their water consumption to be ‘low’, 70% reported ‘average’ use with only 3% reporting their consumption to be ‘high’. Fifty-four per cent reported a monthly household consumption of six kilolitres of water or less, while 29% reported a monthly consumption between seven and nine kilolitres. Eighteen per cent of the respondents reported using more than ten kilolitres of water per month. Respondents reported that laundry, showering, dishwashing, and cooking were the main water-consuming tasks.

Cape Town is in a winter-rainfall region with 78% of the annual rainfall precipitated between April and September. The summer months are comparatively dry. The average monthly domestic water consumption per household in Newlands between April 2017 and March 2018 is graphically illustrated in Figure 1 that shows a precipitous drop from a peak in April 2017 to a low level through winter, spring, and early summer, even lower during the first three months (summer) of 2018. Monthly water consumption in Newlands decreased by almost two thirds in one year owing to the residents’ using less water as prescribed by the various levels of water restriction in place at specific times.

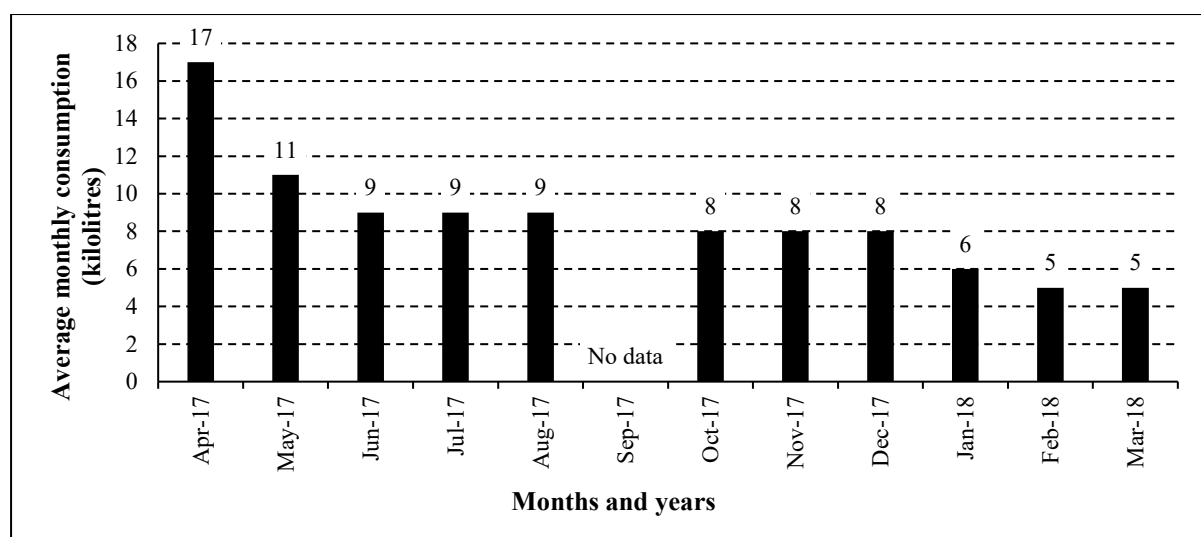


Figure 1: Average monthly household water consumption, in kilolitres, in Newlands, April 2017 to March 2018. Source: Authors’ construct from City of Cape Town (2019) data.

The implementation of water restrictions significantly influenced water consumption patterns. In April 2017 Level 3B water restrictions were already in place, yet water use in Newlands averaged 17 kilolitres per household per month. In May 2017 the drought was declared the worst in over 100 years as dam levels were 10% lower than usual. These dam levels and the water restrictions affected water consumption as average water demand dropped by as much as six kilolitres in one month. By June 2017 demand had fallen by a further two kilolitres, quite likely due to the implementation of Level 4 restrictions which encouraged each person to use no more than 100 litres per day. Water demand remained consistent from June to August 2017, but in September 2017, with only around 27% of water left in the dams, Level 5B restrictions were implemented, limiting citizens to 87 litres of water per person per day (*Cape Town Magazine*, 2017). The concept of Day Zero was publicly announced in the media in October

2017 (Joubert & Ziervogel, 2019). However, the announcement seemed to have a negligible effect on water-use behaviour in Newlands with the average domestic water consumption remaining at eight kilolitres a day. The beginning of 2018 ushered in Level 6 restrictions that remained at 87 litres of water per person per day but made households that consumed a total of more than 10.5 kilolitres of water per month liable to fines and to having a water-management device installed on the premises (Haden, 2017). In February 2018, Level 6B restrictions limited water uses to 50 litres per person per day (Western Cape Government, 2018). This reined Newlands residents in to water-saving actions as evidenced by the decrease in monthly water consumption to five kilolitres, a 70% reduction compared to April 2017. Winter rains arrived fortuitously in May 2018 and Day Zero was eventually postponed indefinitely.

The respondents reported changes in their water-use behaviour as the threat of Day Zero loomed large. Two respondents believed that Day Zero was simply a scare tactic, one of whom (Respondent F) exclaimed: “How can we not have water? Water is running away! The day I see there is no alcohol here and there are no sodas and Coke then I’m going to believe there is a drought.” Despite this, both respondents confirmed that they did engage in water-saving behaviour. Overall, 89% of the respondents reported showering daily with the remainder doing so two or three times a week. Some three out of five (57%) respondents indicated that they no longer bathed. The households that bathed daily (17%) confirmed that it was for bathing small children in shallow bathwater. The number of times gardens are watered a week signifies high per capita water consumption (Pearce et al., 2013). Disconcertingly, 10% of the sampled households continued to use their garden sprinklers, which were connected to the potable water supply, three times a week. Respondents’ changes in water-use behaviour were (in order of percentage of multiple responses) attributed to environmental concerns, the fear of Day Zero, anxiety over water cuts, the implementation of water restrictions, financial concerns, the influences of family and friends, and religious convictions (Figure 2). There were thus multiple disparate concerns that prompted respondents to reduce their consumption of water.

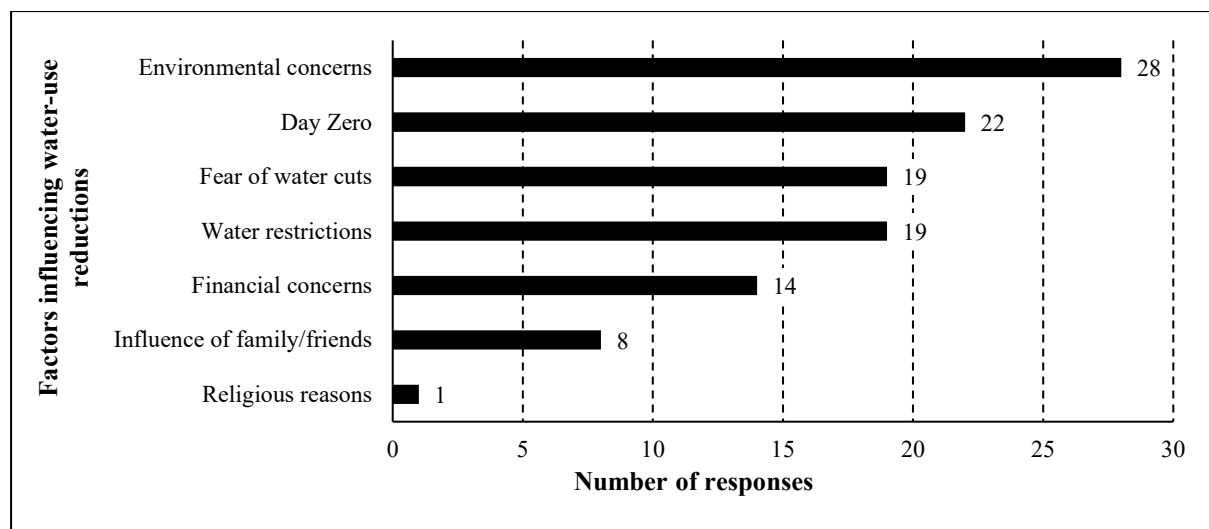


Figure 2: Reported factors influencing water conservation among respondent households in Newlands, Cape Town.

On average, each respondents’ residence was equipped with three showers, four toilets, a geyser and a bath. The age of dwellings can also be a determinant of water consumption. More than half (54%) of the sampled households lived in homes constructed before the 1980s and only 18% were built during the past decade (2009 to 2019). With respect to this, Millock and Nauges (2010) point out that older buildings are more likely to have water-inefficient equipment installed, which can result in greater water use. However, they added that it behaves

homeowners to retrofit homes for water efficiency. The acceptance and the use of water-saving devices are examined next.

Prevalence of water-saving devices

The installation of water-saving devices, appliances and infrastructure is an effective way to reduce household water consumption. Households in the higher income cohort are more likely to own larger properties with more water-using appliances and amenities such as dishwashers, washing machines, showers, baths, and toilets. According to Majuru et al. (2016), wealthier households are likely to engage in capital-intensive water-use reduction strategies. However, this study found that barriers to the implementation of such strategies are the cost of the devices and difficulties with their installation. These barriers had similarly been recognised by Dolnicar and Hurlimann (2010).

Most (87%) of the respondent households owned at least one water-saving appliance before and/or after the water crisis (Figure 3). The two most common appliances were rainwater tanks (56%) and water-saving washing machines (50%). Other water-efficient appliances owned before the onset of the water crisis were dishwashers, dual-flush toilets and tap timers. The water crisis inevitably prompted the installation of rainwater tanks, low-flow showerheads, and water-efficient taps. Those who did not have water-efficient appliances before the drought, invested in them during the water crisis. In addition, some respondents reported the adoption of innovative water-saving infrastructure such as a system for reusing grey water and/or an extensive rainwater-harvesting system. One respondent had a borehole drilled. These actions spotlight not only the reduction of water consumption, but also that residents in Newlands had the financial resources to purchase various devices and become hydro-resilient.

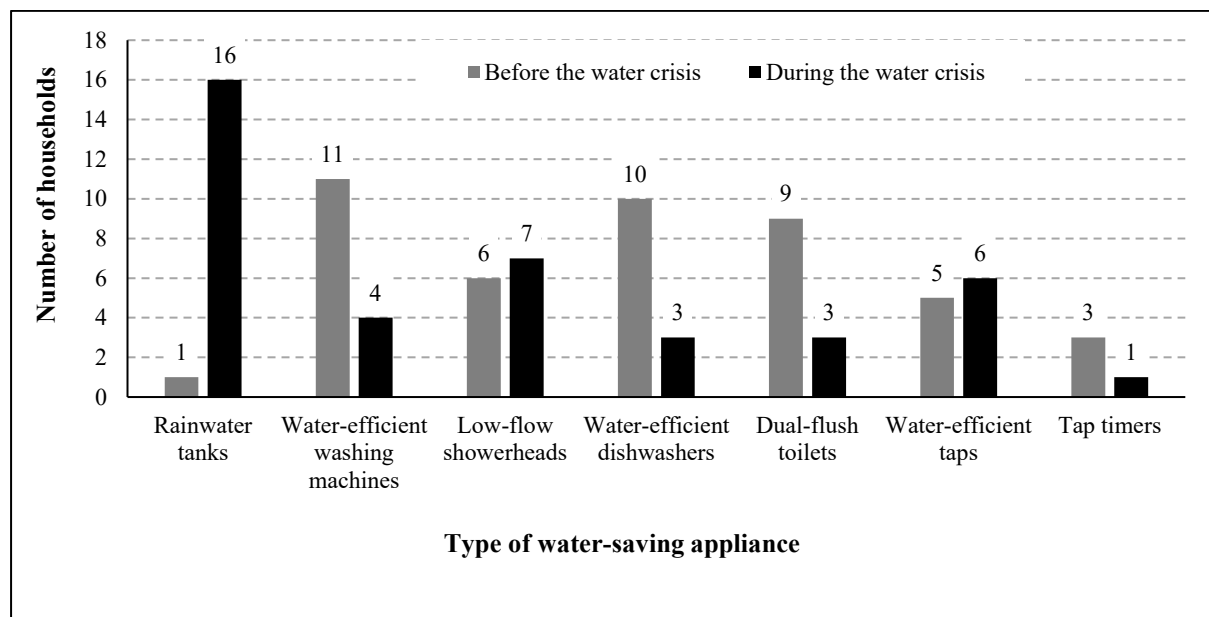


Figure 3: Water-saving appliances installed by households in Newlands before and during the water crisis.

Households have taken advantage of the high rainfall in Newlands by installing rainwater tanks, with the 5000-litre capacity tanks being the most popular. Rainwater harvesting via rainwater tanks involves collecting rainwater from house roofs via gutters and storing the water in large plastic containers for later use for domestic and garden irrigation purposes. The benefits of having rainwater tanks are that they provide households access to relatively clean and safe water during periods of low precipitation; reduce pressure on households' municipal water demands; and reduce demands on surface- and groundwater resources. The main disadvantages (named by respondents) of harvesting rainwater by installing a rainwater tank are the expense (about

R5000 for a 5000-litre tank) and that the tanks require regular maintenance. Respondent A complained that: “We’ve just discovered there is a lot of these mosquitoes in these water tanks, and I think there hasn’t been any help to people as to how to prevent these mosquitoes.” While the installation of various household water-saving appliances and infrastructure does save water and build water resilience, it is imperative that these actions are accompanied by behavioural changes by residents. This is the theme of the next section.

Water-saving behaviour of respondents

All the respondents reported that they purposely conserve water. Respondents adopted a variety of water-saving strategies in their attempts to contend with the water rations. The flushing of human excreta and the irrigation of gardens were identified as the two main water-guzzling activities. Some respondents opposed the use of potable water for flushing toilets and suggested treated seawater as a substitute. The most common (70% or more of the respondents) water-saving actions were flushing toilets less often (giving credence to the saying ‘if its yellow, let it mellow’), watering gardens less often, reducing the length of time under the shower, showering less frequently, using less water for laundry and cleaning purposes and the recycling of dishwater (Figure 4).

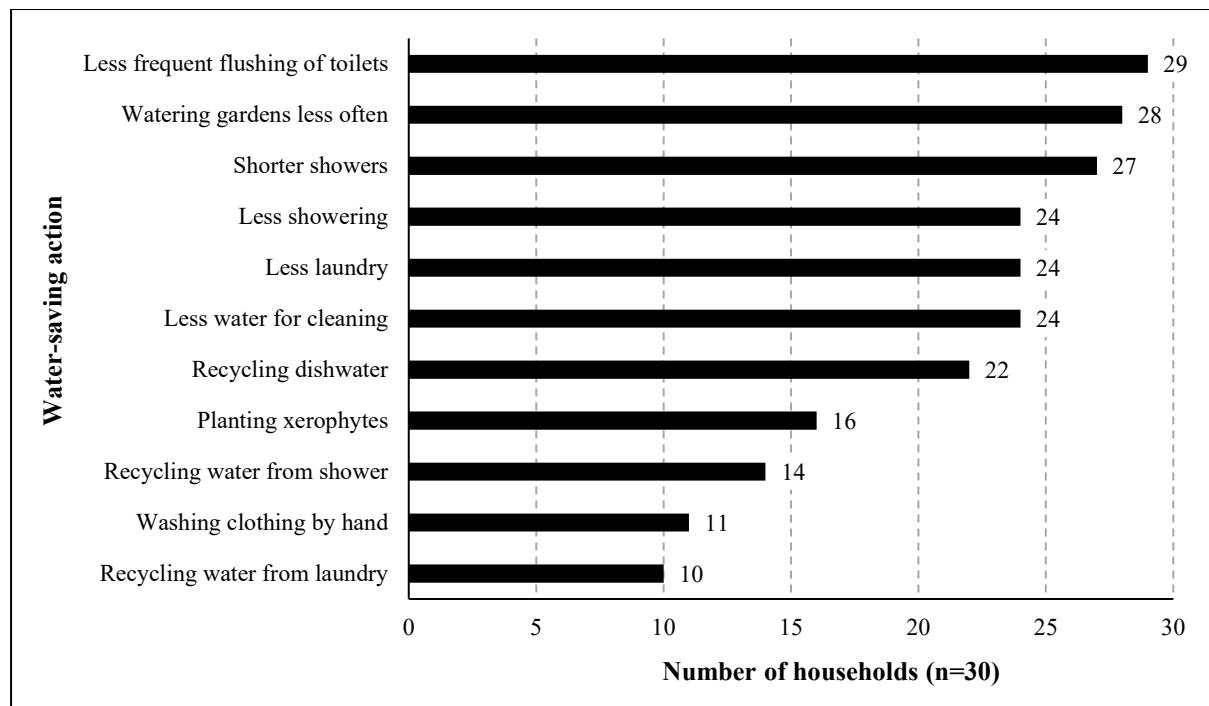


Figure 4: Water-saving techniques reported by respondents in Newlands.

In times of drought, it is crucial to change citizens’ water-use behaviour. Domestic water-reduction strategies assist in placing less strain on potable supplies. For example, respondents reported a great awareness of the time they spent under the shower. A quarter of the respondents reported that before the water crisis they showered for more than ten minutes, and half reported showering for between six and ten minutes. This behaviour changed during the water crisis, specifically after the tightening of water restrictions and the advent of warnings about a possible Day Zero. Changed behaviour was confirmed by none (versus 25% before) of the respondents reporting showering for longer than ten minutes and only 8% (as opposed to 50%) showered for between six and ten minutes. Ninety-two per cent of the respondents showered for fewer than five minutes during the water crisis – a marked behavioural change in water use. It is remarkable that after the indefinite postponement of Day Zero this prudent behaviour continued with no respondent showering for longer than ten minutes, 16% taking six to ten minutes to

shower and 84% continued to shower for fewer than five minutes. These changes strongly suggests that the respondents became more water conscious during the drought with most opting not to return to their pre-water-crisis habits. Despite the threat of the taps running dry, citizens hunkered down and did their part in saving water as a way to cope with the drought. These coping actions are the focus of the next subsection.

Coping with Day Zero looming

Unreliable water supplies place substantial coping burdens on households (Majuru et al., 2016). Because this survey was conducted after abundant winter rainfall arrived in 2018, respondents were asked to reflect on how they would have coped had Day Zero been a reality. Fifty-three per cent were confident that they would have been resilient to the shocks of a Day-Zero situation, whereas the others were unsure about how they would have survived. Respondent B, for example, confessed: “Er, no. I mean we would have been alright for a bit. We would have gone out and got bottled water, and we would have survived, honestly. Were we prepared? No.” In contrast, Respondent C claimed that their household would have been prepared to cope in the event of water cuts being implemented: “Yeah, reasonably well prepared. Well, we had water tanks installed, we also had a hundred bottles of five-litre bottles of water, no, more than that, whatever, lots. Maybe just a hundred.”

For some residents there was a strong desire for convenience. This desire was supported not only by the large number of water-using amenities they owned (such as dishwashers that require less labour than washing dishes by hand) but also by their purchasing of water-saving appliances and bottled water. Rainwater tanks have capacities of thousands of litres of water so allowing owners to collect and store large volumes without much effort, especially in Newlands with its high annual rainfall. By purchasing bottled water, residents could have delayed visiting one of the 140 water-collection points around Cape Town to collect the daily allocation of 25 litres per person should Day Zero have arrived. In this context Pearce et al. (2013) noted that high-income households represent a stubborn group to be convinced of the need to reduce water demand because of the importance they place on water-using practices and their ability to pay for excessive water use. Respondent D’s answer to whether they would change their water-consumption habits when the water tariffs change, demonstrates this attitude:

“Not at this point because we are at R150, R300 a month. It’s not a big price on our household budget, but obviously, if they slap it up 10 times then yes, we monitor it more because it becomes a little fun exercise to how low can you go”.

However, the overall finding of this study is that the residents were willing to drastically reduce their water consumption during the drought period. But it is noteworthy that Pearce et al. (2013) insist that not all reductions of water use are desirable, and that conservation should not allow the loss of human welfare. Although the concomitant negative effects of the water crisis on health and welfare in Cape Town are still mostly unknown, care and caution should be exercised with some water-saving ways. It is reasonable to assume that some water-saving practices may put good hygiene at risk. In describing how their household saves water, Respondent E hints at such perils:

“When there was a drought, they [the kids] bathed in buckets, so didn’t even bath, just jumped in the pool...we don’t wash as regularly, [and] everything, [we] take short showers, we were very much part of water saving”.

By collecting spring water, households can ensure extra quantities of safe water when other potable water supplies are precarious. Majuru et al. (2016) observed that households with higher incomes are more likely to have the ability to store large amounts of water. Seventy per cent of the Newlands respondents purchased bottled water during the water crisis, 27% did not and 3%

purchased home-delivered water for their 20-litre water filtration systems. Buying water builds resilience against scarcities of municipality-supplied potable water. Undoubtedly, drought-proofing homes and building hydro-resilience come at a cost. Some concluding remarks follow.

Conclusions

In 2018 Cape Town was on the brink of disaster as authorities warned the populace that the city's rain-fed dams only had a three-months' supply of water. Subsequently, water use declined as citizens made unprecedented water-saving efforts. It has been posited that the wealthier, suburban classes in South African cities have not been afforded much academic scrutiny despite their using disproportionately higher quantities of natural resources. Hence, this research investigated how middle-class suburban households in Cape Town responded to the water crisis through their resilience strategies.

Structural and behavioural changes were identified in the 30 households. Overall, common coping strategies included harvesting rainwater, recycling grey water, collecting water from the local spring(s), and the purchasing and storing of water. Coping strategies were influenced by strong moral obligations to the environment, perceptions of the severity of the drought, punitive water tariffs and the number of people in the household. It was found that the households are relatively resilient to drought conditions and will be able to cope with future drought scenarios by using minimal amounts of water despite the many water-using appliances and amenities such as showers, toilets, and dishwashers that they have. These water-saving fixtures contributed positively to reducing household water demand. An overwhelming majority of households purchased water-saving devices, including rainwater tanks. The absence of water-saving appliances was imputed to the high cost of appliances and difficulties with their installation. The water restrictions and threat of dry taps prompted residents to develop a new water consciousness and to change their behaviour. Water-saving practices included reducing the frequency of toilet flushes, reducing, or stopping the watering of gardens with municipal tap water and taking shorter showers.

Regarding municipal authorities, it is advisable that their water-saving campaigns be target-group specific as households within a neighbourhood have diverse water needs. A successful campaign requires the initial gathering of information about household characteristics. Thereafter, citizens will give effect to campaigns through essential changes in their water-use behaviour and the implementation of water-saving strategies to give meaning to household hydro-resilience.

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Time series analysis of climate impacts on sugarcane yield in the lowland region of southeastern Africa

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Abstract

The study explored the statistical links between climate variables and indices, and sugarcane yield in South Africa and Eswatini, using time series analysis. Climate datasets were derived from the Koninklijk Nederlands Meteorologisch Instituut climate explorer and extracted for the period 1970-2016 over southeastern Africa (31-23°S and 28-33°E). The main datasets are version 8 of the Global Precipitation Climatology Centre rainfall, Climatic Research Unit (University of East Anglia) temperature, Sea Surface Temperature patterns, and Sea Level Pressure datasets. The methods employed are Mann-Kendall test for trend detection, Pearson correlation and Multivariate Linear Regression time series analysis for exploring the degree of association and its extent between climatic variables and indices and sugarcane yield. Annual sugarcane yield has been decreasing since the 1980s. This is partially, due to climate impacts but there are also non-climatic influences. The study found a strong relationship between local crop-drivers and the yield due to its long-cycle (12-24 months) in contrast to short-lived crops such as maize with a cycle of 3-4 months. Surface air temperature emerged as the main climatic factor for sugarcane production in both rainfed and irrigated sugarcane. It is evident from this study - that in rainfed agro-climatic regions, the soil moisture availability as a function of precipitation in the preceding season is essential for sugarcane growth and development, and this increases the sugarcane yield in the upcoming season. Hence, the sugarcane prediction technique that will incorporate Palmer Drought Severity Index and regional climate indices is desired to improve the forecast skill in sugarcane modelling.

Keywords: Time Series Analysis, Climate impacts, Sugarcane yield, Southeastern Africa

Introduction

Sugarcane (*Saccharum officinarum* L.) is a C₄ crop that is grown in both tropical and subtropical agro-ecological zones, mainly for the production of sugar and bioenergy. Plants and crops are spatially distributed according to their responses to climate fluctuations, topographical features, land cover or land use, and soil types (Lehmann *et al.* 2011; Krysanova *et al.* 1998; Hua *et al.*, 2019). Hence, C₃ (temperate plants), C₄ (tropical plants) and CAM (semi-arid condition plants) plant species are reported to have different abilities for temperature acclimation of photosynthesis (Yamori *et al.* 2014). Sugarcane yield and production have been reported to be directly and ultimately affected by crop drivers such as evapotranspiration, rainfall, temperature, and pests and diseases (Everingham *et al.* 2003; Zhao & Li 2015). Gbetibouo and Hassan (2005) estimated the economic impacts of climate change on the major South African crops using the Ricardian model. The model employed the agricultural data for sugarcane, maize, wheat, sorghum, soybean, groundnut, and sunflower. Further, the study of Gbetibouo and Hassan (2005) revealed that field crops are more sensitive to increased

temperatures than precipitation. Thus, the impacts of greenhouse warming are an important factor for consideration in field crop production, mainly for adaptation readiness.

This present study explored the statistical association between climate variables and indices and sugarcane yield and detected trends using the time series analysis. Figure 1 shows the study area and the area which was averaged for time series which is over south-eastern Africa (31-23°S and 28-33°E).

Materials and Methods

Study Area

Figure 1 below shows the study area which comprises of the sugar-belts of South Africa and Eswatini. In South Africa, sugarcane is chiefly grown by about 22 950 farmers (21 581 small-scale and 1 369 large-scale farmers) in KwaZulu-Natal (KZN) and Mpumalanga (MP) provinces, with six milling companies and 14 sugar mills in the country (Van den Berg & Singels 2013; Dubb 2015; Dubb 2016). It should be noted that 12 of the sugar mills are located in KZN while only two are located in MP, and Eswatini has only four sugar mills in the whole country as shown in Figure 1. Sugarcane is grown from rainfed (coastal agro-climatic) regions to irrigated (further inland agro-climatic) regions (Van den Berg & Singels 2013; Mbhamali & Jury 2021). Further, the study area is characterised by rainfall variability with about 500-1000 mm per year of mean annual rainfall and 25°C of mean temperatures (Mbhamali & Jury 2021).

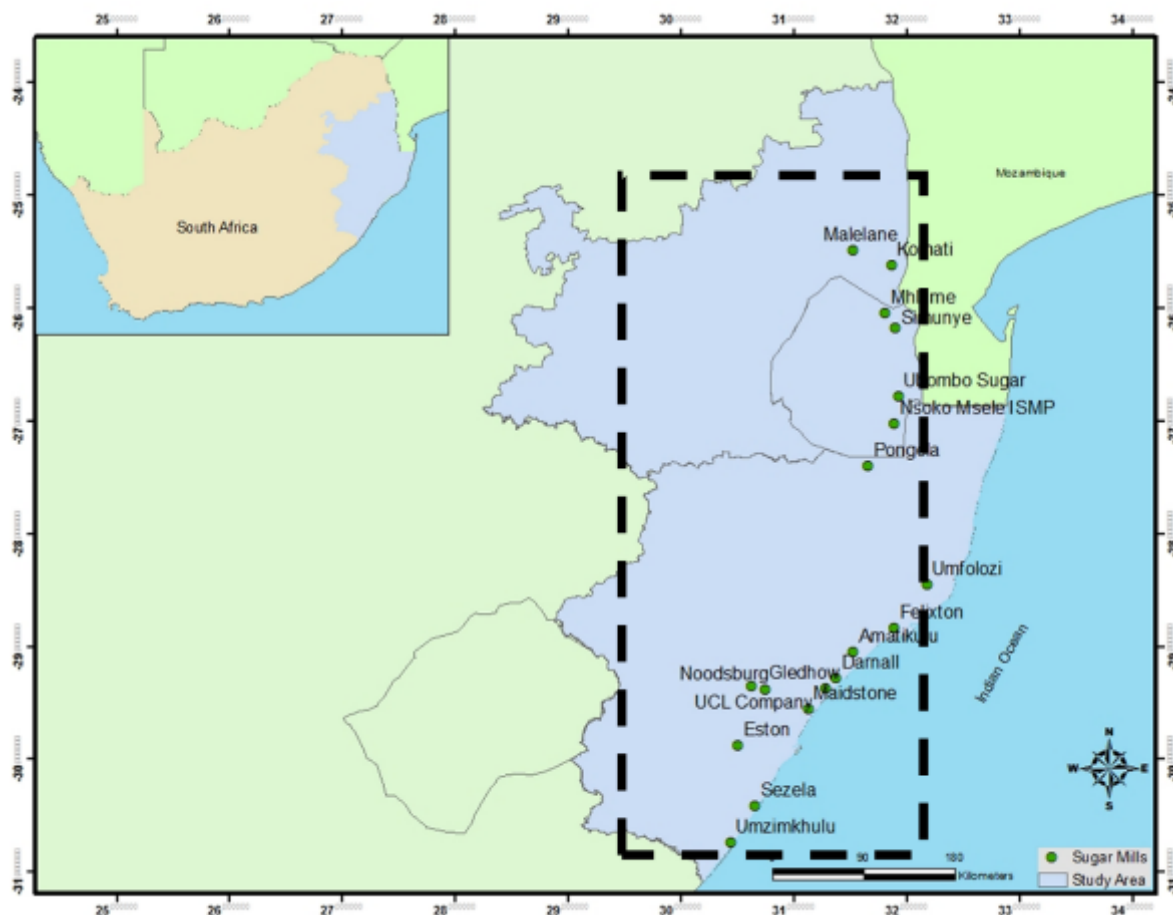


Figure 1: Map of South Africa and Eswatini sugar belts. Individual sugar mills are represented by the green dots. The dashed box indicates the area which was averaged for time series analysis. [Source: Mbhamali et al. 2017].

The study area comprises of the eastern parts of KZN, MP (in South Africa-SA) and Eswatini-Swazi. It has been found that the sugar-belt of the southeastern African lowland region is vulnerable to rainfall variability (Gbetibouo & Hassan 2005; Dube & Jury 2000), which affects the annual sugarcane yield. It is worth-mentioning that in South Africa 75% of sugarcane production occurs under rainfed conditions while only about 25% is under irrigation, and in Eswatini sugarcane is 100% irrigated (Inman-Bamber & McGlinchey 2003; Shikwambana *et al.* 2021).

Data and Methods

The station-based monthly rainfall derives from the Global Precipitation Climatology Centre version 8 (GPCP8) as described in Schneider *et al.* (2018), and the GOCC8 is available through the Koninklijk Nederlands Meteorologisch Instituut climate explorer (KNMI-CE) website. An area average was calculated over eastern South Africa and Eswatini (Figure 1) for the period from 1970-2016. Sugarcane yield time series from the Food and Agriculture Organization (FAO) of the United Nations and rainfall were compared and tested for statistical links, and rainfall influence on the yield was explored using the Multivariate Linear Regression (MLR) and correlation methods. Monthly averaged high-resolution gridded station-based surface air temperature time series of the Climatic Research Unit (CRU4) (Harris *et al.* 2014), was extracted as an area-averaged time series and related to the yield, thus tested for its influence on the yield in the study area.

Sea level pressure (SLP) data was available via KNMI-CE climate explorer for the period 1970-2016, and it was used to compute Pearson correlation heatmap and performing variable importance through MLR. The Met Office Hadley Centre's sea level pressure (HadSLP2) reanalysis from the interpolation system is described in Allan and Ansell (2006). The Climate Prediction Center (CPC) Southern Oscillation Index (SOI) was employed to explore the statistical association between the Pacific El Niño-Southern Oscillation (ENSO) and sugarcane yield. SOI data was extracted from KNMI-CE for the period 1970 to 2016. The SOI data was used as defined in the study of monthly weather review by Ropelewski and Jones (1987). Niño4 is defined as a monthly ENSO index that is calculated through averaging SST anomalies (SSTA) [12] in the central equatorial Pacific (5°N-5°S and 160°E and 150°W). The SSTAs that exceed ± 0.5 °C are used to define La Niña and El Niño signatures (Ashok *et al.* 2012). The Niño4 time series derives from averages of Met Office Hadley Centre SST datasets (HadSST) that are available through the KNMI-CE. In this present study, Niño4 provided a better explanation for the sugarcane yield variance from time to time than other SST indices. Hence, it was useful for scrutinising ENSO influence (remote / global climate influences) on sugarcane yield over south-eastern Africa for the period 1970 to 2016. The monthly NOAA reconstructed Sea Surface Temperature (SST) version 4 (Rayner *et al.* 2003), has been interpolated to 1 degree, and was drawn for the period 1970-2016. This was used for the Pearson correlation and MLR to test the statistical association with the yield and evaluate its importance to sugarcane production.

National sugarcane yield data was extracted from the Food and Agriculture Organisation (FAO) of the United Nations (UN) database for the period 1970-2016. The South African and Eswatini sugarcane yield time series were used independently because in South Africa sugarcane is largely rainfed (75%) while in Eswatini sugarcane is 100% irrigated (Shikwambana *et al.* 2021; Inman-Bamber & McGlinchey 2003). Hence, in Eswatini the storage dams provide a buffer during the dry seasons.

It should be noted that, the study adopted the Time Series Analysis performed using the R programme by writing the codes in a programming language. The Mann-Kendall test is used, in the R software to calculate the monotonic trends in a time series, and here this technique is

used as described in previous studies (Kendall 1975; Mbatha & Xulu 2018). The Mann-Kendall test is non-parametric and rank-based and is often used for detecting monotonic trends in the time series of geophysical data (environmental sciences, climate, and hydrological data). Non-parametric techniques are robust and resistant to time series with outliers, hence in this study it was paramount to employ this technique (Mbatha & Xulu 2018). According to Kendall (1975), the Mann-Kendall test statistic is calculated as shown in Equation 1

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^n \text{sign}(X_j - X_k) \quad [1]$$

and Equation 2

$$\text{sign}(x) = \{+1 \text{ if } x > 0 \text{ } 0 \text{ if } x = 0 \text{ } -1 \text{ if } x < 0\} \quad [2]$$

The mean magnitude of the statistic S is denoted by $E(S) = 0$, and the variance (σ^2) is calculated from the Equation 3

$$\sigma^2 = \{n(n-1)(2n+5) - \sum_{j=1}^p t_j(t_j-1)(2t_j+5)\}/18 \quad [3]$$

where t_j represents the number of data-points in j^{th} tied group, and p indicates the number of the tied group in the data.

It should be noted that the large-operator summation in the equation above is not used in any instance other than tied groups of the time series. This reduces the influence of extreme values in tied groups in the ranked statistics. When assuming that the time series is random and independent, the statistic S virtually exhibits the normal distribution, given that the z-transformation Equation 4 is employed.

$$z = \left\{ \frac{S-1}{\sigma} \text{ if } S > 0 \text{ } 0 \text{ if } S = 0 \text{ } \frac{S+1}{\sigma} \text{ if } S < 0 \right\} \quad [4]$$

The value of the statistic S is related to the Kendall tau (τ), which is expressed as Equation 5

$$\tau = \frac{S}{D} \quad [5]$$

and Equation 6.

$$D = \left[\frac{1}{2}n(n-1) - \frac{1}{2}\sum_{j=1}^p t_j(t_j-1) \right]^{\frac{1}{2}} \left[\frac{1}{2}n(n-1) \right]^{\frac{1}{2}} \quad [6]$$

With reference to the z-transformation equation outlined above, this study considered a 5% confidence level, by which the null hypothesis of no trend was rejected if z is beyond the perimeters of ± 1.96 . The test also provides the Mann-Kendall tau (τ) that measures the correlation, which shows the extent and degree of association between two or more variables (Kendall 1975; Mbatha & Xulu 2018). Here, the Mann-Kendall test was used to detect trends in sugarcane yield in South Africa and Eswatini for the period 1970-2016 ($N = 47$). However, the former, only detects whether the monotonic trend is upward or downward. Hence, to quantify for the onset of the trend and approximate the Potential Trend Turning Points (PTTPs) in a time series, the Sequential Mann-Kendall (Seq.MK) test is robust and desirable (Chatterjee *et al.* 2014). This technique (Seq.MK) is used as defined in Chatterjee *et al.* (2014). Where the Seq.MK is applied in a series x_i , and it detects the PTTP of a long-term data. The Seq.MK test statistics is calculated by ranked values of y_i of the original time series ($x_1, x_2, x_3 \dots, x_n$). The test allows a comparison between $y_i (i = 1, 2, 3 \dots, n)$ and $y_j (j = 1, 2, 3 \dots, 1 - i)$. Then, the t_i statistic is expressed as Equation 7.

$$t_i = \sum_{j=1}^i n_i \quad [7]$$

The mean of t_i distribution could be computed a Equation 8.

$$E(t_i) = \frac{i(i-1)}{4} \quad [8]$$

and if the variance is (Equation 9)

$$Var(t_i) = \frac{i(i-1)(2i+5)}{72} \quad [9]$$

Now, if t_i , $E(t_i)$ and $Var(t_i)$ are known, sequential values of a standardised variable known as $u(t_i)$ can be calculated for each value of t_i statistic as Equation 10.

$$u(t_i) = \frac{t_i - E(t_i)}{\sqrt{Var(t_i)}} \quad [10]$$

Note, the forward sequential (Prog) values ($u(t_i)$) of the standardised time series derive from the original data ($x_1, x_2, x_3 \dots, x_n$), and the backward sequential (Retr) values ($u'(t_i)$) are approximated using the same approach but beginning with the last value of the original time series. In the plot of $u(t_i)$ and $u'(t_i)$ curves their intersection shows the PTTP, and the trend is considered significant when $u(t_i)$ and $u'(t_i) \geq \pm 1.96$. Here, the Sequential Version of the Mann-Kendall Trend Test Statistic was used to detect trends and approximate potential trend turning points as done in previous studies (Chatterjee *et al.* 2014; Mbatha & Xulu 2018). It should be noted that the intersection of $u(t)$ and $u'(t)$ curves indicate the approximate PTTPs. If the intersection is within ± 1.96 at 5% level the PTTPs could be inferred. The Pearson Correlation method was also use, it uses the Pearson Correlation Coefficient (PCC) to show the statistical links between variables, and their extent and direction (positive or negative) of two variables (Mbatha & Xulu 2018; Mbatha & Bencherif 2020). In this study, it was used to investigate the statistical associations between rainfall, temperature, PDSI, SLP, SST patterns, SOI, Niño4 and sugarcane yields over south-eastern Africa. In this present study, Multivariate Linear Regression (MLR) analysis described the relationship between a dependant variable and one or more independent variables using Equation (11).

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \dots \beta_n x_n + \epsilon \quad [11]$$

where y is the dependant variable (sugarcane yield), x_1, x_2, \dots, x_n denote the independent variables (rainfall, temperature, PDSI, SLP, SST patterns, SOI, Niño4), β_0 is the intercept from the model output, $\beta_1, \beta_2, \dots, \beta_n$ are the coefficients of x terms and ϵ is the standard error.

In this study it was used to quantify and test the importance of each independent variable to sugarcane yield over the study area. These methods (Pearson correlation and MLR) are also explained in the recent studies (Mbatha & Xulu 2018; Mbatha & Bencherif 2020).

Results and Discussion

Drought tends to suppress sugarcane yield, such as the strong dip of the 1992/93 season (Dube & Jury 2000; van den Berg & Singels 2013), where minimum yields (41.7 ton/ha for South Africa and 90.8 ton/ha for Eswatini) were recorded as illustrated in Figures 2a and b, respectively. There is some incommensurable and heterogeneous behaviour detected in the above inter-comparisons (Figures 2a, b; c, d; e and f). Sugarcane yield varies according to rainfall with its unclear trend while temperature is increasing and causing yields to decline as shown in Figures 2a, b, e and f. As expected, local and regional climate tends to provide more explanation of sugarcane variability in the most rainfed agro-climatic zones (SA: 75% rainfed and 25% irrigated) as compared to Eswatini, where sugarcane production took place under fully 100% irrigation. PDSI seems to explain much of the sugarcane variability over time and this necessitates performing other statistical tests to explore the statistical links between these climatic variables and indices with the yields to make meaningful judgements.

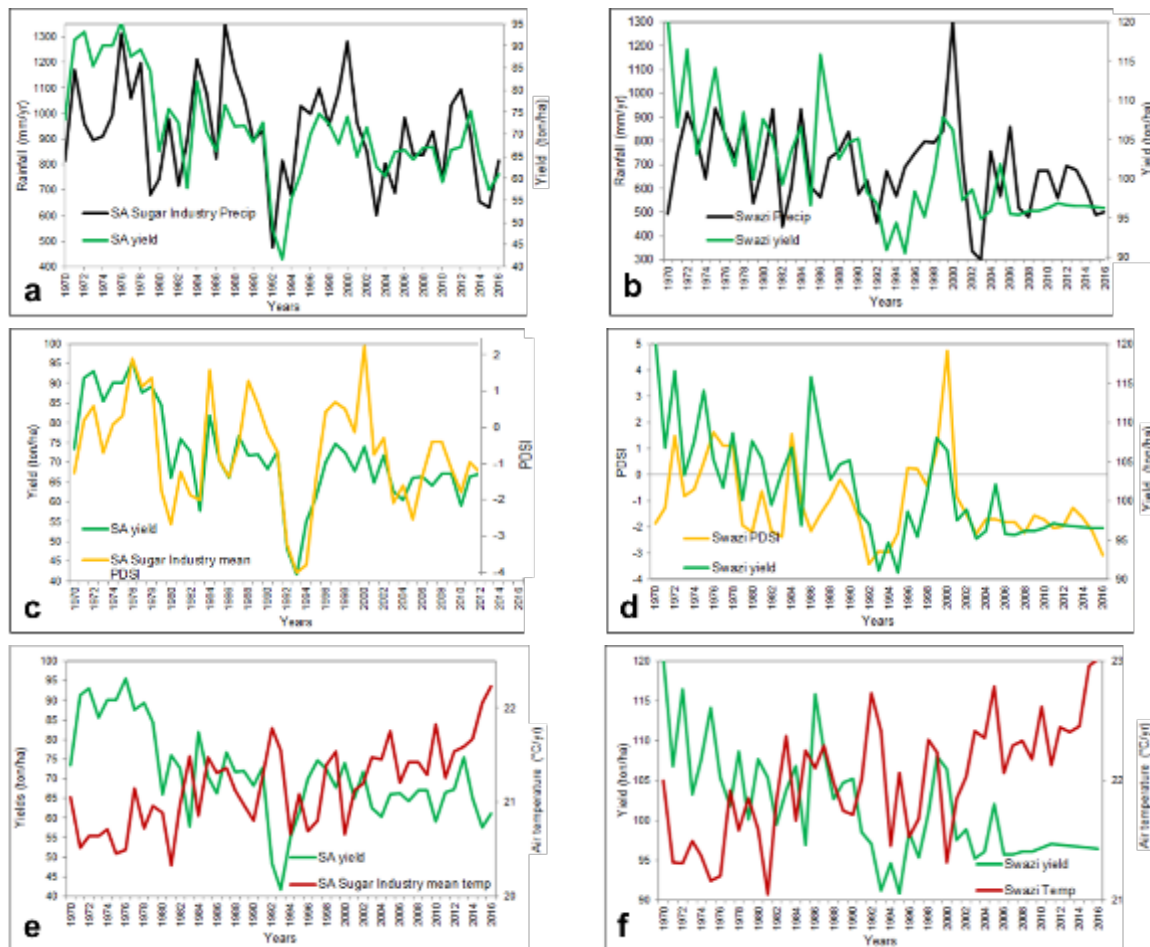


Figure 2: Inter-comparison between climate and FAO sugarcane yields for the period 1970-2016 a) South Africa, area-averaged rainfall has been extracted from different sugarcane growing areas, then annual-averaged over time b) ESwatini rainfall vs sugarcane yield, rainfall was extracted over eastern Eswatini, c) Annual variability of sugarcane with respect to the Palmer Drought Severity Index (PDSI) for the period 1970-2016 over d) South Africa and b) Eswatini, e) Annual variations of annual area-averaged air temperature against sugarcane yield from 1970-2016 over South Africa and Eswatini.

The Mann-Kendall test uses z-score and the p -values statistics to detect and evaluate trends and their significance. The trend must exhibit the absolute value of z of 1.96 with the $p \leq 0.05$ to be considered significant. Table 1 presents a summary of the Mann-Kendall statistics for sugarcane yield time series from FAO database for South Africa and Eswatini (southeastern Africa). Table 1 revealed that South African sugarcane time series exhibits a declining trend with z-score of -4.604 and the p -value of 4.15×10^{-6} , while Eswatini has a z-transformation of -4.631 and the p - value of 3.63×10^{-6} .

Table 1: Mann-Kendall (MK) test statistics for sugarcane yield (ton/ha) trends over South African agro-climatic regions, bold z-score are significant at the 95% level.

South Africa and ESwatini (FAO yields)		
SA_FAO	<i>z</i>	-4.604
SA_FAO	<i>p</i> -value	4.15E-06
SA_FAO	Tau (τ)	-0.465
Swazi_FAO	<i>z</i>	-4.631
Swazi_FAO	<i>p</i> -value	3.63E-06
Swazi_FAO	Tau (τ)	-0.468

The Mann-Kendall statistic test method is useful for investigating overall trend in the time series, and it is always useful in defining when the trends begin and how far do, they decline before they recover again. Therefore, a Sequential Mann-Kendall trend test method was used for this purpose because it detects trends and their potential turning points (Chatterjee *et al.* 2014; Mbatha & Xulu 2018) using the R procedures. Figure 3 shows the Sequential Mann-Kendall trend test results for South Africa and Eswatini.

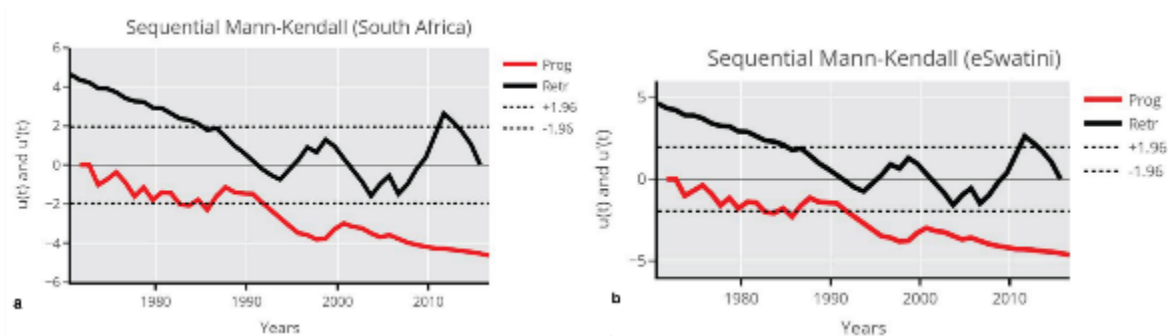


Figure 3: Trends in FAO sugarcane yield sequential version of Mann-Kendall test statistic, $u(t)$ forward sequential curve represented in solid-black line and $u'(t)$ backward sequential curve represented in solid-red line over a) South Africa and b) ESwatini.

The Mann-Kendall statistic test indicated that sugarcane yields have certainly been decreasing since 1980s over South Africa and Eswatini. A huge decline of the yield was observed during the period from 2010-2016, where z-score values were observed to be below -4 , which is an indication of a significant downward trend (*see* Figure 3). These results are consistent with observations by van den Berg and Singels (2013) in their study of modelling and monitoring for strategic yield gap diagnosis. The trend is declining and additional influences in a form of non-climate have been reported (van den Berg and Singels 2013), which makes the discrepancy complicated and requiring multidisciplinary collaboration between climate forecasters, crop modellers, and decision-makers (Bezuidenhout & Schulze 2006).

Figure 4 shows the Pearson Correlation Coefficients of -0.68 and -0.48 between temperature and yield were observed for South Africa and Eswatini (Figures 4a and b). Rainfall and yield have a statistical association of $PCC = +0.50$ and $PCC = +0.45$ for South Africa (a) and Eswatini (b), respectively. This further indicates that sugarcane farmers must use climate forecasts for their farming management practices, decision-making and policy formulation. The abrupt temperature and potential evapotranspiration increases tend to reduce the amount of soil moisture which then suppress sugarcane yield as shown in Figures 2e and f. This implies that despite potential rainfall increase or decrease, temperature has the ability to deplete soil

moisture and surface water through potential evapotranspiration, which then results to crop failure.

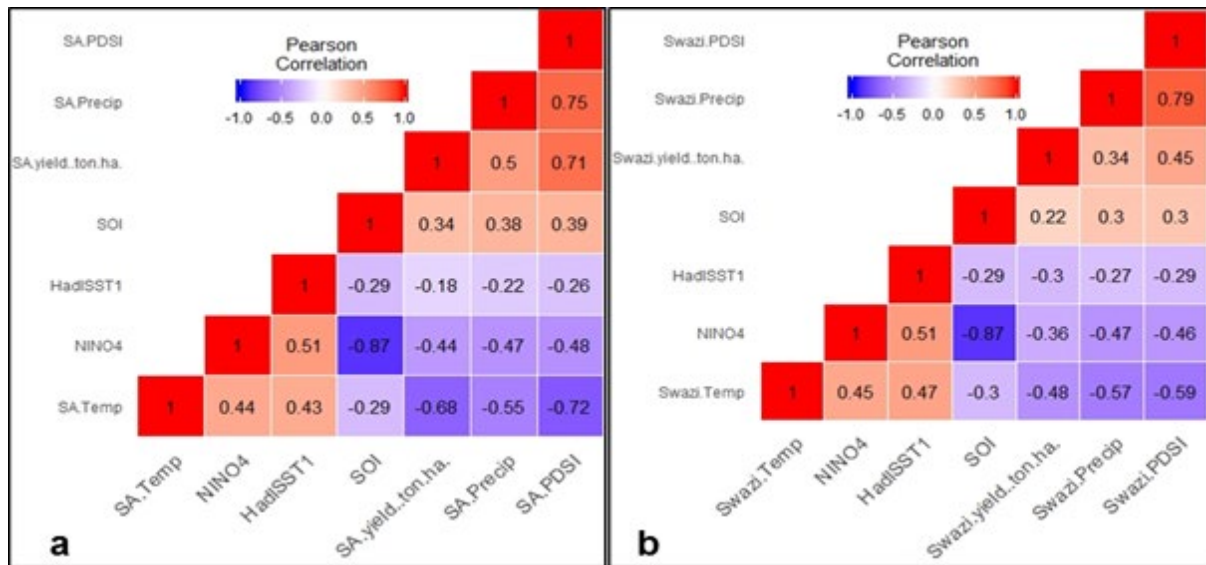


Figure 4: Heatmap of Pearson Correlation representing statistical degree of association and its extent between climatic factors and sugarcane yield from 1970-2016 in a) South Africa and b) ESwatini. PCC is defined as +1 for strong positive correlation, 0 indicates that there is no linear relationship, and -1 means strong anti-correlation. In some cases, closer to 0 values result from the noise in the time series.

The rainfall-temperature relationship is incorporated into the PDSI, and this study also affirms this drought index as a good proxy for sugarcane yield in rainfed agro-climatic regions because the latter and former are strongly correlated ($PCC > +0.7$) in South Africa. In Eswatini PDSI explains about 50% of yield variation from season-to-season, due to irrigation as expected. Niño4 has PCC of -0.44 and -0.36 with the yield in SA and Eswatini, respectively. These indicate that warming of the Pacific Ocean decelerates sugarcane growth one year after the warm phase of ENSO. This was also substantiated with the negative relationship between SST patterns over South-western Indian Ocean and the yield, where the PCC was -0.18 and -0.30 over SA and Swazi, respectively. This suggests that – local climate parameters (rainfall and temperature) provide large explanation about sugarcane variability in comparison to global or remote influences such as ENSO as illustrated in Figure 4.

The model output from MLR algorithms shows the influence of rainfall, temperature, PDSI, SOI, SSTs, and Niño4 on sugarcane yields as illustrated in Table 2. These climate variables and indices were chosen because of their interdependence and potential role in climate variability over the subcontinent. A statistically significant relationship between the drought index (PDSI) and surface air temperature with the sugarcane yield was observed at 1% level of confidence and the p -values of 0.01 (PDSI and sugarcane yield) and 0.03 (temperature and sugarcane yield) over South Africa. This statistical connection also exists between surface temperature and the sugarcane yield in Eswatini. Although, this is slightly weaker than in South Africa as indicated with a p -value of 0.10 at 5% level, and this was expected due to 100% irrigation over Eswatini as compared to 25% irrigation in South Africa. The irrigation increases the buffer during the dry season. Thus, it is essential to explore other water resources in future since the reservoirs are hot as the land and during severe drought conditions, evapotranspiration is triggered. Therefore, the surface water resources run dry and sugarcane decay / wilting occur due to water loss, which then suppress the annual sugarcane yield.

Table 2: Model output from MLR for FAO sugarcane yields (dependant variables) and climatic variables and indices are independent variables for the period 1970-2016.

MLR for South Africa					
	Estimate	Std. Error	t-value	p-value	Signif. Codes
(Intercept)	4.851e+01	1.004e+02	0.483	0.6318	
SA_PDSI	5.842e-02	2.248e-02	2.599	0.0131	*
SA_Precip	-1.505e-04	2.009e-04	-0.749	0.4584	
SA_Temp	-1.260e-01	5.499e-02	-2.291	0.0274	*
HadlSST1	1.486e-01	8.900e-02	1.670	0.1029	
HadSLP	-4.473e-02	9.905e-02	-0.452	0.6541	
Niño4	-6.986e-02	7.438e-02	-0.939	0.3534	
SOI	-2.863e-02	6.432e-02	-0.445	0.6586	
MLR for Eswatini					
	Estimate	Std. Error	t-value	p-value	Signif. Codes
(Intercept)	2.413e+01	5.086e+01	0.474	0.6378	
Swazi_Precip	-5.737e-05	8.396e-05	-0.683	0.4985	
Swazi_Temp	-4.073e-02	2.408e-02	-1.691	0.0987	.
Niño4	-4.310e-02	3.871e-02	-1.113	0.2724	
SOI	-3.193e-02	3.209e-02	-0.995	0.3260	
HadSLP	-1.843e-02	5.016e-02	-0.367	0.7153	
HadlSST1	5.250e-03	4.446e-02	0.118	0.9066	
Swazi_PDSI	1.268e-02	9.581e-03	1.323	0.1935	

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 where these numbers from 0-1 are p-values and the order of significant is strongest at p – value = 0 and denoted with '***' while p-value = 1 means that the independent variable is not statistically significant.

Conclusions and Future Perspectives

Sugarcane yield trend is significantly declining as indicated with z-transformation far less than –4 in the lowland region of southeastern Africa. This is partially due to environmental changes such as drought conditions, but it should be noted that there are additional non-climatic influences (van den Berg & Singels 2013). This includes sugarcane pests and diseases; monetary policy and land-use change issues. There is a strong statistical connection between rainfed sugarcane and climate than its counterpart irrigated sugarcane. There is a heterogeneous and intermittent intercomparisons detected in the statistical links between climate and sugarcane yield over south-eastern Africa, hence increasing temperature and reduced rainfall attributable to anticyclonic circulation which tends to suppress the annual sugarcane yields over the lowland region of south-eastern Africa. Interestingly, PDSI appears to explain much of the sugarcane variability / variance over time at 1-5% level in South Africa and Eswatini. The results revealed clear evidence of detrimental impacts of drought in sugarcane yield, as confirmed with the strong dip of the yield during 1992/93 season (Figures 1a and b) – where the minimum yields (41.7 ton/ha for South Africa and 90.8 ton/ha for Eswatini) were reached. The surface air temperature reveals itself as a key climatic feature for sugarcane production in

both South Africa and Eswatini (Table 2). This provides the evidence of ENSO induced drought impacts over the south-eastern Africa sugar-belt. Therefore, in addition to the crop-drivers employed / fitted in the seasonal climate forecasts, sugarcane monitoring and modelling systems (Singels & Paraskevopoulos 2017), the PDSI, ocean and atmospheric elements could be incorporated to improve to forecast skills. It should be noted that some sugarcane models such as the Canesim model are based on water, temperature, and radiation (van den Berg & Singels 2013; Singels & Paraskevopoulos 2017). Yet, sugarcane production is also affected by large-scale climate features and sugarcane has a longer cycle (12-24 months) which should be accounted for in scale and resolution greater than that of the daily data. PDSI uses both temperature and precipitation (Dai *et al.* 2004) and has been proven as a good proxy for soil moisture and sugarcane yield (Dai *et al.* 2004; Mbhamali & Jury 2021). It should be noted that other drought indices such as Standardized Precipitation Index use only precipitation (Dai *et al.* 2004).

The farmers may consider sugarcane growing for ethanol production which evade the challenges of low economic returns to the farmers, and further maintain the viability of sugarcane production. Hopefully, the former could assist small-scale farmers to best cope with financing their adaptation and mitigation strategies during severe drought conditions. However, extensive research is necessary to assess the potential of ethanol production from sugarcane in southeast Africa.

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Conflict of Interests

The authors would like to declare that there is no conflict of interests with this article.

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Steps taken to prepare South African military geography honours students for successful publication of their research

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Abstract

The process of accepting an article for publication provides students with valuable experience and validation for the research they are conducting. However, postgraduate students who are ill-prepared in terms of research skills and article writing are at a distinct disadvantage when attempting to publish research. Ensuring that postgraduates have well-developed article writing skills has benefits not only for students and supervisors but also for the institutions where these students are enrolled. This paper aims to report on an initiative by the Department of Military Geography at the South African Military Academy (SAMA) to develop their honours students' research projects into publishable accredited outputs. In recent years, the focus of the academic staff at the department has been to develop the research skills of their honours students by getting their research projects published. Since 2014, six honours research projects have been approved for publication, four of them in the last two years. This initiative by the department is said to have a three-fold benefit. First, it should greatly encourage the development and progression of these students, which may spill over to other departments within the Faculty of Military Science; Second, students will be adequately prepared to write their master's and doctoral theses and better equipped to become established researchers should they pursue this option; and Third, this process will improve the academic profile of the supervisors and is likely to have a financial and reputational benefit for the University of Stellenbosch by contributing to the research goals of that institution.

Keywords: research skills, writing for publication, postgraduate students, South African Military Academy, Department of Military Geography, Faculty of Military Science

Introduction

Globally, universities recognise that developing the writing skills of postgraduate students is increasingly important. (Comer et al., 2013, p. 2) states that “*written and oral communication skills have received attention in a range of engagements.... Yet effectively preparing postgraduates to write for publication has received less attention, although this area may be even more crucial for both their professional careers and their universities' academic standing*”. Without publications listed in their curriculum vitae, postgraduate students, find it difficult to enter academia and start academic careers (Comer et al., 2013). Getting research published is not easy and can be a frustrating undertaking because of the sometimes lengthy and confusing publishing process, long delays and the high rejection rates, especially of high-impact journals (Cooksey & McDonald, 2019). To embark on the process to publish is even more challenging for students. Postgraduate students at any level are novice researchers, yet academic departments, educational institutions and specifically supervisors often assume that these students have the necessary skills to publish their research (O'Clair, 2013; Rempel & Davidson, 2008). Also, vast amounts of money and energy are spent annually on postgraduate

students to complete their studies, and publishing their research is one way to increase the return on these investments (O'Clair, 2013).

Writing for publication is a science that is based on solid scholarly research, and comprehensive and meticulous methodology built around a clear and concise research theme (Harling & Misser, 1998; Pickett & McDonnell, 2017). A sound academic vocabulary in the publishing language of the targeted journal is required. Adherence to the writing and style guidelines and instructions of the targeted journal is essential. Skills to present the flow of the research in a logical way that sparks interest and attraction to the specific topic promote chances of acceptance for publication (Ecartot et al., 2015; Mestres & Sampathkumar, 2019). Article writing is concise and focussed, restricted in word and page length, and well-suited to the audience – in most cases, peers in the field of research (Pickett & McDonnell, 2017).

Universities commonly concede that the advancement of knowledge-sharing and scholarly innovation must be embedded in postgraduate programmes (Fourie-Malherbe et al., 2016; Sady et al., 2019). Postgraduate programmes are seen as the gateway to developing research capacities. Universities thus dedicate much time and effort to fostering the writing and research skills of their graduate students (Mutula, 2009; O'Clair, 2013; GD Goenka University, 2020). They present regular workshops, seminars, and training opportunities to both academic staff and postgraduate students (Harvard Extension School, 2021; Stellenbosch University, 2021a; University of Auckland, 2021; University of Birmingham, 2021; University of Glasgow, 2020). The enhancement of research capacities contributes to a university's academic standing among peer Higher Education Institutions (HEIs) and supports its aim to define, analyse and solve national and international challenges regarding technical, industrial, social, economic, political and environmental issues (Ismail et al., 2011; Vogel, 2011). In South Africa, another advantage of accredited publications relates to monetary benefits through subsidies. Authors that want to receive funding for their research outputs need to publish in one of the journals endorsed by the DHET, which includes journals indexed in the Web of Science (WoS), the International Bibliography of Social Sciences (IBSS), the list of South African published journals (DHET), SciELO SA, Scopus and the Norwegian list (Peter, 2021). South Africa is the only country that makes a distinction between publishing in accredited and non-accredited journals. Thus, the South African Department of Higher Education and Training (DHET) provides funding only to academic and research institutions that publish in accredited journals (University of Stellenbosch Business School, 2018). Each year the South African Department of Higher Education and Training publishes a list of all subsidised 'accredited' journals. These journals must "*comply with stringent quality criteria, including peer-reviews*" (University of Stellenbosch Business School, 2018, p. 1). Some countries do not need such a system, as their universities either receive outright government funding or are well funded privately, i.e., no funding shortfall needs to be made up through subsidised publications.

A supervisor mentors the academic and research development of a student by providing tools, support and encouragement (University of Melbourne, 2011). A good supervisor-student relationship is essential for the success of postgraduate studies (Ismail et al., 2011). Research approaches can differ depending on the research theme and associated or chosen research methodology. Effective supervision and mentoring may require additional education and training, especially for first-time supervision, or for supervisors having to deal with new or unfamiliar research instruments.

Besides the obvious responsibility to evaluate a student's academic writing and provide concrete feedback, supervisors are required to offer students opportunities to improve their writing and any other data collection, analysis and reporting skills. Sometimes, supervisors themselves may require additional skills, particularly if a new research tool or software is proposed to assist students effectively, and optimally in their research process.

In terms of writing up research, approaches to writing a dissertation and writing an article for publication are different. It is the supervisor's responsibility to inform students accordingly. According to (Meerah, 2010), research skills are acquired in five stages, namely: pre-search, search, quantitative/qualitative skills, interpretation, and reporting. Students also learn to identify gaps in existing research, collaborate with academics, develop a publishing network and follow respective journal guidelines and rules (Rose, 2021).

Buckner (2007) states that at the honours level students are mostly encouraged to attend academic conferences to present their research to instil confidence to discuss their research and respond to research field questions. Although these are important skills to acquire by any scholar, Buckner rightfully asserts that publishing research work is permanent, and the skills acquired by publishing are invaluable to any academic. Buckner (2007) further highlights ten steps that faculties should follow to get their honours work published, namely: prepare an appropriate abstract, identify two or three possible journals, and send a query email to editors of the possible journals to inquire if they accept the particular type of scholarly work, select the most appropriate journal for submission, prepare the manuscript according to author or journal guidelines, submit the manuscript and wait for feedback, receive a review and respond, keep the process in perspective, receive an acceptance letter and anticipate the time of publication, notify and thank those who assisted when the actual publication occurs – they share in your success (celebrate).

Academic publications by postgraduate students also benefit the supervisors by increasing their research outputs and enhancing their academic profile. It is the firm belief of most academics that postgraduates, especially doctoral students, need to publish to develop and enhance these students' academic careers and contribute to their fields of study (Flaherty, 2017). Besides enhancing the academic profile of postgraduate students, scholarly publications also contribute to the academic profile and peer recognition of mentors and supervisors. It is a tireless process to supervise and mentor postgraduate students. Most established South African academics employed at HEIs have numerous postgraduate students at any given time that are at different levels and phases in their studies. Juggling between supervising students, lecturing, conducting their research, and performing routine and ad hoc academic and administrative can be daunting. Therefore, one might question supervisors urging their postgraduate students to publish research (if not a requirement of the educational institute) while students complete their degree (Flaherty, 2017) unless suitable training and guidance are offered by those supervisors. A well-designed research plan and carefully chosen topic for a postgraduate student can allow for publication before the completion of the study project. Supervisors may not assume that their postgraduate students possess research and writing skills to publish, or will acquire the skills on their own without providing suitable support and training to complete their degree and publish their research (Lee & Murray, 2015; O'Clair, 2013).

Cooksey and McDonald (2019, p. 1) state that "there is increasing pressure for the results of postgraduate, especially doctoral, research to be made public with doctoral students more commonly being encouraged to publish not only after completion of the doctorate, but also during their study". It is common practice at HEIs that postgraduates, especially doctoral students, publish their research and results. Besides the obvious benefits for postgraduate students to publish (gaining writing and research prowess), i.e. greatly enhancing their employment opportunities or career advancement in academia, students that submit their research for publication gain valuable experience in the peer review process (Cooksey & McDonald, 2019; Flaherty, 2017), which prepares them better for future postgraduate studies and subsequent publications.

Publication is an important aspect of the postgraduate process and for many students its successful undertaking depends heavily on assistance from supervisors. The extent and

usefulness of this assistance is a topic which appears not to have been adequately researched in the past (Ferris, 2019). Presently, more and more emphasis being placed on capacity building within HEIs. This places more pressure on doctoral students in particular and their supervisors to deliver published research outputs. However, getting published should not be limited only to doctoral students, but be incorporated into earlier postgraduate programmes, even from the honours level (Buckner, 2007).

This article highlights the initiatives taken by lecturing staff in the Department of Military Geography of the Faculty of Military Science of Stellenbosch University (SU) in preparing their honours students for successfully publishing their research in accredited publications. This initiative is anticipated to deliver an array of advantages. Besides enhancing the research and report writing skills of honours students in this department, these skills are intended to improve their progress towards master's and doctoral studies, in particular through scaffolded research and thesis writing competencies. These competencies will also manifest in academic outputs delivered in other departments within the Faculty of Military Science in which these students are (modularly) registered. Products of this initiative will also enhance the academic profiles of supervisors and will have a monetary and reputational benefit for the affiliated university in terms of its collective research output. Lastly, it will advance the field of (Military) Geography in a South African and African context.

Materials and Methods

This study follows a retrospective analysis of the publications delivered by honours graduates in the Department of Military Geography of the Faculty of Military Science of Stellenbosch University. This Department's first honours students graduated in 1993, yet the first research papers extracted from honours theses were only published in 2014 and 2016, respectively. However, between January 2020 and June 2021, a total of four honours papers were approved for publication in accredited national and international publications. The present exploratory research project is conducted to report the initiatives by the lecturing staff in the Department of Military Geography to increase the research outputs of the Department by encouraging and supporting postgraduate students as early as at honours level to publish their research. Currently, at the SAMA postgraduate students at any level are not required to publish their research findings as a prerequisite to obtaining their degree, whether honours, master's, or doctorate. However, this changed in August 2021 with the development of a new standard working procedure (SWP) for the master's and doctoral study programmes in the Faculty of Military Science (FMS). The SWP stipulates that evidence of submission of at least one research paper for publication in a DHET-accredited journal be submitted before the dissertation/thesis is offered for external examination. It is then the responsibility of the supervisor to support the student to get the submission published, even if it is after the degree was conferred because scientific journal publication schedules and journal space restrictions are justifiable impediments to getting students' submissions published in time.

Background to the Faculty of Military Science and postgraduate studies

The FMS is a relatively small faculty in terms of lecturing staff and student numbers compared to other faculties in and beyond Stellenbosch University. There are currently 75 academic staff members in this faculty, of whom three are Professors, four are Associate Professors, 29 have PhDs, 31 hold master's degrees and eight an honours/LLB degree (personal communication, FMS Faculty Director, 21 June 2021). On average, since 2011, 446 undergraduate (residential) and 100 postgraduate students register per annum for studies in the Faculty of Military Science. All undergraduate students are junior military officers employed in the South African National Defence Force, whereas postgraduate students comprise both military members and civilians

employed in state departments within the South African government, primarily in the Department of Defence. A few students are foreign nationals with the focus of their studies on broad military and defence-related topics (Stellenbosch University, 2020).

Postgraduate students are seldom the main source of accredited research publications at HEIs. That responsibility is generally left to academic research and teaching staff. The FMS itself has struggled until recently to maintain a culture of publication of research among its lecturing staff, mainly due to being a comparatively junior faculty not in terms of years of experience, but in terms of academic qualifications. This changed steadily since roughly 15 years ago with the appointment of a senior academic and established researcher from another university as the first Dean of Faculty from outside the Department of Defence, and the resultant raising of the bar of minimum qualifications of new MUE candidates for appointment. By 2021, the staff academic component changed from having on average six doctorates by end of the millennium to 35, and 31 who held a master's degree. Throughout its existence, based largely on its rather exclusive or designated primary clientele, the FMS never had the number of postgraduate students comparable to other faculties of Stellenbosch University. In 2018, only 90 postgraduates enrolled at the FMS (the average over the preceding 10 years is 67), compared to an average of 1 157 for much larger, open faculties of SU (Stellenbosch University, 2021b). The small size of the faculty in terms of lecturing staff and postgraduate students equates to an equally small research output by this faculty, especially by its very small cohort of doctoral students. In 2020 this faculty produced 26 post-graduates during the December graduation ceremonies, two of whom received a PhD, three of whom obtained a master's, and 21, an honours degree. The latest research-related information package (2019) received from the mother campus for its FMS shows that 61 accredited research outputs were delivered for the 2018 academic year. This constitutes an increase of approximately 70% compared to the 2017 academic year. Accredited research outputs have increased markedly over the past 10 years, which is indicative of Stellenbosch University's vision and strategy to be Africa's leading research-intensive university (Stellenbosch University, 2021b). The Faculty of Military Science itself is committed to reaching and maintaining a competitive research output relevant to the size of its academic staff and postgraduate students. Therefore, networking amongst academics and other national and international institutions is becoming pertinent to sustaining a culture of accredited publishing within the FMS. Getting post-graduate students to become home-grown research timber serves as the primary driver of an initiative to develop, support, and structure, as part of formal requirements for graduation, the publication of research by FMS honours students.

The Department of Military Geography and its honours programme

The Department of Military Geography is part of a faculty that by its very nature, as an HEI created by the DoD for the DoD will apply acquired graduate and postgraduate skills directly in their military careers as future military commanders in the SANDF. This is one of the aspects of HE that sets the department apart from many others. Their undergraduate programmes provide academic scaffolding for advanced studies in the field or sub-field of geography. The military geography undergraduate programme consists of six modules that cover all branches of geography.

Military geography is cross-disciplinary because it is offered in support of other undergraduate programmes in the FMS (Henrico, et al., 2020). However, postgraduate programmes are subject specific and the honours programme in Military Geography was only developed in 1992. The first Military Geography honours student graduated in 1993. This programme has been modular since its inception, but its focus and content have changed steadily over the years to stay abreast of new knowledge in the discipline. Currently (2021), the honours programme in Military Geography includes seven modules, each carrying a 15-credit load. A research project carrying 30 credits completes the course requirements (Stellenbosch University, 2020). Based on the

organisational positioning of all FMS academic courses, research projects in the Department of Military Geography preferably cover themes from the South African military geography environment, but themes in general geography are also accepted when suitably motivated (Table 1).

Table 1: Honours modules currently presented in the Department of Military Geography, FMS (Stellenbosch University, 2020:45).

Module Name	Module Code	Credits
Geographical Thought	741	15
Geographical Methodology	742	15
Geographic Information Systems	743	15
Political Geography	744	15
Environmental Studies and Military Action	745	15
Environmental Skills and Techniques	746	15
Research Project*	747	30
* A theme from the South African military geography environment is preferred.		Total = 120

Since its design, the research project is arranged as an academic monograph consisting of various chapters and written in a style compatible with accredited scientific journals. The student's methodological approach to her/his research should be well mastered and explained, although not as thoroughly as with master's and doctoral studies. Students also need to display technical mastery (relating to mechanical, information technology, mathematical, or scientific tasks) and the logical presentation and analysis of their research results.

In the Department of Military Geography, lecturing staff do not focus much on teaching their honours students the skill of writing for publication. The focus is much rather on encouraging the student to thoroughly research the theme for their project and follow the generic structural prescripts (introduction, literature review, methodology, results, and conclusion) of writing up research. Upon completion of their research project, it is submitted for external examination. The supervisor will at this point assist the student in preparing a research paper for publication from the research project. Although supervisors are actively involved in guiding and supporting students in completing a research project, additional research and analysis are often required by students to comply with the submission guidelines of the targeted journal. In such cases, the supervisor, sometimes with the assistance of other academic staff, will do further research and analysis, and then help the student to incorporate additions and changes into the manuscript before they deliver a finished product for possible publication. Primary and secondary authors are all kept abreast of such changes or additions.

The student is normally the first author, with the supervisor and co-supervisor as the second and third authors. A qualitative assessment of the amount of input of the student, supervisor and any other academic collaborator is conducted to determine the order of authors. If supervisors are writing most of the research article, then the role of the honour's student is seen as that of a data collector. Said data may provide further development of the research towards an advanced study, i.e., a master's or doctoral study.

When extensive further research and analysis will be required to produce a publishable article, the collaborating academic responsible for most of the further research, analysis and actual article writing will be the first author. Students in FMS who finish their honours degree are not

guaranteed permission by their employer to progress immediately thereafter with master's studies or stay on in the institution for academic purposes. In some cases, the student who initiated the research for honours degree purposes had either deployed militarily beyond national borders, assumed a military post within the Department of Defence, or had even left the Department of Defence and found employment elsewhere, with little or no time to spend on the post-graduation publication process.

Ultimately, although honours students are not always directly involved in all steps of the research paper writing process, their involvement still prepares them for thinking critically about their research and the academic writing process. It also holds the advantage that students gain valuable experience regarding the article writing and review process, something that will serve them well should they pursue master's and doctoral studies in future or convert any future research into publishable outputs.

Results and Discussion

Since the inception of the Military Geography honours programme at the South African Military Academy in 1992, thirty-one honours students completed their B Mil Hons degrees in Military Geography. In the past, it has not been a priority to encourage these honours students to publish their research. However, for the past decade in particular academic staff in the Faculty of Military Science are under increasing pressure to improve their academic profiles and produce published research according to targets set by the university. Since the responsibilities of an academic staff member are quite extensive, one viable option to regularly produce research outputs is for supervisors to help their postgraduate students to publish their research. This has benefits for all three actors in the publishing partnership, viz., the student, the supervisor, and the university to which they are affiliated. Besides the advantages to students, supervisors and affiliated HEIs, as highlighted in this paper, this initiative also encourages honours students to continue their postgraduate journey and register for the master's programme in Military Geography – a fact that is proven below. It is envisaged that this trend will also spill over to the master's and doctoral programmes in Military Geography, and even to post-graduate programmes in other FMS disciplines.

Since 2014, six honours research papers were accepted for publication in an accredited scientific journal. Some are either still subject to the publication review process or in the final stages of drafting (Figure 1).

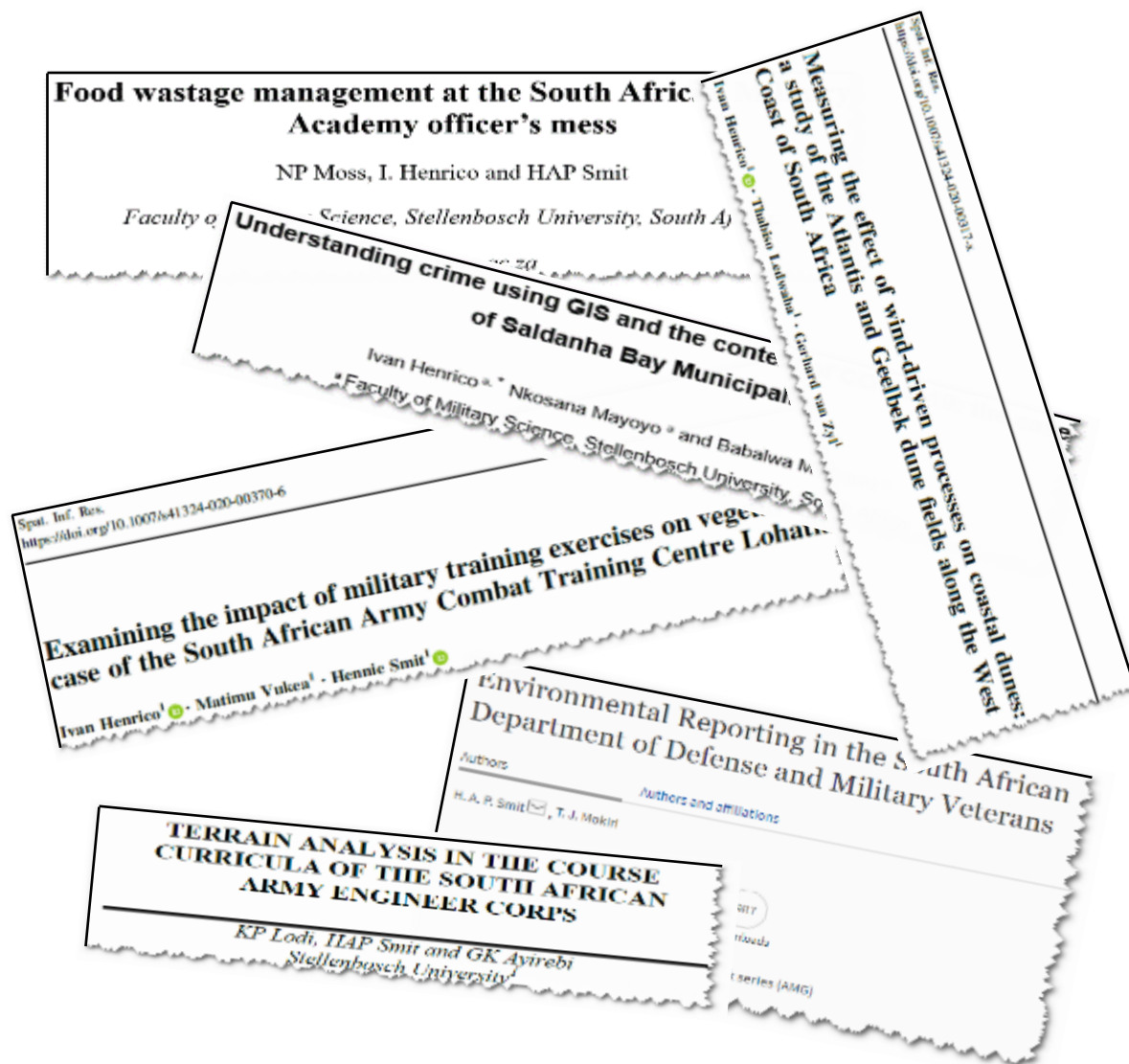


Figure 1: Publications of military geography honours students in DHET accredited journals since 2014.

The first honours graduate paper that was developed into an article was published in 2014 by Lt K.P. Lodi (student), Prof H.A.P. Smit (supervisor) and Mr G.K. Ayirebi (Military Geography lecturer). The title of the article is: “*Terrain Analysis in the Course Curricula of the South African Army Engineer Corps*”. The article analysed the curricula of the South African Army Engineer Corps. The findings in this article eventually led to changes instituted in the curricula of the relevant service (Lodi, 2014). The paper was published in *Scientia Militaria*, a DHET-accredited national journal published by the Faculty of Military Science. The second article was published in 2016 by Prof H.A.P. Smit (supervisor) and Lt T.J. Mokiri (student) as an accredited book chapter in the book: *Military Geosciences and Desert Warfare: Past Lessons and Modern Challenges*, which is part of the *Advances in Military Geosciences* book series published by Springer. The title of this publication is: “*Environmental Reporting in the South African Department of Defence and Military Veterans*”. In this article, the reporting of military environmental issues in official military publications was analysed. Trends and limitations were identified, and measures to rectify problems were suggested (Smit & Mokiri, 2016).

In 2020, two research reports were prepared for publication. Both these articles were published in the *Spatial Information Research* journal, an international publication published by Springer. The first of these research outputs, titled “*Measuring the Effect of Wind-Driven Processes on*

Coastal Dunes: A Study of the Atlantis and Geelbek Dune Fields along the West Coast of South Africa “was published by Dr I. Henrico (supervisor), Lt T.V. Ledwaba (student) and Dr G.M. van Zyl (third author). This article reported on the use of remote sensing to analyse the impact of wind direction and strength on two prominent dunes along the West Coast of South Africa (Henrico, Ledwaba, et al., 2020). The second article was published by Dr I. Henrico (co-supervisor), Lt M.M. Vukea (student) and Prof H.A.P. Smit (supervisor), and the title of the article is: “*Examining the Impact of Military Training Exercises on Vegetation: Case of the South African Army Combat Training Centre Lohatla*”. The important issue of the impact of military training on vegetation in training areas was investigated and reported on in this publication (Henrico et al., 2021).

In 2021, another two articles were prepared and submitted for publication. The first manuscript by Maj N.P. Moss (student), Dr I. Henrico (co-supervisor), and Prof H.A.P. Smit (supervisor) was published in the 2021 second edition of *Scientia Militaria*. The title of this manuscript is: “*Food Wastage Management at the South African Military Academy Officer’s Mess*”. It deals with food wastage and how to prevent this in military mess facilities (Moss et al., 2021). The second article was published online in the early part of 2022 in the South African Crime Quarterly (SACQ) journal. The authors are Dr I. Henrico (supervisor), Capt N.P. Mayoyo (student) and Dr B. Mtshawu (co-supervisor). The title of this manuscript is: “*Crime in the context of COVID-19: The case of Saldanha Bay Municipality*”. In this study, Geographic Information System (GIS) software is used to illustrate the spatial distribution and trends of crime in the Saldanha Bay Municipality as impacted by COVID-19 (Henrico et al., 2022).

Since 2020, four honours projects were developed into accredited publications, a direct consequence of academic staff in the Department of Military Geography realising the benefits to students, supervisors and associated HEIs of publishing honours research. The small Department of only four lecturing staff over the past 5 years developed from having one doctorate to having three members hold PhDs, of whom one is an Associate Professor. The lecturing staff of this Department are well-established academics. Thus, supervising postgraduates and delivering research outputs consistently are expected of them. The number of students that register for the honours in Military Geography programme in the Faculty of Military Science increased steadily over the past four years from an average of only one per annum since the programme’s inception to three per annum.

Notably, not all honours research projects are suitable for accredited publication in publicly accessible scientific journals. Since post-graduate research and senior academic research will often focus on military-specific themes, results will not easily be generalisable. This might impact the publishability of research stemming from the Department of Military Geography of the Faculty of Military Science of Stellenbosch University. This department’s dual affiliation to a public HEI and a national security department (DoD) further implies that data collected will often not be allowed, for security purposes, to be published in mainstream accredited scientific journals. Thus, paradoxically, an increase in student numbers might not necessarily lead to a proportionate increase in research outputs for accredited publications. However, said increase in honours student numbers does create more opportunities for supervisors to help students to develop their research into accredited publications. Generally, a set of research topics are provided to the students before commencing with their research projects. However, students can choose their subjects if they focus on military and security related issues. Despite these restrictions, since 2014, six out of a potential 13 (2018-2021) honours research papers were converted into accredited publications. The initiative started by the Department of Military Geography is proving successful in its stated objectives: to improve post-graduate students’ scientific research and writing skills, hone the supervision skills of academic staff, and

contribute to the research targets of the Faculty of Military Science and Stellenbosch University.

Conclusions

This study reported on the initiative by the Department of Military Geography lecturing staff to develop the research projects of their honour's students into publishable outputs in accredited publications. The advantages of such an initiative are threefold because it benefits postgraduate students, their supervisors and the institutions at which these students are registered. Benefits to the students include experience gained in the publication process, the development of scientific writing and research skills, and confidence in their ability as academics. The skills acquired will stand them in good stead in their jobs as future military leaders in the SANDF where they can showcase such competencies as clear learning, more concise communication, ability to present key facts logically, etc. Furthermore, publishing the research projects of honours students prepares these students for their master's and doctoral studies. At the same time, it contributes to the research outputs of their supervisors with whom they may publish collaboratively. For the associated HEI, an improved research output "*strengthens and grows the institutional knowledge base, ensures financial sustainability, promotes academic staff and postgraduate student success, and promotes diversity through research capacity development and support*" (Stellenbosch University, 2021b).

The Faculty of Military Science is comparatively small. Its Department of Military Geography currently consists of only four lecturing staff – a full complement in terms of the posts structurally allocated to this department. Only 31 honours students graduated from the Department in the 30 years since 1992 when the honours programme was conceived. However, the average number of students per annum has steadily increased over the past few years. Yet, the first accredited publication emanating from an honours student research project only occurred in 2014. In recent years, the current initiative by the lecturing staff as part of a comprehensive effort to increase research outputs in the Department of Military Geography directed staff to emphasize getting the research projects of their honour's students published. This process led to four publications in accredited publications in the last two years which cover topics related to the military and the environment, security and the environment, and military geography curriculum design. In most cases, remote sensing and GIS techniques are used to conduct the research. These publications contributed greatly towards developing these honours students' scientific research and writing skills which may set them on the path to becoming established researchers. They may also benefit these students when they progress to master's and doctoral levels. Through intra-departmental collaboration, students' publishable research outputs will enhance the research profile of the lecturing staff of the Department of Military Geography, the Faculty of Military Science and Stellenbosch University.

An important contribution of the present paper is to showcase the quality of honours research projects at the Military Academy through the Faculty of Military Science, in particular the Department of Military Geography. The quality of honours research in this department is often hailed by external examiners and peer reviewers. Their favourable estimation is confirmed by the degree of success achieved by this department in getting honours research projects published in accredited national and international publications. As anticipated, this success is starting to deliver anticipated benefits through the number of honours students enrolling for a master's degree upon completion of their honours programme. Of the six students whose honours research projects were published, four are currently registered at the Department of Military Geography for the master's in Military Geography. Some of these students are expanding on the research that they conducted during their honours programme. The writing

skills of these students have also greatly improved since their honours research projects, which is evident in the ease that they write up their master's research proposals and from the feedback received from other academics during the delivery of their master's colloquiums. But, further research through scientific measurements and quantitative assessments is required to determine whether the manifestation of advanced research for publication skills is directly related to the initiative by the lecturing staff of the Department of Military Geography to publish the research of its honours students.

It is hoped that this trend will spill over to other departments within the Faculty of Military Science. It will greatly benefit the faculty in that these students will acquire the confidence to become well-established academics who will pursue doctoral degrees and a career-long desire to publish their research.

The researchers are planning a follow-up study to assess through a qualitative-quantitative survey the steps taken to prepare postgraduate students to get published. The questionnaire will survey all past and present Military Geography postgraduate students (honours, master's and PhD) over the last decade that completed their degrees at the South African Military Academy. Results will be quantitatively analysed through SPSS statistical software to draw informed conclusions and trends regarding students' perspectives on publishing their scholarly research. The results of such a study will be valuable to evaluate and enhance the process of preparing postgraduate students for converting their research results into publications from the very start of their postgraduate journey. This will empower students to establish themselves as researchers and academics and to hone the skill set required to pursue active research throughout their careers either as academics or as military professionals, or both.

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Unpacking community environmental sustainability education in Ward 17 Biriiri Rural Area, Chimanimani District, Zimbabwe

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Abstract

This paper contributes towards rural planning policy and management through a critical analysis of the environmental education programmes in Biriiri Ward 17, Chimanimani District, Zimbabwe. Focus is on its planning, implementation, and programme review structures in place. Key informants were drawn from educators and field monitors employed by Towards Sustainable Use of Resources Organisation (TSURO), Agricultural, Technical and Extension Services (AGRITEX) department, Environmental Management Agency (EMA), Chimanimani Rural District Council (CRDC) and Christian Care. Chief Muusha, headman Saurombe, village heads and villager-composed focus group discussions (FDGs) also provided essential data for the research. Findings indicated that villagers receive education in the area through various Learning Support Materials (LSMs), a situation that has commendably augmented livelihood sustainability in the area. However, lack of adequate grassroots community participation, fragmented policy structures and limited financial capital for more capacity development and project funding hinder beneficiaries from deriving maximum benefit from sustainability education initiatives. The paper recommends heightened capacity building supported by effective participation of grassroots communities and traditional leaders to achieve environmental sustainability goals.

Keywords: Learning Support Material, Local Traditional Authorities, Community of Practice, Indigenous knowledge

Introduction

The 2030 Agenda for Sustainable Development is an inter-governmental obligation that hinges on three sustainable development dimensions which are environmental, economic and social. Accordingly, sustainable Development Goal number 4 is to ‘ensure inclusive and equitable quality education and promote lifelong learning opportunities for all’ (Ng, 2019). There have been some commendable efforts to mainstream environmental sustainability education in the formal education system. Unfortunately, formal education provided by the school system alone does little to impact choices and practices of the public in the real world (Wade, 2008). In fact,

a study by Komatsu and Rappleye (2018) demonstrates that countries that have better enhanced formal education attainment levels also contribute more detrimental impacts on climate change than those with an inferior education.

This paper on environmental sustainability education falls within the geographical realm because Geography is a science that focuses on place and space (Urbanska et al., 2022). We consider the argument that sustainability education does not specifically fall within a single subject area (Latchem, 2018; Alam, 2003;). However, we argue that geographers study different earth patterns that are created by nature and humanity. Likewise, literature supports the notion that geography knowledge helps to facilitate the transfer of environmental knowledge including ways to solve the related problems (Jeronen, 2020; Urbanska et al., 2022; Alam, 2003). Environmental sustainability issues lie on the forefront of initiatives to solve the current and future environmental challenges. Given that several kinds of patterns have emerged and are repeatedly forming, geography becomes a fundamental field to address such issues as the degradation of the air, water and all land-based resources.

The term 'sustainability' is broadly used to refer to world continuity for the benefit of the upcoming generation with specific reference to its environmental, social and economic dimensions (White, 2004; UNESCO, 2005; Ardoin & Ryan, 2011; Ng, 2019). Accordingly, sustainable development calls for a change in the mental models which shape human perception and the decisions ultimately made (UNESCO, 2011; Urbanska et al., 2022). Environmental sustainability education for all citizens opens the doors for such a development. Citizen education to preserve the local environment is therefore an essential tool for building sustainable rural communities.

A myriad of terminology has been applied over the years to refer to education envisioned to ensure environmental sustainability. Whether it is termed 'environmental education' (Batchuluun, 2001; White, 2004; Ardoin & Ryan, 2011; Da-Silva-Rosa, 2015), 'sustainable education' (Sterling, 2005; Ng, 2019), 'education for sustainable development' (McKeown, 2002; UNESCO, 2005; Wade, 2008; Gehlawat, 2016), 'sustainable environmental education' (Akiyode et al., 2018) or 'ecological education' (Ghiurca et al. 2012), the all-inclusive goal is to transform the human mind towards sustainable conceptualisation and management of the environment. White (2004) applies the term Environmental Education (EE) to refer to an interdisciplinary and holistic form of education that is geared towards action and change, which promotes the use of participatory learning, learning by doing and action-based methodologies. UNESCO (2005:01) uses the term Education for Sustainable Development (ESD) to imply:

learning how to make decisions that balance and integrate the long-term future of the economy, the natural environment and the well-being of all communities, near and far, now and in the future.

In this paper, we acknowledge and adopt diverse terminology that implies any educational programme whose goal is to promote the development of citizens with environmental literacy. Likewise, we operationally use the term 'environmental sustainability education' to mean any form of eco-friendly awareness programme done with a view to change the mind-set of the public towards an eco-friendly utilisation of their surroundings. Whilst much has been written on formal education (Ng, 2019) we specifically focus on community education because this

paper aims to influence perception and promote sustainable choices and practices within local community settings threatened with serious environmental degradation.

In cases where environmental sustainability education is carefully and appropriately designed, it is capable of creating opportunities for people to learn new knowledge, skills, and attitudes that enable them to act out within their community in an environmentally responsible way (Shava, 2003; EPA, 2008; Urbanska et al., 2022). Such education is indispensable since it carries with it perspectives that are important for understanding global issues as well as local issues in a global context (McKeown, 2002; Akiyode et al., 2018). Thus, sustainability education should engage people of all age groups to make informed decisions about critical issues such as biodiversity loss, climate destabilization, resource overuse, and other environmental concerns. This is crucial to consider, given the currently topical climate change phenomenon (Tilbury, 2011; Ng, 2019). Consequently, communities and the various education mainstreaming agents should dovetail their efforts in order to achieve their intended sustainability goals.

Environmental sustainability education also plays a critical role in downscaling the prevalence of disasters (Da-Silva-Rosa et al., 2015; Akiyode et al., 2018). Such education adds value to disaster risk reduction (DRR) strategies by enabling vulnerable people to better comprehend the nature and severity of hazards threatening their communities including the ways of coping with them. Accordingly, there are often reduced ecological fatalities in community settings where citizens of all groups are well educated on disaster prevalence within their vicinity.

Zimbabwe, in which setting this paper is based, has the bulk of the population situated in rural environments in which it is extremely problematic to secure basic needs. The country is already experiencing the dreaded effects of climate change, notably temperature variability and extreme events (Mutasa, 2008; Fisher & Reid, 2012), the results of which continue to degrade the physical state of the rural environment. Soils, woodlands and water resources in many rural parts of the country are getting depleted (Mutasa, 2008). The physical vulnerability to degradation coupled with ever growing population has resulted in accelerated land deterioration in most areas as communities compromise the poor fragile environment in the course of trying to meet their livelihood requirements.

In recognition of the challenges at hand, the post-independence government of Zimbabwe has introduced capacity building projects which involve the villagers in ensuring sustainable practices within their communities. The Environmental Management Act states that every person “has a right to access environmental information and right to participate in promulgation and implementation of legislative, policy and other measures that prevent pollution and environmental degradation” (Fisher & Reid, 2012:27). EE is therefore an essential tool within rural communities so as to pave way for sustainable practices.

As environmental sustainability initiatives are implemented within communities, their evaluation at various phases is quite essential (Stormwater Trust, 2004; EPA, 2008). Evaluation is a systematic process of collecting credible data and using it to make judgements about the worth of a product, service or process at any point in a program’s life cycle (Stormwater Trust, 2004). Paulsen (2002) argues in support of the implementation of an evaluation exercise for various intervention programmes because it helps identify problems with a programme before

it ends so that changes in the programme can still have an impact. Likewise, effective community environmental education suffices where governmental organizations, non-governmental organizations and other stakeholders continuously review their programmes to remain functional to the communities they work with.

To ensure sustainable practices in communities, environmental education has also seen the incorporation of indigenous knowledge systems into the sustainability campaign. With strong encouragement by New Partnership for Africa's Development (NEPAD), for instance, IKS can be mainstreamed in the formal and informal education systems in Africa to yield significant conservation goals. IKS is now incorporated in Zimbabwe's environmental policy planning to aid in the management and sustainable use of natural resources (Mapira and Mazambara, 2013). Given the fact that IK is embedded within people's culture, traditional leaders are often tasked with the mandate to educate people so as to ensure that resources within local communities are used wisely.

Whilst environmental sustainability education is being mainstreamed at different levels, no comprehensive reflections have been documented about the processes and approaches including social and lifelong learning experiences outside the formal classroom (Akiyode et al., 2018; Tilbury, 2011). Likewise, there is a lack of literature that clearly documents an inventory of activities, challenges, and possible options to ensure that sustainability education in typically localised and rural communities such as Biriiri Ward 17 becomes a realisable initiative. To achieve this aim, the specific objectives were to:

- (a) identify the package of learning support materials used by various environmental educators,
- (b) discuss the challenges that various educating agencies are facing and
- (c) explore additional options for more effective environmental education pathways in the ward.

Materials and Methods

Study area

The study was done in Ward 17 Biriiri Communal Lands, Chimanimani District. It is a rural setting situated approximately 117 km south of Mutare, the provincial capital of Manicaland Province in Zimbabwe. Adjacent to it are commercial timber forests to the north-eastern, eastern and southern edges owned by Boarder Timbers, Wattle Company and Allied Timbers respectively. The north-western edge is a former white-owned irrigation and dairy farmland later appropriated for resettlement of smallholder farmers soon after independence. The area falls under the traditional jurisdiction of Chief Muusha. Generally, the study area is physically an elongated narrow stretch of low-lying terrain trending north to south direction and confined between Nyarunheng and Chingundu Mountains. It falls in the marginal agro-ecological region 4, currently drifting eastwards due to shrinking annual rainfall record with a tendency to fluctuate between 400-500 millimetres (Mutasa, 2008). Most of the population comprises of smallholder settlers who were squeezed into this rain shadow environment during the then land apportionment era of the colonial times. The geophysical constraints, coupled with a fast-

growing communal smallholder farming community, have increased the area's vulnerability to widespread environmental degradation.

Methods

The study employed a case study design executed using a predominantly qualitative methodology. A total of six (6) representatives from agencies mainstreaming environmental sustainability education in Biriiri were selected for in-depth interviews. These were drawn from Towards Sustainable Use of Resources Organisation (TSURO), Agricultural and Rural Extension Services (AGRITEX), Christian Care, Environmental Management Agency (EMA), Chimanimani Rural District Council (CRDC) and World Vision. The basis for their selection hinged on their hands-on experience in the provision of environmental sustainability education to members of the community. Five (5) village heads were also purposefully selected and interviewed with a view to solicit primary views from the fraternity of the traditional leadership that is host to the grassroots communities targeted by educating agents.

A total of four (4) focus group discussions comprising of 8-12 participants were administered with purposefully selected household representatives in various villages. These were held in Saurombe, Nyamusundu, Mutakura and Chinamira. The FGDs served to corroborate sentiments emanating from the interviewed educators. To confirm all responses and mentions made, researcher visits and observations were done in repeatedly indicated settings. The obtained data was analysed using thematic content analysis technique, in which recurrently stated responses were condensed to narrow concepts leading to specific conclusions. To execute the thematic content analysis, we aggregated the narratives from various participants as they responded to questions relating to the three set objectives. We then grouped the narratives based on their resemblance of meaning. Furthermore, we synthesised the views by selecting those that were in line with our objectives and later drew a list of themes that we compressed into three specific categories involving (i) the various learning packages used by intervening agencies (ii) sustainability challenges incurred and (iii) options pointing to effective environmental education in the area.

Qualitative descriptions, tables and key participants' citations were used to unveil the findings. Tables and detailed quotations from the interviews done with selected participants were included to make the findings more explicit.

Results

The findings represent the perceptions of the environmental sustainability educators and recipients of the education in various communities in the Ward. Some perceptions are also a product of the researchers' ground verification of both the educators and education recipients' assertions.

Acknowledgement of environmental education practice by educators

All the interviewed educator representatives acknowledged their involvement in sustainability education throughout the Ward. These are Towards Sustainable Use of Resources Organisation (TSURO), Environmental Management Agency (EMA), Chimanimani Rural District Council

(CRDC), Agricultural Technical and Extension Services (AGRITEX) and Christian Care. The interviewed local traditional leaders who include also confirmed their involvement in various environmental education initiatives.

The entitlement to decide on appropriate educational venues in the ward vary depending on the involved organisation and the environmental issue to be addressed. Traditional leaders reportedly perform a significant role in the selection of venues and mobilisation of villagers to attend educational meetings. Interviewed Environmental Management Agency and Chimanimani Rural District Council officials stated that they rely on traditional leaders as agents of coercion to mobilize villagers to attend meetings at *dare ramambo* (village court). The widely mentioned reason was that local people respect traditional leaders more than the agents from outside such as government and non-governmental organisation (NGO) officials. When they are given the mandate to summon villagers to meet unknown agents for sustainability education meetings, the traditional leaders push to boost the attendance.

A senior official working with CRDC noted that educators who work in the district are mainly guided by the government’s environmental conservation mandates. He reiterated that the government also draws its themes from international blueprints on environmental conservation, which in turn are narrowed down into national environmental policy frameworks. In addition to that, one EMA representative indicated that their choice of sustainability education themes was guided by the prevailing livelihood practices threatening the environmental at any given moment in the ward. For instance, Biriiri Ward 17 is situated close to several commercial forests owned by Boarder Timbers, Allied Timbers and Wattle Company of Zimbabwe. Complaints from the forestry companies about villagers causing fire outbreaks and illegally extracting timber for own use were reported as key drivers for the mainstreaming of environmental education in the ward. We interrogated various environmental sustainability educators to reveal their target initiatives including their learning strategies and support materials that they use. Table 1 indicates a drawn summary of the findings.

Table 1. Environmental Education (EE) goals and their related learning support materials.

	Organisation	Target initiatives	Learning strategies and support materials
Non-governmental Organisations (NGOs)	TSURO	<ul style="list-style-type: none"> ▪ Conservation farming ▪ Material recycling ▪ Biodiversity promotion ▪ Forest management ▪ Promotion of indigenous species 	<ul style="list-style-type: none"> ▪ Posters ▪ Newsletters ▪ Demonstration projects ▪ Field demonstrations
	Christian Care	<ul style="list-style-type: none"> ▪ Conservation farming ▪ Social networking ▪ Organic farming 	<ul style="list-style-type: none"> ▪ Demonstration projects ▪ Field demonstrations ▪ Village clusters ▪ Workshops
	World Vision	<ul style="list-style-type: none"> ▪ Conservation farming ▪ Forest management 	<ul style="list-style-type: none"> ▪ Community projects ▪ Field demonstrations

	Organisation	Target initiatives	Learning strategies and support materials
		<ul style="list-style-type: none"> ▪ Social networks 	<ul style="list-style-type: none"> ▪ Workshops
Government Agencies	AGRITEX	<ul style="list-style-type: none"> ▪ Conservation farming ▪ Livestock management 	<ul style="list-style-type: none"> ▪ Field visits ▪ Field days ▪ Demonstration projects
	EMA	<ul style="list-style-type: none"> ▪ Anti-fire awareness ▪ Forest management ▪ Firefighting techniques ▪ Anti-poaching campaigns 	<ul style="list-style-type: none"> ▪ Online campaigns ▪ Posters ▪ Public address ▪ Public demonstrations
	CRDC	<ul style="list-style-type: none"> ▪ Sustainable sand mining ▪ Sustainable brick molding ▪ Forest management ▪ Anti-poaching campaigns 	<ul style="list-style-type: none"> ▪ Posters ▪ Public address

The study established that there is no regular schedule of provision and use of the various learning support materials to which many organisations alluded. The latter was confirmed by EMA, CRDC, TSURO, AGRITEX and Christian Care. In fact, TSURO and EMA confirmed that they produce calendars annually but hardly make these available to all communities due to the related production costs. An interviewed AGRITEX officer stated that:

To pursue specific annual schedules to educate communities comes with problems in the sense that the educating agencies may not readily be available at all times. As AGRITEX officers, we live with grassroots communities and therefore can easily spot areas where there are environmental challenges. During the fire season, we invite officials from EMA to help educate people on the dangers of causing fire. When villagers show elements of resistance to what they are taught by AGRITEX, NGO officials and traditional leaders, we sometimes invite members of the Zimbabwe Republic Police (ZRP) to intervene.

Traditional leaders echoed their lack of capacity to generate and use any tangible learning support materials. Another village head deplored the no contextual nature of some of the educational materials used by some organisations, the bulk of which is published in English. The anomaly therefore limits the effective dissemination of knowledge to some of the villagers whose only intelligible language in the area is *Shona*. It was reported that TSURO and EMA occasionally translate their instructional materials into *Shona* language for the majority to benefit. Nevertheless, the organisations lack the capacity to translate all their sustainability education materials due to escalating production costs prevailing in the country, a situation which creates a gap in the information dissemination discourse.

AGRITEX was reportedly the most involved educating organization. There are four resident extension officers at Biriiri Rural Service Centre who hold regular meetings with smallholder

farmers at the local community hall. The extension officers correspondingly visit and advise smallholder farmers on individual and farmer cluster levels. For various agencies, what was high on their sustainability agenda is conservation farming techniques. One senior AGRITEX official explained that conservation farming comprises of three key thrusts. Firstly, it seeks to counter soil disturbance by adopting minimum tillage of the land. Accordingly, the local small-scale farmers confirmed the growing tendency towards the use of dug pits filled with soil covered manure or fertiliser, a conservation programme locally called *dhiga ugute*. Secondly, conservation farming seeks to maintain consistent soil cover with the purpose of reducing soil erosion. Thirdly, conservation farming aims to increase crop diversity. To increase crop diversity helps to enhance ecological balance in the environment, which in turn creates an enriched ecosystem.

TSURO, Christian Care and World Vision are the foremost NGO educators in the Ward. Besides their humanitarian aid provision mandate, they offer sustainability education to the community too, with the aim to minimise resource depletion and ascending rural poverty trends. Members of the community are taught to nurture indigenous tree species not only to ensure land cover and soil erosion eradication but also to evade acute food shortage through fruit harvesting. A senior field officer who works with TSURO's Department of Sustainable Agriculture and Land use (DSAL) reiterated that to boost agroforestry initiatives, their organisation encourages smallholder farmers to plant indigenous fruit trees such as mutohwe (*Azanza garckeana*), munyii (*Berchemia discolor*), muuyu (*Adansonia digitata*) mutamba (*Strychnos coculoides*), mushumha (*Diospyros mespilliformis*) and muzhanje (*Uapaca kirkiana*). By encouraging the locals to propagate their own indigenous fruit trees, there is a sustainability benefit in that the destruction of existing indigenous fruit trees in local forests declines significantly.

It was established from the study that traditional leaders do not hold meetings specifically for the environmental sustainability education agenda *per se*. Instead, they employ random dissemination of environmental awareness information at public gatherings such as church, wedding and funeral ceremonies. Interviewed traditional leaders specifically acknowledged that public gathering events are opportune platforms to warn defaulters against environmental malpractices on local resources such as water, vegetation, soil and wildlife. However, in cases where educators hijack the scene at other meetings, there was a high record of lack of compliance by the villagers as one interviewed resident stated:

Vanhu havateereri zvimwe zvidaidzirwa zvinongomuka vari parufu nepamuchato nokuti vanenge vasina gadziriro yazvo mupfungwa dzavo (People do not listen to ad hoc information disseminated at funerals and weddings, they will not be ready for it hence they feel short-changed).

We conducted some field visits to educational sites and projects that some educators recurrently mentioned as key sustainability education and demonstration sites for communities. We visited Biriiri Women's Craft, a focal point in Ward 17 where EMA and CRDC often conduct sustainability education campaigns with local handcrafts workers. Biriiri Women's Club is specifically an industrious group of artisan women who integrated to form a community of practice producing wood fibre mats, hats, and several other artefacts. They engage in the

extraction of wood fiber (locally called *rudzi* or *rwodzi*) from commonly available tree species such as *muunze* (*brachystegia spiciformis*) and *munhondo* (*Julbernardia globiflora*).

With the guidance of various environmental sustainability educators, the members share knowledge of forest resource conservation techniques for the sustainability of their project. One senior project member explained that EMA specifically taught them to rather initially target and utilise fibre from the shrubs in their crop fields before they venture into forests. The rationale is to guarantee dual benefits through obtaining craft fibre and undertaking field clearance in preparation for the forthcoming planting season. Again, when craft fibre harvesting is done in the forest, the locals were taught by EMA and CRDC that a single branch should be debarked at a time, leaving trees with the capacity to regenerate.

Sustainability challenges in Biriiri

In order to explore the broad range of views as to why the level of sustainability remains low despite the ongoing environmental sustainability education efforts, we aggregated the narratives, grouped them according to their resemblance of meaning, synthesised them and drew a list of themes implied by each segment of participants. Table 2 shows the categorised summary of responses that were collected and analysed.

Table 2: Perceived challenges hampering the practicability of environmental sustainability in Biriiri.

Participants category	Sustainability challenges
Non-governmental agency educators	<ul style="list-style-type: none"> ▪ So far a significant change is noticed in terms of what has been done on the ground. Resources are however not adequate for efforts to be expanded. ▪ Communities tend to pull back when support agencies withdraw their resource mobilisation. ▪ There is lack of effective follow up to our educational efforts by designated government agencies.
Government agency educators	<ul style="list-style-type: none"> ▪ We lack the necessary financial capacity to effect regular educational programmes within communities. ▪ We minimise sustainability law enforcement because communities lack the capacity to purchase certain resources.
Community members (education recipients)	<ul style="list-style-type: none"> ▪ We lack the capital needed to purchase assets that allow us to switch to more sustainable forms of practice. ▪ Some of the taught practices are not compatible with our culture so we cannot adopt them.

Sentiments from the interviewed participants from TSURO, EMA, CRDC, AGRITEX and Christian Care concurred that resources needed to undertake effective environmental sustainability are not readily available. Based on previous initiatives, they further lamented the failure by local communities to continue to maintain the taught sustainability standards following the withdrawal of intervention by the various intervening agencies.

Evidence that villagers are willing to commit themselves to the environmental sustainability education agenda was confirmed by the purposefully selected and interviewed village residents, who as well happen to be smallholder farmers in the area. Nonetheless, it emerged that their zeal to learn is confronted by a myriad of socio-economic challenges currently prevailing in the country. One outspoken resident of Biriiri had this to contribute during a focus group discussion:

We are aware of the need to conserve the local resources. We receive a lot of education from various government and nongovernmental organisations. Unfortunately, poverty limits us from connecting electricity to our homes. Even those with electricity are also joining us in cutting trees because power is too expensive. People also continue with their stream bank gardens because of the huge costs of drilling boreholes and installing solar pumps

Similar poverty-related sentiments were confirmed by the entire sample of interviewed environmental sustainability education agencies in the ward. One interviewed participant from the Environmental Management Agency had this to say:

We are aware of the poverty situation within communities. Resources are not in an adequate state. Therefore, we try by all means to encourage members of the community to utilise and what they have in a sustainable way. It is possible to cut trees but in a selective way that allows forests to thrive. Also, local communities can still utilise their indigenous ways of managing resources, which is a cheaper and locally friendly way of managing the resources.

In line with the utilisation of indigenous knowledge, a Chimanimani Rural District Council (CRDC) had this to say:

During our routine meetings with chiefs who are the custodians of traditional culture, we discuss the need to revert to the indigenous ways of managing local resources. Unfortunately, the traditional leaders often report widespread lack of consideration for these by communities. Traditional leaders often blame the disrespect for environmental taboos on the general decline in the availability of resources in areas set aside for exploitation. In addition, the western values that have shaped today's society make it difficult for many people to pay the expected respect to indigenous norms and values.

Cross sentiments from the five interviewed village heads concurred in revealing an anomalous pattern of traditional leadership selection that has been going for several years. The eldest member of the village heads fraternity in the area said:

We are not against the central government. We need their presence. However, this is a rural set up where traditional leaders are the custodians of the communities and the local culture. Look here, it's over five years now. We do not have a substantive chief chosen by the elders in our area. A young man from the traditional leadership family has been in power for a long time. Unfortunately, he does not deserve it. He is too young and not capable of performing the routine ritual tasks of a governing chief. Our people are aware of that and that is why they no longer pay respect to traditional leadership.

In line with the above, it was repeatedly stated by the rest of the village heads that the Biriiri community is typically rural and therefore should be directly governed using traditional administrative approaches headed by chiefs, headmen and village heads.

Options for more effective environmental sustainability education pathways

Based on views from the educating agencies and the members of the community, we drew a summary of the relevant options for ensuring that the environmental education offered to Biriiri rural community becomes beneficial to the recipients and their local environment. The summary of the key options is shown in Figure 1.

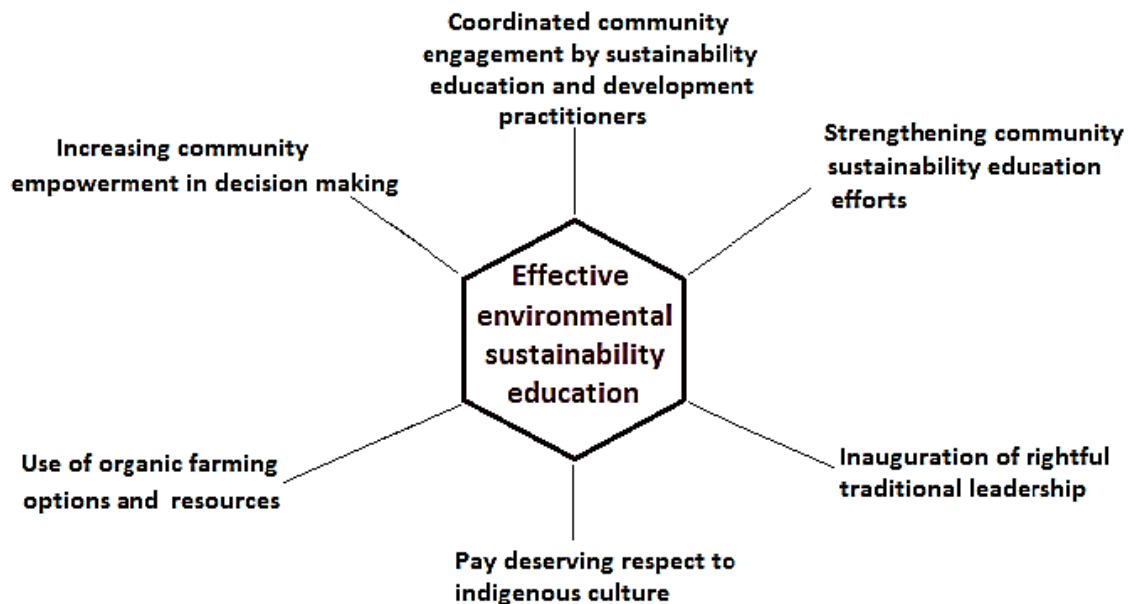


Figure 1. A summary of the options for more enhanced environmental sustainability pathways in rural Biriiri.

To empower the members of Biriiri rural community in terms of decision making is critical. Officials from TSURO, AGRITEX, CRDC, EMA, Christian Care and World Vision must respect the interests of local people. Thus, environmental conservation ideas that come from outside must supplement the already existing societal values, thereby helping to minimise resistance by the locals to participate in the options that the various intervening agencies offer. Members of the local community are prepared to receive additional knowledge from outside and have their choices and practices be corrected following an appreciation of what they have already done.

As environmental agencies plan and undertake their intervention initiatives, a high level of coordination is required. The adoption of a well-coordinated approach by environmental agencies helps to eradicate conflict of interest by various agencies. Once an environmental challenge has been identified, the agencies can distribute responsibilities and begin to intervene in an amicable way. In a way, community environmental sustainability education will be strengthened.

Challenges to do with high economic costs can still be dealt with using local area options. Members of the community can opt to start with low-cost practices such as the use of organic farming options and resources. Intervening agencies can do so by putting communities ahead in selecting the options that are compatible within their settings. Members of the community need to be further educated for them to place value in less costly options such as use of organic manure which is not only cheap but also environmentally friendly.

It is of the essence to expedite the inauguration of a deserving chief who is well endowed with expected knowledge of local cultural norms and values. When local elders are given enough room to select their deserving candidate for a chieftaincy office, the outcome will attract a lot of respect for indigenous culture. Such a chief will attract respect not only for himself but for cultural practices as well. Likewise, when outsiders come and mainstream various conservation initiatives, they find it easier to work with local traditional leaders whose ascendancy to power received the approval of the local people.

Discussion

What is observed in Biriiri ward 17 mirrors what many other rural communities with a high demand for resources are experiencing. Akiyode et al. (2018) aver that in Sub-Saharan Africa, only a limited number of countries are assigning attention to environmental sustainability education. Environmental sustainability education is a mandatory practice for all communities since it promotes a participatory and action-oriented approach to resource conservation (Gehlawat, 2016).

The fact that many educating agencies drew their sustainability education themes from local livelihood practices helped to make learning valuable. In practice, when local people develop a greater understanding of their own environmental concerns, they have a better understanding of the options available to address these concerns (EPA, 2008; Gehlawat, 2016). In the case of Romania, Ghiurca et al. (2012) advance a similar dimension, which considers the interaction between environmental, economic, socio-cultural and political-institutions as a preliminary step towards effective ecological education of people from rural settings including their participation in environmental policy resolutions.

The education that is being mainstreamed by various agencies in Biriiri outside the formal education system offers greater opportunities for sustainable practices. Communities can hardly rely on formal education that conventional learners receive in the school systems since it is usually outside the context within which the learners exist (Batchuluun, 2001; Shava, 2003). This has shortfalls in that it creates two separate worldviews for learners; firstly, the school world and secondly, the world in which they live (Shava, 2005). Likewise, environmental sustainability communities of practice such as Biriiri Rural Women's Club provide a critical platform for the purpose of transmitting environmental knowledge and skills. In Brazil, project-based environmental education initiatives in landslide-risk areas of Niterói (RJ) and Jaboatão dos Guararapes (PE) cities significantly reduced the level of fatality (Da-Silva-Rosa et al., 2015). Tilbury (2011) considers such practical involvement as critical social change engagement, which manifests with the view to empower the groups involved through capacity-building and knowledge exchange. To attain sustainable development, it requires transformative change that occurs at the cultural and social level to create effective social capital (Tibury, 2011).

Nongovernmental organisations are key actors in mainstreaming environmental awareness as part of their community engagement. To disseminate environmental knowledge and awareness is the pathway to poverty reduction and general development (Cheboi, 2014). When people

gain knowledge about their own environment, they develop a sense of belonging and empowerment to manage their own resources (UNESCO, 2005; Tilbury, 2011; Ardoin and Ryan, 2011). In Uganda, the involvement of various organisations in different stages has continued to engage and shape the citizenry and society's environmental knowledge and awareness in different parts of the country (Akiyode et al., 2018). Although the government and communities may, to some extent, develop a sense of over-dependency on aid agencies (Cheboi, 2014), the presence of the agencies also provides key environmental sustainability awareness packages.

Indigenous food harvesting creates a vital food supplement particularly in rural smallholder communities (Shava, 2005). Climate change has severely contracted the most smallholder food production systems, forcing communities to depend on forests as alternative food sources. Therefore, the increased dependence on wild fruits that is rapidly manifesting in Biriiri is in congruence with other rural community situations. In response to this, environmental sustainability education plays a critical role in disseminating the knowledge needed to enable people to manage the natural resource base sustainably.

When sustainability education media get translated into locally spoken languages, there is greater motivation for recipients of the packages to learn. The promotion of Learning packages delivered in indigenous languages inculcates a sense of effective learning and enables people to solve immediate challenges (Togo and Shumba, 2009; IFRC, 2011). Local taboos, riddles and names of indigenous tree species for instance are easier to understand if they are published in local languages.

Efforts by educators to make use of local traditional authorities in mobilizing sustainability education are a positive move. According to Tbilisi Principles for environmental education (UNESCO UNEP, 1977 in Palmer, 1998), there is need to prioritise perspectives that embrace culture and history in addressing today's pressing environmental issues. Again, the primary responsibility of chiefs is to provide traditional leadership to their communities as well as to perform duties assigned to them under customary law and the chiefs and Headmen Act. Under customary law, traditional leaders have custody of communal land (Makumbe, 2010).

With packs of environmental knowledge and awareness programs in Biriiri, communities still fall on the wrong side of environmental sustainability. This has been the case in several community settings where greater emphasis was directed to the biophysical part of the environment without equally considering the socio-economic perspective (Wade, 2008). Similar problems were shown by Ayidole et al. (2018) in Uganda where there has been a pervasive violation of the regulations set by the government to preserve and conserve some of the areas, despite the government laws forbidding people to reside and engage in farming activities in conservation and protected areas. With all the environmental awareness campaigns at hand, Ugandan forests have continued to reduce due to the demand for timber, charcoal and fuel wood without any subsequent sustainable afforestation initiatives. Nevertheless, an educated community errs much less than one which is completely deficient of the much-needed environmental consciousness.

Conclusions and Recommendations

The research findings revealed that sustainability education is taking place in Biriiri Ward 17 by both government and non-governmental agents. To draw their sustainability education themes, agencies rely on existing livelihood practices which are a threat to the local environment. The majority of villagers are smallholder farmers who depend directly on the locally available resources which puts the local environment under immense pressure, rendering it vulnerable to accelerated degradation. Environmental sustainability educators are also guided by national and international blueprints on sustainable management of the environment. They translate these to suit local environmental sustainability needs.

Accordingly, the paper makes the following recommendations:

- There is a need to dovetail sustainability education with practice in order to create sustainable communities.
- Additional demonstration sites are needed to enhance more hands-on learning which enables ordinary members of the community to appreciate environmental sustainability education.
- Extra gender-sensitive programming of intervention programmes is needed to allow active participation by all population groups.
- Traditional leaders should be exposed to more environmental literacy in order for them to become effective capacity builders of communities that they lead.

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Evaluation of siting of renewable energy development zones in South Africa

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Abstract

Since the early 1980s, geographic information systems (GIS) have increasingly been applied in research or used to support research in South Africa. The South African government has identified eleven Renewable Energy Development Zones (REDZs) for the development of large-scale wind and solar photovoltaic facilities. The Department of Forestry, Fisheries and the Environment (DEFF) and the Council for Scientific and Industrial Research (CSIR) applied a holistic approach that considered environmental, technical, social and economic factors in siting the REDZs. This paper considers the renewable energy resource availability and technical factors to evaluate the locations of the REDZs. The evaluation tests the effectiveness of the DEFF's process and identifies areas within the REDZs that should be prioritised for development. A GIS-based approach with a two-step framework for both solar and wind suitability analysis was conducted. The first step includes identifying unsuitable regions in South Africa for large-scale solar and wind facilities. The second step derives suitable areas in a number of classes for wind and solar facilities using solar radiation/wind speed, distance from power transmission lines, distance from major roads, distance from residential areas, elevation, slope, and land use. The relative weights for the defined criteria are determined using the Analytical Hierarchy Approach (AHP) approach. Results indicate that 67% of the land in the solar REDZs is suitable for solar energy development, and 79% of the land in the wind REDZs is suitable for wind energy development. The Upington REDZs is most suitable for solar development, with the Springbok and Beaufort West REDZs highly suitable for solar and wind energy development. Given the great variation in suitability of the land with the REDZs, it is important for each new project to conduct comprehensive siting studies.

Keywords: Renewable energy, suitability analysis, spatial analysis, Geographic Information Systems

Introduction

The energy transition in South Africa commenced in 2011 when the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) was initiated. Fifteen units at coal-fired power stations had been placed in reserve storage as of 31 March 2020

(Eskom, 2020), and the capacity is being replaced with wind and solar energy installations. While the transition to renewable energy will lower emissions of greenhouse gases and air pollution, water consumption and waste production, it will result in more land being transformed for electricity generation (Cheng and Hammond, 2017; Kiesecker et al., 2020; McDonald et al., 2009; Trainor et al., 2016).

To support large-scale renewable energy development in South Africa, eight Renewable Energy Development Zones (REDZs) were designated in Government Notice No. 114 in Government Gazette No. 41445 of 16 February 2018. An additional three were identified in Government Notice No. 144 in Government Gazette No. 44191 of 26 February 2021. The designated REDZs (Figure 1) are strategically located to support utility-scale wind and solar photovoltaic (PV) projects in terms of Strategic Integrated Project 8 (green energy). REDZs were developed to boost the South African economy and to support the development of transmission corridors which include both the high voltage electricity transmission network and low voltage electricity distribution network in terms of Strategic Integrated Project 10. New renewable energy capacity provided for by the Integrated Resource Plan 2019 should preferentially occur in the REDZs.

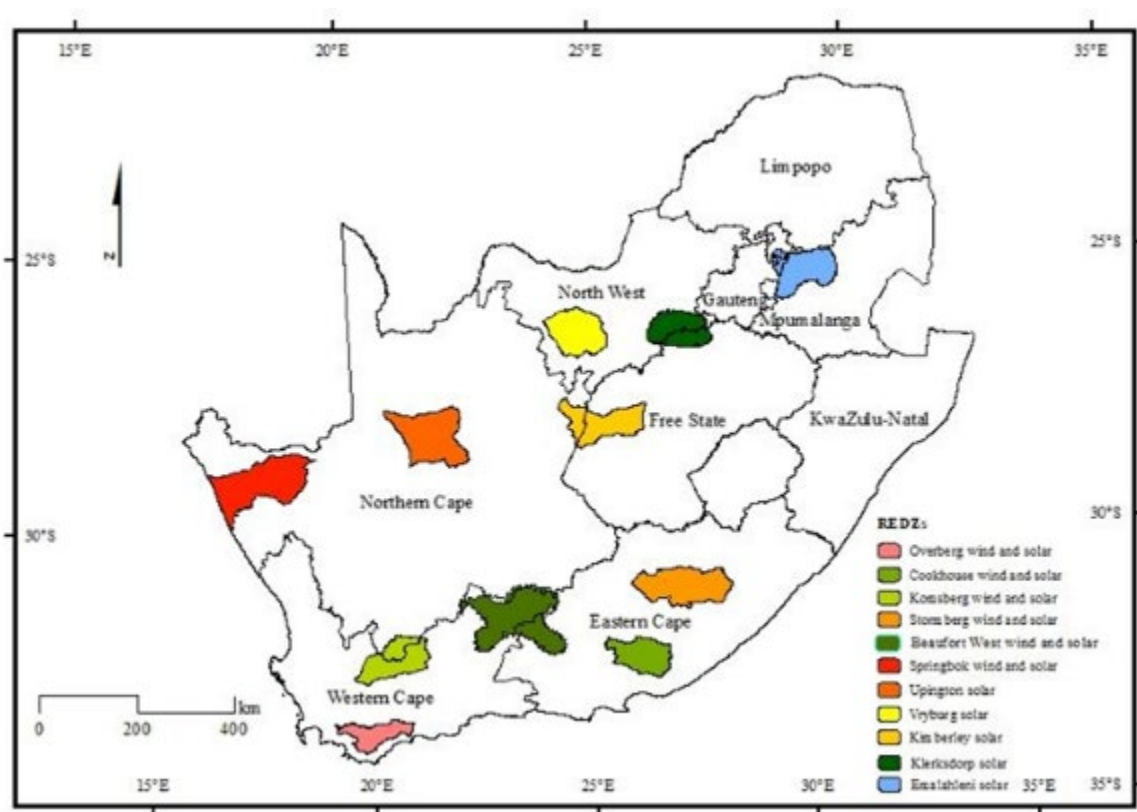


Figure 1: Phase 1 and 2 Renewable Energy Development Zones (Department of Environmental, Forestry, and Fisheries, 2020).

he locations of the REDZs were informed by Strategic Environmental Assessments that were conducted in a consultative fashion (Eberhard et al., 2014; Bischof-Niemez, 2015; Cape-Ducluzeau and van der Westhuizen, 2015). Spatial planning for solar and wind development also considered the siting of already confirmed Renewable Energy Independent Procurement

Programme (REIPPPP) selected preferred bidders. Factors used to identify REZs in South Africa are outlined in Table 1.

Table 1: Factors used for the identification of REDZs in South Africa (Eberhard et al., 2014; Bischof-Niemez, 2015; Cape-Ducluzeau and van der Westhuizen, 2015).

Pull Factors	<ul style="list-style-type: none"> ● Power transmission loss ● Municipalities with the potential ● Exceeding the social need for renewable energy development ● Proximity to existing power transmission lines and substations
Push Factors	<p>Discarding of sensitive areas such as:</p> <ul style="list-style-type: none"> ● Protected areas, ● Regions of known bird sensitivity ● Existing national facilities such as the Square Kilometre Array electromagnetic telescope project
Other Technical Factors	<ul style="list-style-type: none"> ● Proximity to major roads ● Slope ● Considering dolerites and hardrock formations as engineering risks ● Designated strategic coordination corridors for wind power

The aim of this paper evaluates the locations of the delineated REDZs using a suitability analysis conducted using Geographical Information Systems (GIS). This provides an independent assessment of how optimal the locations of the REDZs are from a technical perspective.

Materials and Methods

The Analytic Hierarchy Process (AHP) using GIS is used here to select suitable sites for solar and wind energy development in South Africa. GIS is a system of hardware, software and procedures to facilitate the management, manipulation, analysis, modelling, representation and display of georeferenced data to solve complex problems regarding planning and management of resources (Star and Estes, 1990). The AHP approach was introduced by Saaty (1990) and it has since been utilised by numerous researchers in varying fields to deal with complex problems (Charabi and Gastli, 2011). AHP is defined as a multi-criteria decision-making multi-objective approach that allows users to infer a rational agreement (Saaty, 1990). Suitability analysis aims at identifying the most appropriate spatial pattern for future land uses according to specific requirements, preferences, or predictors of some activity (Hopkins, 1977 and Collins et al., 2001). The selection of factors to consider in the siting of renewable energy developments was based on expert opinions in literature (Mierzwiak and Calka, 2017; Khemiri, Yaagoubi and Milky, 2018; Nebey et al., 2020; Sedrati et al., 2019).

Suitability Analysis for solar energy developments

Data acquisition and criteria selection for solar parks' suitability analysis

To determine the most suitable areas for solar farms, site selection criteria normally vary in different studies. The criteria include geographical, environmental, economic factors and climatology (Noorollahi et al. 2016). The suitability analysis for solar developments used 10 datasets, based on other studies that performed location suitability analysis for solar PV farms (Charabi and Gastli, 2011; Noorollahi et al. 2016). Table 2 outlines datasets used in the Identification of SOLAR REDZs in South Africa. The obtained data was reprojected to World Geodetic System 1984 Universal Transverse Mercator Zone 36 South (WGS84 UTM Zone 36S). Resampling was conducted on Land-use/Land-Cover and Global Solar Radiation datasets to ensure that all the data have the same resolution of 908 by 908 m.

Table 2: Datasets used in the Identification of SOLAR REDZs in South Africa.

Data	Spatial Resolution	Source
Global Solar Radiation (GHI)	250 by 250 m	Global Solar Atlas (2019)
Land use/Land Cover	20 by 20 m	Department of Environment, Forestry and Fisheries (2018)
Digital Elevation Model	908 by 908 m	Becker <i>et al.</i> (2009)
Existing Transmission Lines	Vector	South African Spatial Data Infrastructure (SASDI) (2015)
Planned Transmission Lines	Vector	South African Spatial Data Infrastructure (SASDI) (2015)
Roads	Vector	World Bank (2019)
Rivers	Vector	Department of Environment, Forestry and Fisheries (2019)
Dams	Vector	Department of environment, forestry and fisheries (2019)
Protected Areas	Vector	Department of Environment, Forestry and Fisheries (2019)
Derived Maps		
Residential Areas	908 by 908 m	Extracted from Land use/Land Cover
Slope	908 by 908 m	Derived from Digital Elevation Model

Global Horizontal Irradiance (GHI) is the most important factor in the evaluation of optimal locations to erect photovoltaic systems (Rodrigues et al. 2017) The obtained average solar irradiance is the average daily total GHI (kWh/m²) from 1994 to 2015 measured at 14 standard solar measuring stations. The power output of PV systems is normally higher in sunnier regions.

A solar PV system requires a minimum daily solar radiation of 3.56 kWh/m² (Noorollahi et al. 2016). The solar raster was reclassified into 4 classes (3.5 – 5 kWh/m²; 5 – 5.5 kWh/m²; 5.5 – 6 kWh/m²; > 6 kWh/m²) (refer to table 3) and the AHP approach was used to allocate weights according to their importance (Figure 2b).

Electricity transmission lines highly influence the siting of solar farms mainly because of the high costs associated with constructing power lines. Proximity to power transmission lines encourages safety, network security and quick accessibility for installing equipment and for potential repairs (Mierzwiak & Calka, 2017; Rodrigues et al. 2017 and Noorollahi et al, 2016). The study used both the planned and existing power lines to reduce the possibility of excluding suitable locations for PV installations. Euclidian distance was applied to rasterise the layer, and 5 different classes were created (0–5 km; 5–10 km; 10–15 km; 15–20 km; 20–50 km) (Ignizio, 2010) for further analysis (Figure 2a). Due to the extent of South Africa’s land area, this study extended the last class from 20 – 50 km to avoid eliminating suitable areas.

Table 3: Defined criteria and sub-criteria for suitable site selection for solar parks (adapted from Charabi and Gastli, 2011; Noorollahi et al. 2016).

Objectives	Criteria	Sub-criteria
Climatology	Solar radiation	3.5 – 5 km
		5 – 5.5 km
		5.5 – 6 km
		> 6 km
Location	Distance from power transmission lines	0 – 5 km
		5 – 10 km
		10 – 15 km
		15 – 20 km
		20 – 50 km
	Distance from the roads	0 – 5 km
		5 – 10 km
		10 – 20 km
		20 – 30 km
		30 – 50 km
	Distance from residential areas	2 – 10 km
		10 – 15 km
		15 – 20 km
		20 – 30 km
		30 – 45 km
	Slope	1 – 2 %
		2 – 3 %
		3 – 4 %
		4 – 11 %
	Land use	Barren land
Grassland		
Shrubland		
Mine and quarries		

It is economically reasonable positioning solar farms near the existing main roads than to construct roads for transportation of equipment as road construction is very expensive. The road

layer for South Africa was rasterized using Euclidean distance. The layer was then reclassified into 5 classes ranging from 0.1 – 50 km respectively (0–5 km; 5–10 km; 10–20 km; 20–30 km; 30–50 km) (Figure 2c).

Regarding distance from residential areas, various studies (Noorollahi et al., 2016; Mierzwiak & Calka, 2017; Rodrigues et al. 2017) consider the distance between residential areas and solar farms as an important factor due to the negative environmental impact of solar plants. Consequently, solar farms should not be established within 2 km of settlements, and 45 km is considered the farthest suitable distance from the residential areas (Noorollahi et al, 2016). The layer for residential areas was extracted from the land use/land-cover layer due to difficulties in obtaining the data. The layer was then vectorised and again rasterised using Euclidian distance to enable the calculation of distance. The residential areas layer was then reclassified into 5 classes (2 – 10km; 10 – 15km; 15– 20km; 20 – 30km; 30 – 45km) (Figure 2d).

Slope is also considered highly important in the suitability analysis for PVs. Surface with a slope greater than 4% are not prioritised since panels shadow the next row and adversely affect the system efficiency (Noorollahi et al, 2016). The slope was derived from the obtained DEM. The slope was derived from the obtained Digital Elevation Model using ArcMap tools and reclassified into 5 classes (< 1%; 1 – 2%; 2 – 3%; 3 – 4%; 4 – 11%) (Figure 2e).

Several land use classes are excluded for solar farm construction (built-up areas, cultivated lands, wetlands, waterbodies, and forested lands) and the remaining classes (barren land, grassland, mine, and quarries and shrubland) are considered suitable. Barren land is the most suitable among the considered classes because it constitutes a dry, bare land with very little vegetation (Figure 2).

Removal of unsuitable regions

The following regions in South Africa are considered unsuitable for solar PV installations and are removed from the analysis: locations with a daily solar radiation lower than 3.5 kWh/m²; those located more than 50 km away from the main roads; regions located less than 2 km or more than 45 km from residential areas; regions within 2 km of protected areas; areas with a slope greater than 11%; and various land use types (built-up areas, cultivated lands, wetlands, waterbodies, and forested lands)

Weight derivation for the criteria -Analytical Hierarchy Process (AHP)

Finding potential sites for solar farms poses an intricate decision-making problem because multiple criteria and alternatives need to be considered. Multi-criteria decision-making provides a detailed framework to survey, analyse, and solve such problems (Beinat & Nijkamp. 1998). The AHP method proposed by Saaty (1990) is one of the most thorough methods that has been considered for multi-Criteria Decision-Making. The AHP utilises a pair-wise comparison matrix, that accommodates judgment and computations. In addition, this method of multi-criteria decision-making points out the compatibility and incompatibility of decisions.

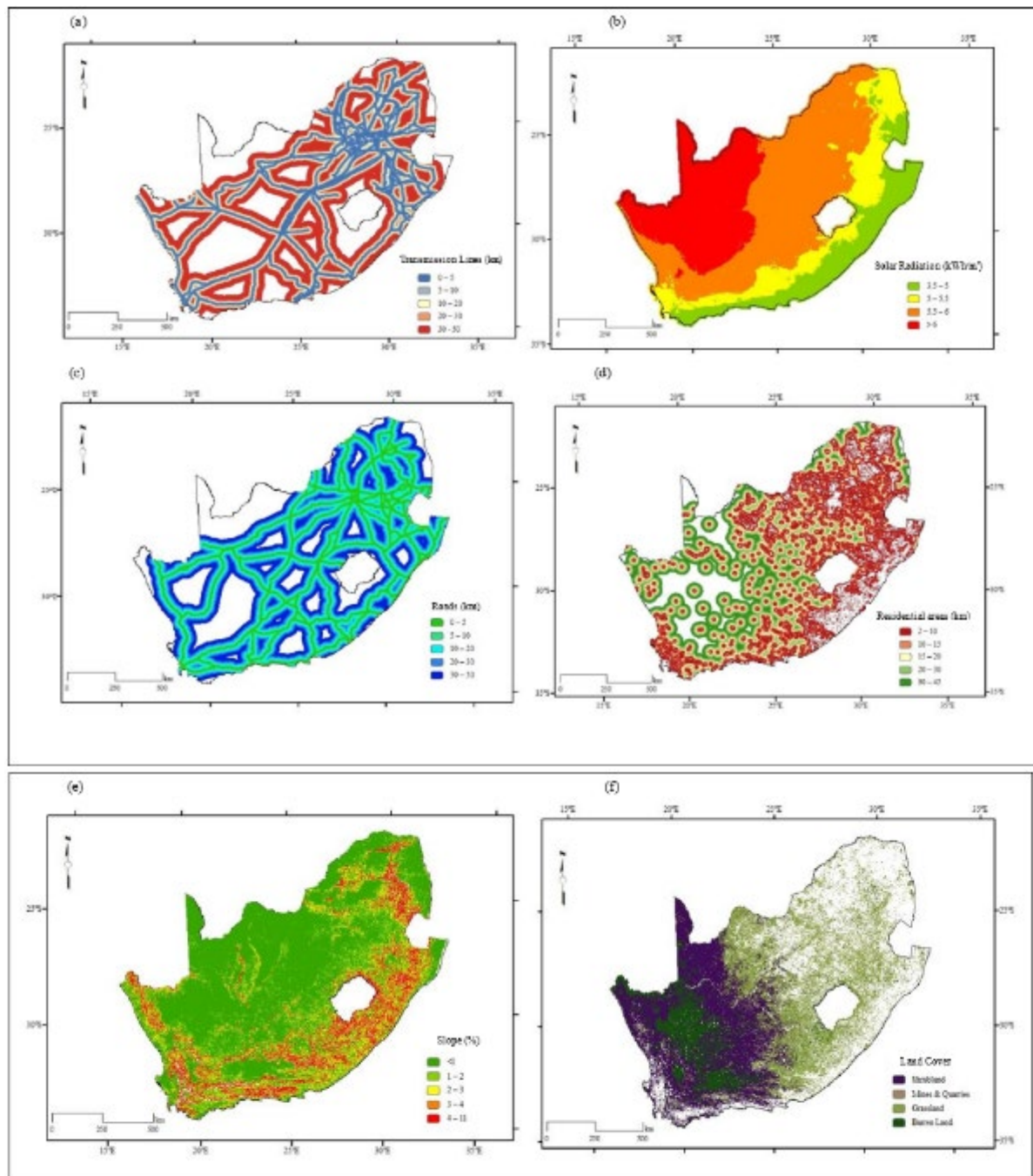


Figure 2: (a) Reclassified South Africa's power transmission lines layer (adapted from South African Spatial Data Infrastructure, 2015), (b) Reclassified South Africa's solar radiation layer (adapted from the World Bank, 2010), (c) Reclassified distance (0 – 50 km) from the roads (adapted from The World Bank, 2015), (d) Reclassified distance (2 – 50 km) from the residential areas (adapted from Department of Environment, Forestry and fisheries, 2018), (e) Reclassified slope layer from < 1 to 11 % distance (adapted from Becker et al. (2009) and (f) Suitable land use/land-cover classes for solar power development in South Africa (adapted from Department of Environment, Forestry and Fisheries, 2018).

The relative importance of siting criteria is assigned using a pairwise comparison matrix. The nine-point scale of importance was used here (Table 4). A pairwise comparison matrix was compiled using past studies to reduce bias (Mierzwiak & Calka, 2017; Khemiri, Yaagoubi & Milky, 2018; Nebey et al., 2020; Sedrati et al., 2019) (Table 5). Priority values on the error matrix were obtained by averaging values from the past studies. If adopted priority values

consistency ratios were exceeded, priority values were adjusted by adopting values from a single study.

Table 4: The nine-point scale for priority decision making (Saaty, 1990).

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one over another	Experience and judgment slightly
5	Essential or strong importance	Experience and judgment strongly
7	Extreme importance	favour one activity over another
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values	When compromise is needed

Table 5: Pairwise comparison matrix for site selection priority decision making (adapted from Mierzwik and Calka, 2017; Khemiri, Yaagoubi and Milky, 2018; Nebey et al., 2020; Sedrati et al., 2019).

Criteria	Solar radiation	PTL	Roads	Residential areas	Slope	Land use
Solar radiation	1	6	4	5	2	3
PTL	1/6	1	2	1	1/2	1/3
roads	1/4	1/2	1	1	1/3	1/3
Residential areas	1/4	1	1	1	1/2	1
Slope	1/2	2	3	2	1	3
Land-use	1/3	3	3	1	1/3	1

The pairwise comparison matrix was then normalised by summing up the values in each column and dividing each value in the column by the column total (Table 3). The normalised approach allows for the conversion of multiple criteria scales into comparable ones. The normalised values were calculated from the pairwise comparison matrix as Equation 1

$$N = \frac{\sum_j^f}{c} \quad [1]$$

where, N is the normalised value, j is the column of the matrix and c the values of the decision.

Table 3: The normalised pairwise comparison matrix for site selection priority decision-making.

Criteria	Solar radiation	PTL	Roads	Residential areas	Slope	Land use
Solar radiation	0.40	0.44	0.27	0.43	0.43	0.35
Transmission lines	0.07	0.07	0.15	0.10	0.11	0.04
roads	0.10	0.04	0.07	0.12	0.07	0.04

Criteria	Solar radiation	PTL	Roads	Residential areas	Slope	Land use
Residential areas	0.10	0.07	0.07	0.09	0.11	0.12
Slope	0.20	0.15	0.24	0.18	0.21	0.35
Land use	0.13	0.22	0.21	0.09	0.07	0.12

After determining the normalised pairwise comparison matrix, the matrix was analysed for eigenvectors and λ_{max} . The eigenvector was calculated by multiplying together the entries in each row of the matrix and then taking the n th root of that product, which gives a very good approximation of the correct answer. The n th roots are summed, and that sum is used to normalize the eigenvector elements to add up to 1.00. In Table 4, the 4th root for the first row is 2,99 and that is divided by 7,53 to give 0.40 as the first element in the eigenvector. The eigenvector of the relative importance or value of solar radiation, power transmission lines, roads, residential areas, slope, and land use is 0.40, 0.08, 0.07, 0.09, 0.22 and 0.13. Thus, solar radiation is the most important criterion, slope and land use are the 2nd and 3rd most important respectively, and roads are less significant than the rest.

Table 4: Eigenvector and lambda max of the priority values.

Criteria	n th root of products of values	Eigenvector	λ_{max}
Solar radiation	2.99	0,40	6,27
Transmission lines	0.64	0,08	6,61
roads	0.52	0,07	6,68
Residential areas	0.71	0,09	6,29
Slope	1.67	0,22	6,42
Land use	1.00	0,13	6,73
Mean			6.50

The next stage is to calculate λ_{max} so as to obtain the Consistency Index and the Consistency Ratio. The paper first multiplies on the right the matrix of the judgments by the eigenvector, obtaining a new vector. The constants are obtained from the pairwise comparison matrix (Table 2). The calculation for the first row in the pairwise comparison matrix (Table 2) is Equation 2.

$$1 \times 0.40 + 6 \times 0.08 + 4 \times 0.07 + 5 \times 0.09 + 2 \times 0.22 + 3 \times 0.14 = 2.49 \quad [2]$$

The remaining five rows give 0.65, 0.46, 0.59, 1.42, 0.89. These 6 vector elements are used to get the 6 estimates of λ_{max} by dividing each component of (0.40, 0.65, 0.46, 0.59, 1.42, 0.89) by the corresponding eigenvector element. This gives $2.49/0.40 = 6.27$ together with 6.61, 6.68, 6.29, 6.42 and 6.73. The mean of these values is 6.50 and that is the estimate for λ_{max} . If any of the estimates for λ_{max} turns out to be less than n , or 6 in this case, there has been an error in the calculation, which is a useful quality check.

The consistency of the results is important for the provision of more accurately represented judgements (Sedrati et al., 2019). The consistency of results at each step and for the opinion on the pairwise matrix was calculated by the Consistency Index (CI), which must be less than 1.

If there were inconsistencies, the conflicting part of the process, which is the priority of intensity for each criterion, was amended. The priorities were amended numerous times to adjust the consistency index until it amounted to 0.08. The final CI indicated that the judgement on the criteria is considered consistent, therefore the analysis can proceed. Consistency index (CI) and consistency ratio (CR) can be calculated as Equation 3 and Equation 4.

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad [3]$$

where, " λ_{max} " is the mean value of the obtained lambda max of the criteria, n is the size of the matrix.

$$CR = \frac{CI}{RI} \quad [4]$$

where CI is the consistency index, RI is the random index. RI values considered are those determined by Saaty and Tran (2007) (Table 5). The n in this study is 6, so RI used is 1.25.

Table 5: Random index (RI) values for different matrix sizes (Saaty and Tran, 2007)

Size of the matrix	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

The consistency ratio was calculated (0,08) and the weights assigned were proved to be stable. Weights were then multiplied by 100 so that they could sum up to 100, as the weighted overlay tool in GIS requires the weights to equal that value. Considering the criteria weights based on the AHP model and using the obtained GIS data, ArcMap ESRI software was utilised to overlay the data, and ultimately the locations for siting solar farms were created.

Data integration

The selected classified suitable areas for solar radiation (section 2.1.1), distance from the power transmission lines, major roads, and residential areas were assigned weights of 40%, 8%, 7%, 9%, 22%, and 13% based on their relative importance on accommodating solar parks (Table 6) and overlaid using a Simple Additive Weighting (SAW). The final map was then categorised into four suitable classes: poor (areas below standard to locate solar PV plants), fair (areas with average capabilities to locate solar PV plants), good (standard areas to locate solar PV plants), and excellent (areas that are above standard to locate solar PV plants).

Table 6: The relative importance of criteria for the siting of solar PV developments.

Classified criteria	Weight (%)
Solar radiation	40
Distance from power transmission lines	8
Distance from major roads	7
Distance from residential areas	9
Slope	22
Land use	13

Suitability Analysis for wind energy developments

Data acquisition and criteria selection for wind farms' suitability analysis

Eight factors derived from eight datasets were used for the wind farm suitability analysis. The datasets include wind speed, existing and planned power transmission lines, major roads, dams and rivers, protected areas and a digital elevation model (DEM). The DEM was used to derive elevation and slope as conducted in previous sections. This section used the same data used in the previous section except for wind resource data which was acquired from the World Bank (2019) at 200 m by 200 m resolution. The DEM obtained had the resolution of 908 m by 908 m and LU/LC of 20 m by 20 m. Resampling the obtained data to the resolution of 908 m by 908 m was important to enable further analysis at a later stage such as overlay. The paper also ensured that the data which were in vector format were transformed to 908 m resolution when rasterised. The data were reprojected to World Geodetic System 1984 Universal Transverse Mercator Zone 36 South (WGS84 UTM Zone 36S). The source of the listed dataset is explained in detail in the solar park suitability analysis except for wind speed (Figure 2) which was obtained from the World Bank (2019) at 200m resolution.

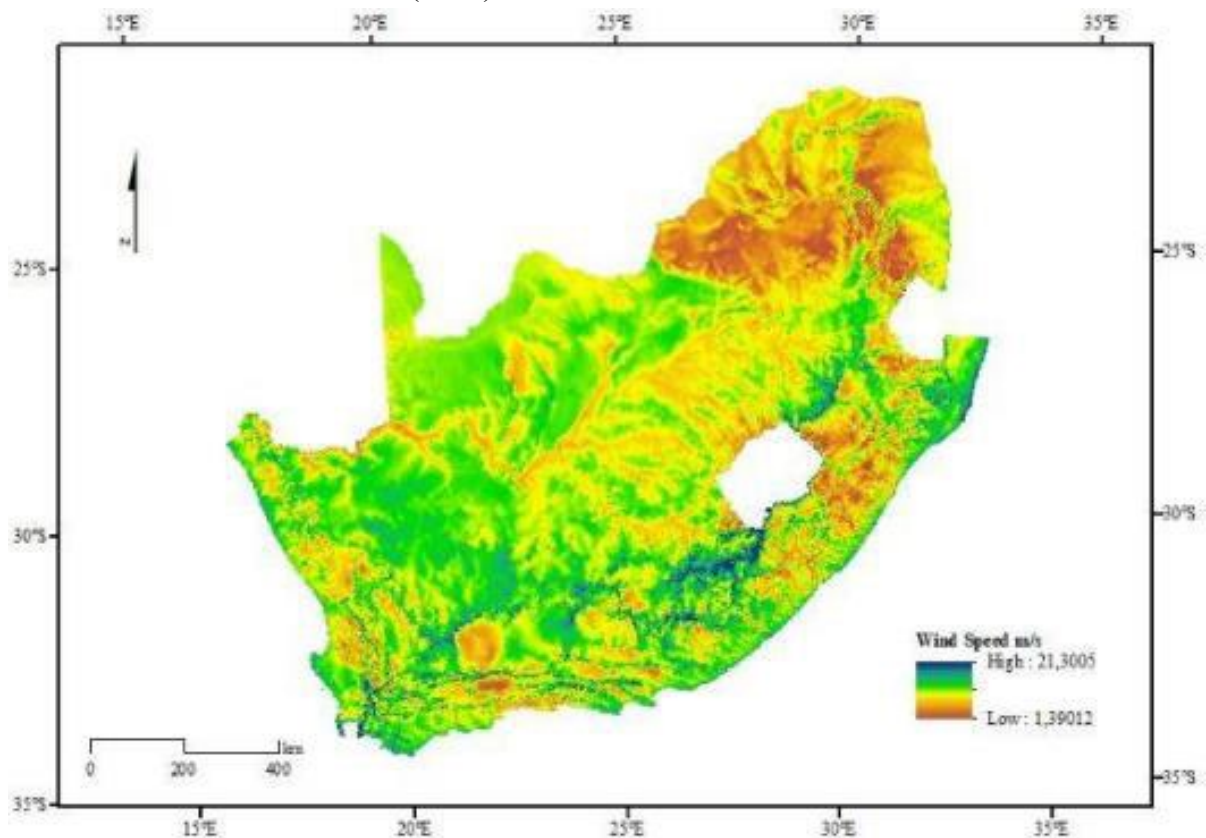


Figure 3: Wind energy resources in South Africa (World Bank, 2019).

The suitability criteria for siting wind farms are categorised into three major groups: geographical factors (elevation and slope), environmental factors (distance from residential areas, major roads, power transmission lines, distance from protected areas and water bodies), and techno-economic factors (wind speed, distance from major roads and power transmission lines). The selected suitable areas for wind speed, distance from the power transmission lines

and major roads were classified and assigned rating (Table 7) obtained from Noorolahhi et al. (2016). Only three factors were selected for weight allocation because high wind speed and areas in closer to major roads and transmission lines are considered the most convenient for wind farms (Noorolahhi et al. (2016).

Table 7: Data layers, sub-classes, and their assigned weight (Noorolahhi et al. 2016).

Category	Data layer	Criterion (subclass)
Techno-economic	Wind speed	< 5.6 m/s
		5.6 – 6.4 m/s
		6.4 – 6.9 m/s
		6.9 – 7.5 m/s
		7.5 – 9.5 m/s
		> 9.5 m/s
	Power Transmission Line	< 250 m
		250 – 2000 m
		2000 – 4000 m
		4000 – 6000 m
		6000 – 8000 m
		8000 – 10,000 m
	Main Roads	<500 m
		500 – 2000 m
		2000 – 4000 m
		4000 – 6000 m
		6000 – 8000 m
		8000 – 10,000 m
>10,000 m		

Table 8 outlines suitability criteria for wind energy development potential (adapted from Noorolahhi et al. 2016). Wind farms must not be in an area with an elevation greater than 2000m or areas with a gradient of >11% (Mostafaeipour, 2010). The following regions in South Africa are also considered to be unsuitable for wind farms: areas within 2000 m of residential areas, < 500 m and > 50 km from the main roads, < 250 m and > 50 km from power transmission lines, < 500 m from waterbodies, and < 2000 m from protected areas (Noorolahhi et al. 2016 and Satkin et al. 2014).

Table 8: Unsuitability criteria for wind energy development potential (adapted from Noorolahhi et al. 2016).

Data	Unsuitable areas excluded
Slope	Areas with a slope of >15%
Elevation	Areas with an elevation of >2000 m
Residential area	Areas in distance to cities < 2000 m
Major roads	Areas < 500 m & > 50 km
Power transmission Lines	Areas < 250 m & > 50 km
Waterbodies	Areas < 500 m

Data	Unsuitable areas excluded
Protected area	Areas < 2000 m
Wind speed	< 5.6 m/s

The study uses two different methods: the restrictive method to eliminate unsuitable areas and the classification method applied to three factors (wind speed, major roads, and transmission lines) for rating allocation according to the area's importance for siting wind farms.

Restrictive and integration method

The restrictive model utilises Boolean logic to produce a map that shows false conditions (unsuitable regions) as 0 and true conditions (suitable regions) as any value other than 0 (Noorolahhi et al. 2016) (Figure 4). Previous studies that conducted suitability analyses (Mostafaeipour, 2009; Yousefi, 2010; Satkin et al. 2014; Noorolahhi et al. 2016) evaluated the importance of each siting factor and suggested specific data layers. Starting with the geographical data layers, the DEM was utilised to derive the slope map, which was then reclassified into 2 classes: gradient <15% and >15%. The DEM was furthermore utilised to derive elevation since air density decreases with increasing elevation (Noorolahhi et al. 2016). Only regions with an elevation of 2000 m or less were considered suitable.

Unsuitable areas were removed using the defined environmental and geographical restrictions. The Euclidian distance was applied, and the underlying layers were reclassified to define the suitable and unsuitable areas. All the regions that fall within the defined boundaries (e.g. 0–2000m from residential areas) are locations that are not suitable for wind farms and classified as 0 according to Boolean logic. Regions located outside the defined restricted areas (e.g. > 2000 m from residential areas) are the areas suitable for wind farms, therefore classified as 1 according to Boolean logic. The restrictive layers from the 6 predefined factors were then overlain in GIS using the intersect tool.

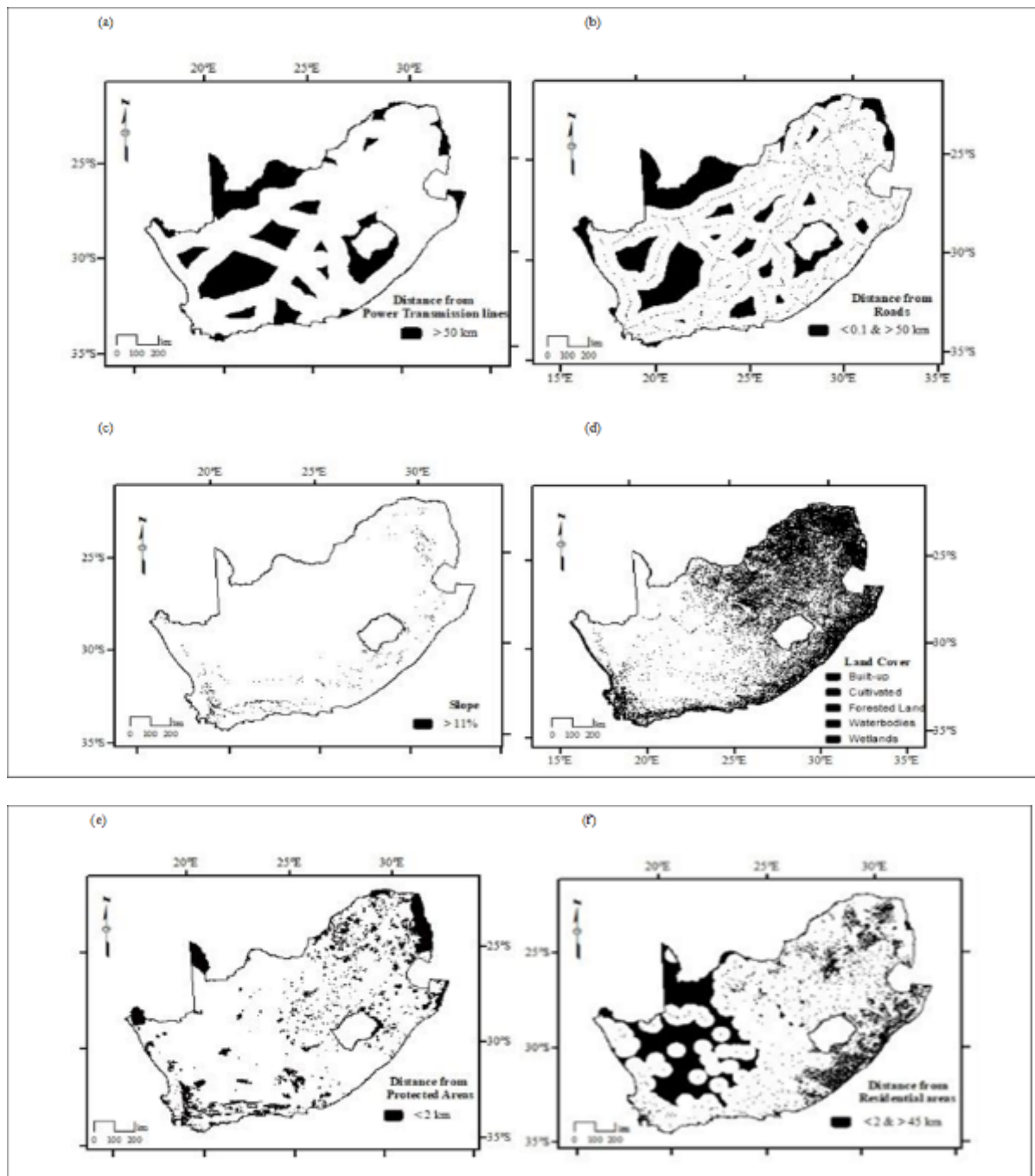


Figure 4: Defined criteria and sub-criteria for suitable site selection for solar parks (adapted from Charabi and Gastli, 2011; Noorollahi et al. 2016).

Classification method

The remaining suitable areas were classified in terms of wind speed, distance from the power transmission lines and major roads, and assigned a rating (Table 8) obtained from Noorollahi et al. (2016). Only three factors were selected for weight allocation because high wind speed and areas in closer to major roads and transmission lines are considered the most convenient for wind farms (Noorollahi et al. 2016). The main objective of conducting this analysis is to classify areas into varying classes based on the suitable locations of the wind farms. Every class of each criterion was assigned weights based on their relative importance in accommodating

wind farms. The classified suitability maps were then overlaid using Simple Additive Weighting (SAW) to categorise wind farm suitability. In the process, the classified maps for the wind speed, distance to power transmission and the distance to the main roads were given 45%, 25% and 30% weight influence (Noorolahhi et al., 2016), respectively. Equation 5 was utilised to integrate the subclasses.

$$s = \frac{\sum w_i s_{ij}}{\sum w_i} \quad [5]$$

where w_i is the weight of i th criterion, s_{ij} is the i th spatial class weight of the j th criterion and s is the classifying suitability value in the output map.

Table 8: Data layers, sub-classes, and their assigned score for wind energy development suitability analysis (Noorolahhi et al. 2016).

Score	Wind speed	Power transmission lines	Main roads
0	< 5.6 m/s	< 250 m	<500 m
1		> 10 000 m	
2	5.6 – 6.4 m/s		>10 000 m
3		8000 – 10 000 m	
4	6.4 – 6.9 m/s		8000 – 10 000 m
5		6000 – 8000 m	
6	6.9 – 7.5 m/s		6000 – 8000 m
7		4000 – 6000 m	
8	7.5 – 9.5 m/s		4000 – 6000 m
9		2000 – 4000 m	2000 – 4000 m
10	> 9.5 m/s	250 – 2000 m	500 – 2000 m

The maps categorized in terms of wind speed, distance from power lines and distance from roads were overlain with the unsuitable areas using the intersection method. Areas suitable for wind energy development were classified into five classes: poor, fair, good, very good and excellent.

Finally, the REDZs boundaries for phases 1 and 2 (Department of Environment, Forestry and Fisheries, 2019) were overlain with the suitability maps for solar and wind energy development, to evaluate how well sited the REDZs are from a technical perspective.

Results

Suitability of solar PV-designated REDZs

Of South Africa's 1 220 813 km² land area, 36% (444 869 km², an area almost equal to the size of Northern Cape and KwaZulu-Natal combined) is suitable for solar energy installations. Of the total suitable area, areas of 'good' suitability comprise a dominant 63% (278 726 km²), followed by excellent regions (22%; 95 799 km²), fair regions (15%; 67 642 km²) and poor regions (1%; 2701 km²) (Figure 5). Suitability for solar farms decreases from the west to the east of the country, with coastal areas being less suitable (Figure 5). This is due to low solar

radiation received because of cloud cover, and semi-arid regions in the north-west of the country receiving the highest solar radiation.

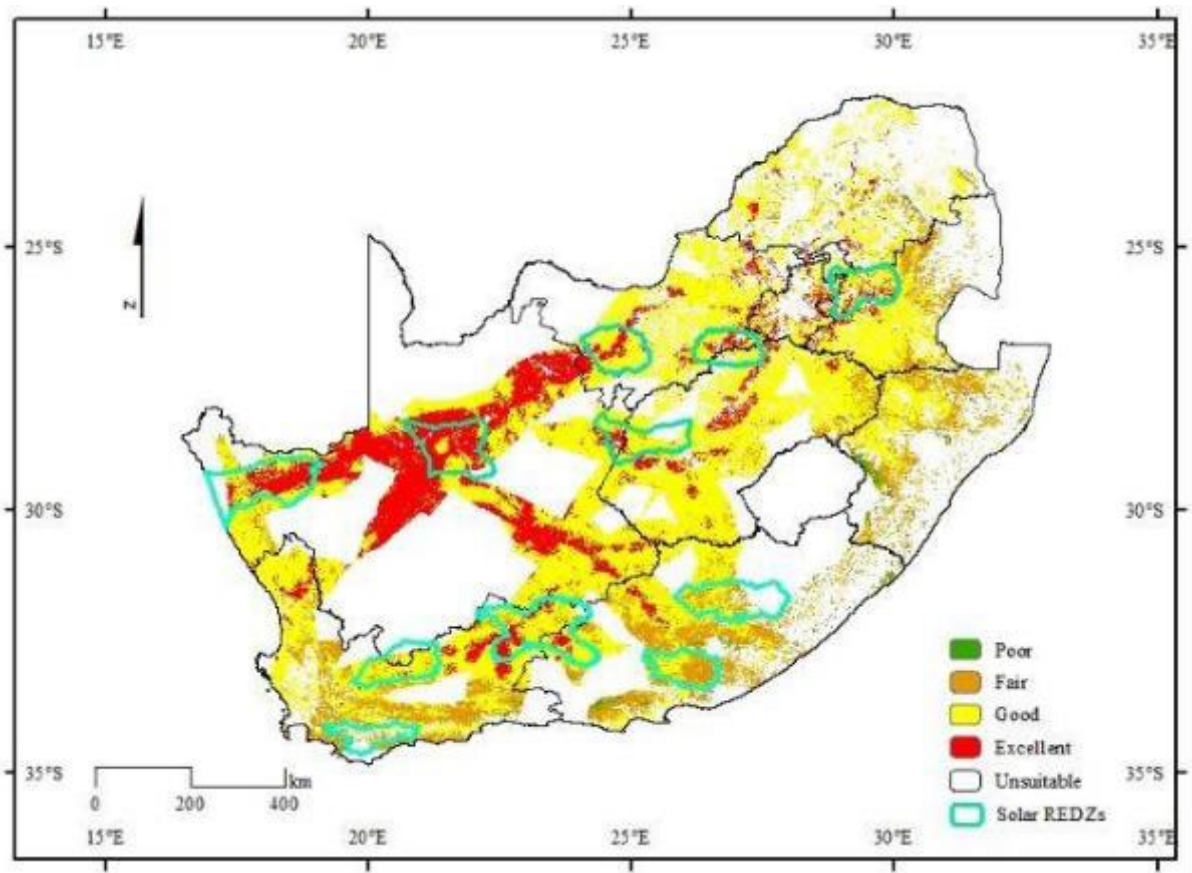


Figure 5: Solar PV-designated REDZs superimposed on suitable areas for locating solar energy developments in South Africa.

The eleven solar PV-designated REDZs cover 115 028 km². Of this, 77 063 km² is suitable for solar energy development. The REDZs located in the Northern Cape province, Upington REDZ and Springbok REDZ, have the highest excellent suitable areas, 8 185 km² and 6 653 km² respectively (Figure 6). The Beaufort West REDZ also has many excellent areas (3 721 km²) for building solar facilities. Over half of Stormberg (6 657 km²), eMalahleni (5 697 km²), Overberg (4 309 km²) and Klerksdorp (4 308 km²) REDZs are unsuitable for solar power development. Overberg and Cookhouse REDZs have no excellent areas to develop solar power.

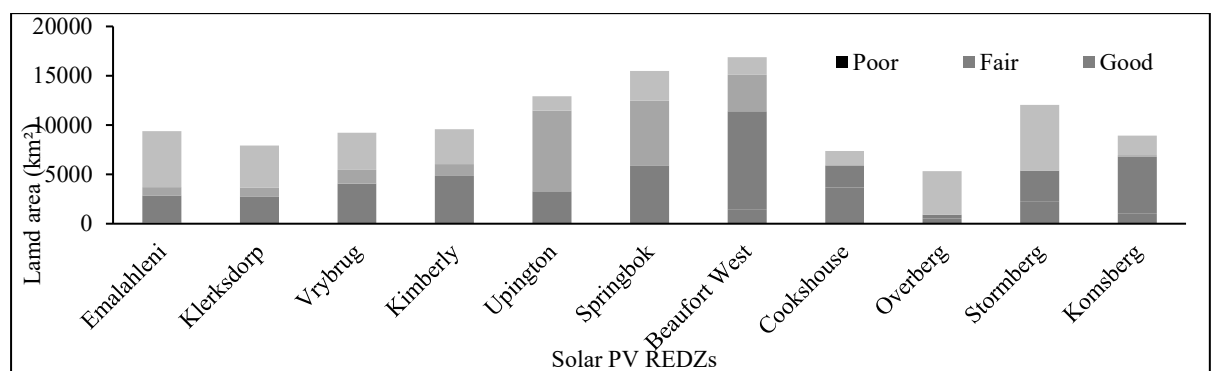


Figure 6: The suitability of land within in the solar-designated Renewable Energy Development Zones for solar energy development.

Suitability of wind designated REDZs

57% (690 876 km²) of South Africa's land area is suitable for wind farms. The southern and the northeast coastal areas of the country, the eastern Free State escarpment and high-lying areas in the Eastern Cape are most feasible for the development of wind farms (Figure 7). A dominant 43% (331 729 km²) of South Africa's land area is modelled as very good for wind development, suggesting multiple sites with high suitability score which signifies the extensive potential for developing wind farms in well-resourced and logistically feasible regions. Areas classified as good for wind farm investment comprise a good share of 22% (153 759 km²). Fair and poorly suitable lands constitute 14 % (97 076 km²) and 13% (90 643 km²) of South Africa's land area, respectively. Land areas of excellent suitability comprises a minor share of 3% (17 669 km²).

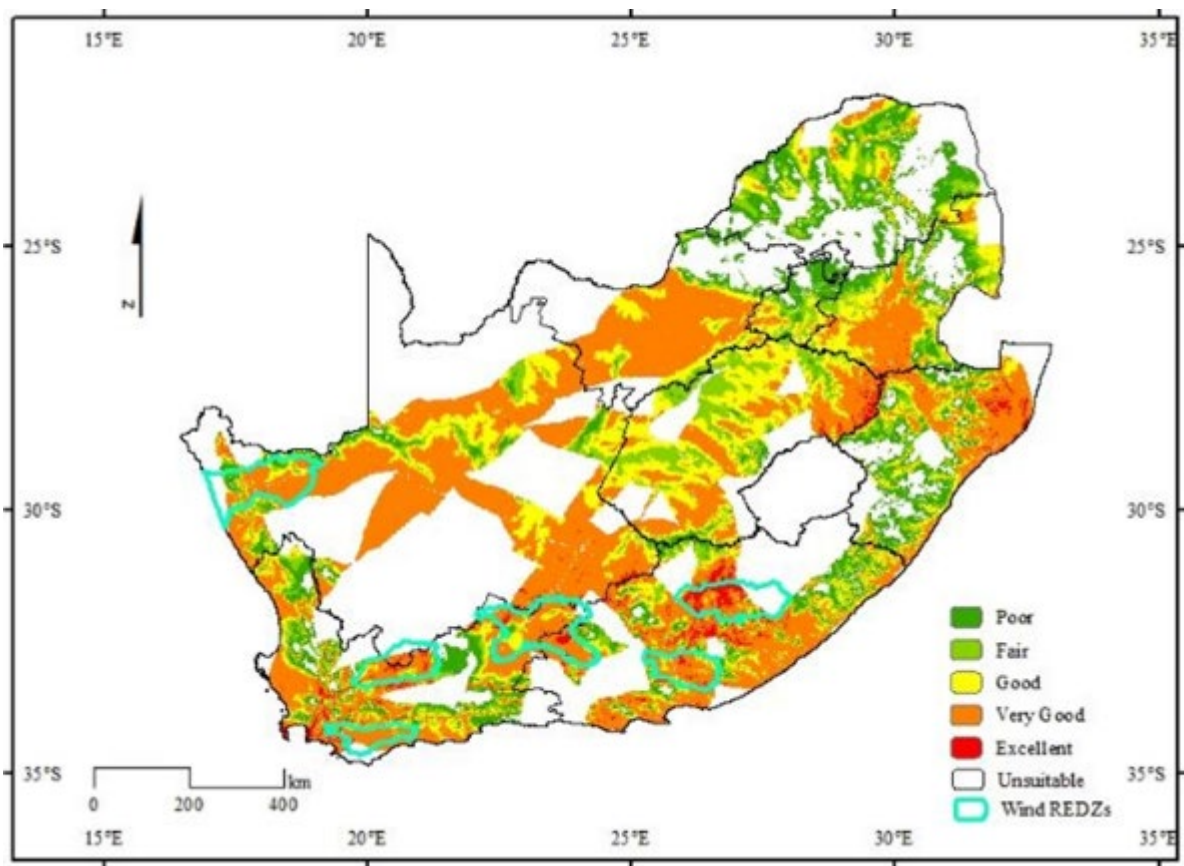


Figure 7: Wind-designated REDZs superimposed on suitable areas for locating wind energy developments in South Africa.

The six designated REDZs for wind power have a total land area for 66 006 km², of which 52 306 km² (79%) is suitable and 13 700 km² (21%) not suitable for wind power development. Beaufort West REDZ has the highest excellent (962 km²) and very good (11 006 km²) land area for wind power development. Springbok follows with 8 059 km² of very good land area; however, it has the lowest excellent area (23 km²) for wind power development (Figure 8). All the wind designated REDZs have a large area of land that is good for wind development. Stormberg REDZ has a large excellent area (2 964 km²) and very good (3 804 km²) land area for wind facilities, followed by Komsberg REDZ (excellent: 656 km² and very good: 4 389 km²) and Cookhouse REDZ with 395 km² and 4 944 km² of excellent and very good land area

for developing wind facilities respectively. Overberg REDZ is also well located with 97 km² of excellent area and 3 707 km² of very good area for wind power development. Unsuitable area for wind power within wind REDZs ranges between 4 374 km² and 565 km², which is insignificant compared to the amount of total suitable area.

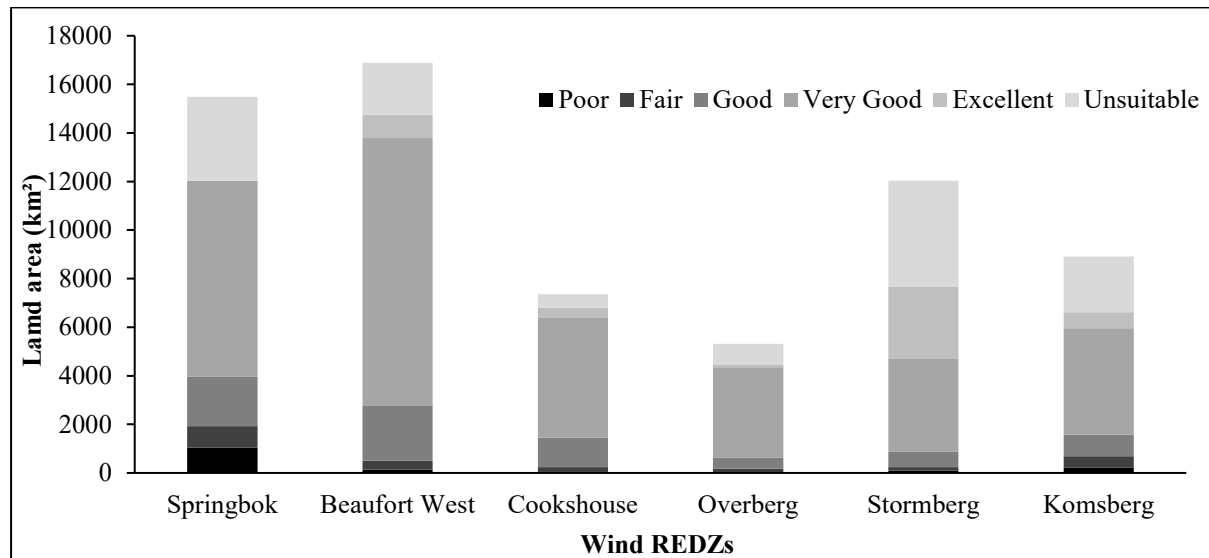


Figure 8: The suitability of land within in the wind-designated Renewable Energy Development Zones for wind energy development.

Conclusions

South Africa, as a developing nation with a need to have renewable energy as a major power provider, needs to conduct a rigorous spatial planning to identify the best regions to develop solar and wind power in the country. Criteria to prioritise sites for renewable energy development differ from study to study; however, a practical approach should be taken which considers technical, environmental, geographical as well as the economic criteria to identify best regions using GIS and any effective MCDM approach (AHP or fuzzy AHP).

This study has evaluated the suitability of the eleven REDZs in South Africa from a resource and technical perspective and identified REDZs and regions within the REDZs that should be prioritised when developing solar and wind energy facilities. The REDZs are well sited in general, are balance technical and resource considerations with social and economic considerations. 67% of the land in the solar REDZs is suitable for solar energy development, while 79% of the land in the wind REDZs is suitable for wind energy development. Upington, Springbok and Beaufort West REDZs are most suitable for solar energy development, while Beaufort West and Springbok REDZs are most suitable for wind energy development.

A total of 22 973 km² within the solar REDZs can be prioritised for developing solar PV plants in the future and a total area of 41 005 km² of very good and excellent areas within the wind REDZs can be prioritised for wind facilities. There are fragments of excellent, very good and good areas within the REDZs to be used in the development of solar and wind development. The boundaries of the REDZs may be misleading to project developers who would solely rely on the designated REDZs for siting solar or wind power plants because according to the

conducted spatial analysis with only several criteria defined, a total of 37 965 km² and 13 700 km² land area within solar REDZs and wind REDZs, respectively, is unsuitable for siting solar and wind facilities.

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The physiognomy of soil detachability on the Soutpansberg Range, South Africa

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Abstract

Soil is a vital part of ecosystems and earth system functions that support the delivery of primary ecosystem services. Therefore, soil conservation is of paramount importance to all life forms. As such, soil erosion becomes a serious ecological and environmental challenge that calls for scientific scrutiny. Soil erosion is a threat to agricultural production and food security. Hence, controlling the erosion process is one way of containing the challenge. Consequently, soil detachability forms part of the backbone of soil erosion modelling for erosion control and management. The objective of this paper is to analyse spatial characteristics of soil detachment susceptibility on the Soutpansberg range using Geographic Information System. Such analysis is important for erosion control and management. The analysis considers both inherent and external factors as adapted from the Universal Soil Loss Equation. The inherent factor is the erodibility. The external factors are slope, hydrography, geology, and land-use-land-cover. All factors were classified into five categories of contribution towards reduction of soil detachment susceptibility. One indicates very low while five indicates very high contribution and erodibility. The classes are determined using either Jenks natural breaks or expert classification. The factors were subjected to online pairwise Multi-Criteria Evaluation using the Analytic Hierarchy Process before applying the weighted sum overlay. Results show that places composed of natural forests, hard rocks and few hydrographical features have the least susceptibility. Low lying areas dominated by hydrographical features, cultivation and soft rocks are more susceptible. This reinforces the interplay of multiple factors in the determination of soil erodibility. Hydrographical features promote water accumulation, hence high erodibility. Natural forests provide organic matter that bind soil particles together and reduce erodibility. It is concluded that such findings indicate the necessity of multidisciplinary approaches to soil erosion issues. A silo approach to the issue produces piecemeal solutions that would not promote sustainable soil conservation.

Keywords: erosion, soil; erodibility; Soutpansberg; detachment; GIS

Introduction

Soil is a vital part of ecosystems and earth system functions that support the delivery of primary ecosystem services (Borrelli et al., 2017; Caon & Vargas, 2017; Le Roux & Smith, 2014). All life forms depend on soil health. Therefore, soil degradation is one of the severe environmental problems that can cause ecological collapse ((Food and Agricultural Organisation & Intergovernmental Technical Panel on Soils) FAO & ITPS, 2015; Fu et al., 2019; Global Soil Partnership, 2016; Le Roux & Smith, 2014; Marzen, 2017; Marzen et al., 2015; Ritter, 2012;

Xanthakis & Pavlopoulos, 2009). Erosion has rendered about 30% of the world's cropland unproductive over the past 40 years (FAO & ITPS, 2015). It reduces land productivity and soil fertility, exacerbates flood disasters which affect land uses as well as the protection and utilization of soil and water resources (Fu et al., 2019). More than 70% of South Africa's land surface is affected by water erosion (Garland et al., 1999). Hence, soil erosion remains an area of keen interest for researchers.

Soil erosion is a natural geomorphic surface process that removes soil particles and regolith from their primary location on the Earth's crust and transports them to another location (Encyclopedia Britannica, 2019; Zorn & Komac, 2013). Soil erosion remains a global challenge in both human and natural environments. It persists to be a critical and widespread problem in many developing countries, posing serious ecological and environmental challenges (Borrelli et al., 2017; FAO & ITPS, 2015; Le Roux & Smith, 2014; Marzen et al., 2015; Xanthakis & Pavlopoulos, 2009). It is a significant issue because soil formation is a slow natural process and soil is a non-renewable resource (Le Roux & Smith, 2014; Ritter, 2012; Zorn & Komac, 2013). Soil erosion is a serious environmental, economic, and social challenge. Therefore, soil erosion research has been growing in scope, depth, and scientific rigor since the mid-20th Century. Hence, many research publications on the subject are available. However, it is not in dispute that as a natural process, soil erosion is complex. Hence there is need for improved understanding of natural soil erosion processes. That sets the broad aim of this paper.

The approach of this paper is to use Geographic Information System (GIS) to analyse the spatial characteristics of soil detachability on the Soutpansberg Range of South Africa. The analysis is a contribution to sustainable and effective soil conservation efforts. This is because soil detachability is a function of particle size distribution, soil structure, organic matter content and permeability (Breetzke, 2004; Kusumandari, 2014; O'geen, 2006; Stocking et al., 1988; Wischmeier & Smith, 1958). To these variables can be added the effect of land uses, geology, slope and hydrographical factors. Therefore, an analysis of the interplay of these factors in determining soil particle detachment equips soil management practitioners with relevant knowledge important for soil conservation planning.

The use of GIS in the analysis of factors affecting soil erodibility is the foundation on which erosion control and management is built and is used because of its capabilities to combine the factors according to their relative contribution to soil detachability. The GIS weighted sum overlay tool is employed for this purpose.

The factors that play a controlling role in soil erosion include rainfall erosivity (R), land use (C), soil erodibility (K), slope length and steepness (LS), and conservation practices (P) (Chakela & Stocking, 1988; Irvem et al., 2007; Wischmeier & Smith, 1958). However, soil erosion is principally determined by erosivity and erodibility (detachability) (Kinnell, 2010; Renard et al., 1997). This paper focuses on soil detachability because it plays a significant role in determining sediment movement (Kusumandari, 2014; Uzun et al., 2017). It represents how a soil reacts to erosion drivers, principally water.

How a soil reacts to erosivity depends on its intrinsic characteristics as well as extrinsic factors. This takes into cognisance that erosional processes begin at soil detachment and transport by raindrop impact and surface flow, followed by deposition due to topography and land-use-land cover characteristics, and rainwater infiltration into the soil profile (Choi, 2002; Kinnell, 2005; Ritter, 2012). The nature and properties of the soil determine soil particle detachment and transportation (Choi, 2002; Kinnell, 2005; Kusumandari, 2014; Ritter, 2012). This is the simplification of the erosion process that this paper attempts to make. The simplification is presented in the following sections of the paper. This section is followed by a materials and

methods. Results and discussion follow before the paper concludes and offers recommendations.

Materials and Methods

Study Area

The Soutpansberg, formerly Zoutpansberg, means "Salt Pan Mountain" in Afrikaans. The mountain range was formed some 1800 million years ago by an east-west trending asymmetrical rift or half-graben along the Palala Shear Belt (Berger et al., 2003). It is a prominent quartzite mountain range in the northern part of South Africa, Limpopo Province in Vhembe District. Figure 1 shows that the Soutpansberg stretches for approximately 210 km from Kruger National Park's Punda Maria gate in the east to Vivo in the west. The eastern end of the range is close to the Zimbabwe-Mozambique-South Africa border. The highest peak is on its western side, reaching an elevation of 1 748 m.a.s.l. The widest part is a 60 km wide north-south axis while the narrowest is 15 km (Berger et al., 2003).

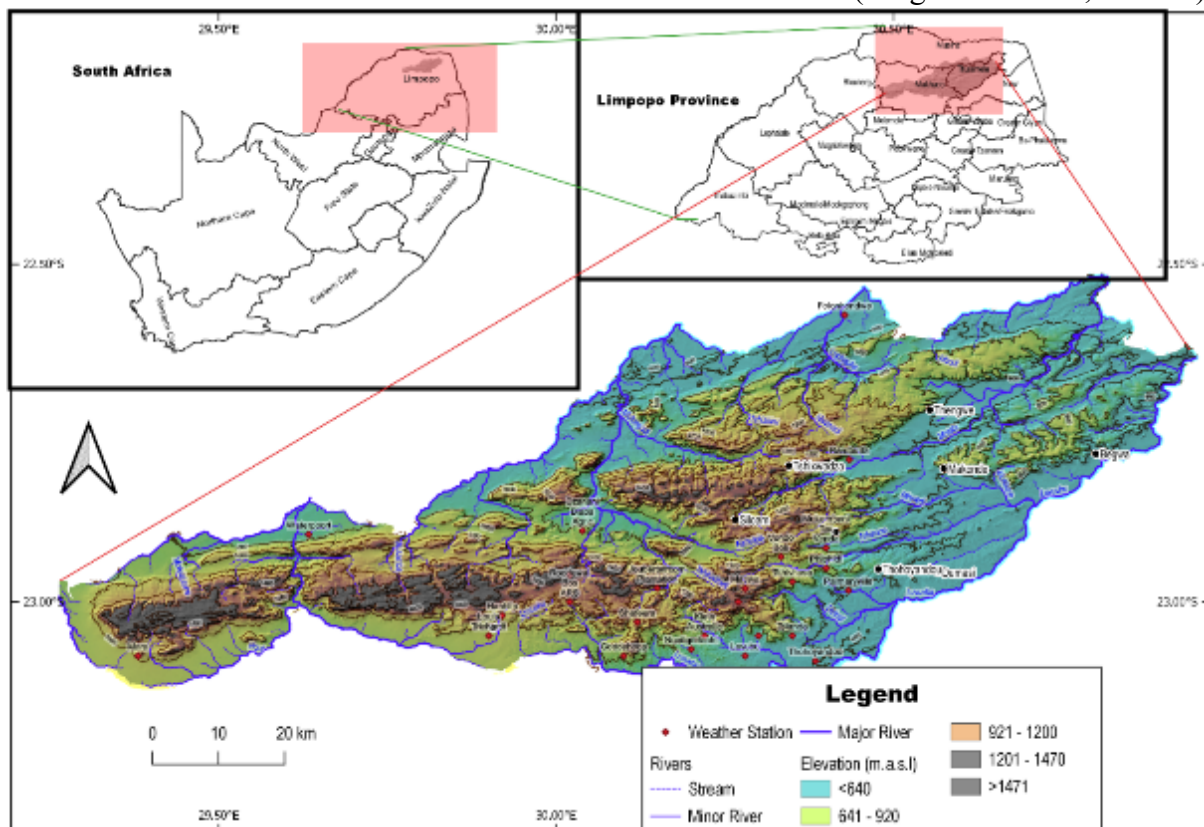


Figure 1: Location Soutpansberg Range in South Africa and Vhembe District (DEM Source: National Geo-Spatial Information, 2016).

The mountain range forms a geological unit with the Makgabeng Plateau and Blouberg Mountain to the west of Vivo (Berger et al., 2003). The Soutpansberg rocks rest on gneisses of the Limpopo Belt and Bandelierkop Complex. Along the eastern and most of the northern margin the Soutpansberg outcrops are tectonically aligned against rocks of the Karoo Super group (Brandl, 2003). The range has the best exposed Rift Sequence in South Africa. The Soutpansberg Group rocks are the most intensively block-faulted sequence in the country (Berger et al., 2003). The 3–4 km thick Basalt unit at the base of the Soutpansberg Group is the thickest uninterrupted volcanic sequence in South Africa.

The mountain range has fourteen soil types belonging to six texture classes (FAO/IIASA/ISRIC/ISS-CAS/JRC, 2012). Lithic Leptosols are the most dominant and are found in the high elevation areas. Together with Eutric Leptosols, Lithic Leptosols are Clay Loam and occupy a large part of the Soutpansberg range. The other soil types of notes include Haplic Acrisols (sandy clay loam), Rhodic Nitrisols (clay) and Ferric Luvisols (sandy loam). Eutric Regosols (sandy clay loam), Calcaric Arenosols (sand), Haplic Lixisols (sandy clay loam) and Ferric Arenosols (sand) are also found on the mountain range. Figure 2 shows the distribution of the different soils.

The Soutpansberg range is part of the Vhembe Biosphere Reserve (VBR) recognised by UNESCO since 2009. VBR is a special area for the conservation of a biodiverse environment and promotion of sustainable development. Covering an area of 6 800 km², the mountain range has been widely studied. The studies covered fields such as biology (Foord et al., 2008; Grey et al., 2017; Hahn, 2010; Taylor et al., 2013) climatology (Kabanda, 2004; Kabanda & Munyati, 2010; Kephe et al., 2016; Nenwiini & Kabanda, 2013), (Kabanda, 2004; Kabanda & Munyati, 2010; Kephe et al., 2016; Nenwiini & Kabanda, 2013), ecology (Mostert, 2006), and on geology (Berger et al., 2003). The range is important for both subsistence and commercial agriculture, rich biodiversity and a tourist attraction in the Vhembe District (Rapolaki et al., 2019). The Levubu valley in the south is known for commercial fruit production. The other parts are largely communal settlements. The population is rural, and therefore, soil erosion is of paramount importance.

Kabanda (2004) describes the Soutpansberg range as a complex terrain of ridges with various peaks, separating vast areas of valley systems. Consequently, the mountainous region has special hydrological, geological and erosional processes. This paper adds the geomorphological analysis of the Soutpansberg region to the library of research on the VBR.

The topographic setting of the mountain range gives rise to orographic rainfall and wind patterns that create a diversity of microclimates (Berger et al., 2003; Kephe et al., 2016). The geological substrate and the geomorphological processes create the basis for the weathering activity and the soil formation that create unique abiotic settings (Musila et al., 2005). Consequently, the soil erodibility assessment of the landscape is a crucial step in the study of ecosystems and ecosystem services provided by the Soutpansberg range.

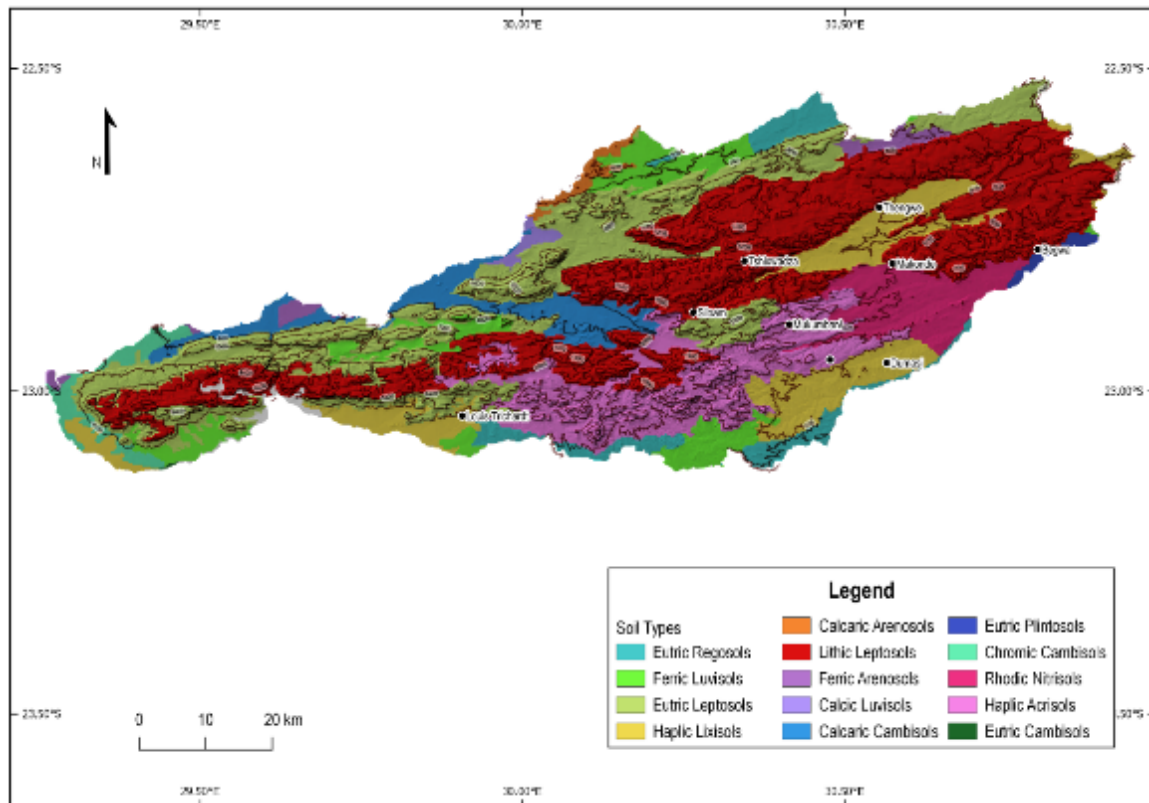


Figure 2: Soils of the Soutpansberg Range.

Data Requirements and Sources

The data needed for the characterisation of soil detachability on the Soutpansberg range consisted of five factors. The intrinsic characteristics as dictated by the USLE are the soil texture variables, that is, the K factor. The extrinsic factors are geology, slope, land-use-land-cover, and hydrography. The extrinsic factors have a bearing on soil susceptibility, thereby affecting the detachability of soil particles. Texture is an important intrinsic soil characteristic. It influences the water holding capacity of the soil as well as infiltration and through flow rates (Kusumandari, 2014). Harmonized World Soil Database (HWSD v 1.21) layer was obtained from The International Institute for Applied Systems Analysis (IIASA) online database for all the soil data.

Slope is the angle of the Earth's surface from the horizontal. The slope length and gradient greatly influence soil detachment through its control on surface water runoff and gravity. Hence, slope gradient is directly proportional to overland flow energy. Slope characteristics were derived from the 30m pixel size SRTM DEM obtained from National Geo-Spatial Information (NGI). The derivations were done in SAGA GIS.

Hydrographical systems indicate places where water has a tendency of accumulating. Water is the main driver of soil detachment. Where water is concentrated, soil detachment is increased. Hydrography systems shape files were obtained from Department of Water Affairs, Forestry and Fisheries (DWAF). However, for line density calculation, river systems derived from the DEM were used. The fluvial channels were extracted through semi-automatic calculations in SAGA GIS and the Strahler's hierarchical classification of channels was applied at level seven (Araujo & Pereira, 2018). This was necessary to include waterways that are not captured in the DWAF system.

The geology of an area determines soil detachability by influencing vertical water movement. Percolation has a direct effect on soil saturation and creation of overland flow. A rock that allows percolation delays overland flow, hence soil detachment. Geological data was downloaded from South African Geosciences online database.

Land-use and land-cover determine the way a raindrop will hit the soil surface. The way horizontal water movement can detach soil particles depend on land use and land cover characteristics. Land-use-land-cover data was obtained from the South African National Land Cover 2018 dataset accessed online on the Department of Forestry, Fisheries and Environment website. The data were analysed as indicated in the following section.

Data Processing and Analysis Methods

Data processing and analysis for this paper followed three stages. The first stage is the computation and derivation from raw data. The second stage is the normalisation of the factor map into five classes using Jenk's natural breaks (Zwoliński et al., 2019). The final map for each factor would then be reclassified to five classes using Jenks natural breaks. The classes are presented in different colours. Green represents the lowest values while red represents the highest values. The third stage is the weighting and overlaying of the factor maps to create a final soil erodibility map. The computation and derivation of each factor map are based on different parameters elaborated upon below.

The soil erodibility factor map was produced based on the K factor of USLE is computed using equation 1 proposed by Wischmeier and Smith (1958). Soil K factor was computed based on soil texture, organic matter, soil structure and soil permeability. The USLE K result from the calculations was added and another column for each polygon in the soil shape file. The soil shape file was converted into a raster layer in ArcGIS 10.7 using the soil erodibility column.

$$\frac{2.1 \times 10^{-4} * (12 - OM) * M^{1.14} + 3.25(s-2) + 2.5(p-3)}{759} \quad [1]$$

where: OM = organic matter content (%)

M = texture product [% silt*(% silt + % sand)]

s = structure class

p = permeability class

Soil texture is of importance in the formula. That is because it has a significant influence on the other soil characteristics (Kusumandari, 2014). Texture reflects the percentage of content of sand, silt and clay of the soil.

The next factor map is for the slope position. The slope position factor classifies the landscape into cliffs, scree slopes, transportation mid-slopes, foot slopes and open valleys (Jenness, 2006). Slopes were obtained using the Topographic Position Index (TPI) in SAGA GIS. The TPI is the difference between a cell elevation value and the average elevation on a neighbouring area around the cell. The TPI was computed considering a 300m radius circle neighbourhood in tandem with the 30m resolution of the DEM. This was done in SAGA GIS.

The third factor is the land-use-landcover layer. Derived from South Africa's 2018 land use land cover map, expert classification was done. The different land uses and covers were classified into five classes according to how they resist soil detachability. Land uses and land covers that would promote soil compaction and resist detachment were classified as one. Those that would offer the least resistance were classified as five. Table 1 shows the classes.

The fourth factor is geology. The geology factor map was created in ArcGIS from the geology shape files obtained from the South African Council for Geosciences online database (<https://www.geoscience.org.za/index.php>). Lithological hardness was expertly considered in the production of the geology factor. The rock hardness classes are shown in Table 2. The rock hardness class was decided from the main rock, defined in the attribute table as litho1. The rock hardness was used for rasterization in ArcGIS to produce the geology factor. The geology factor was normalised into five categories following Jenks Natural breaks using the reclassification tool in ArcGIS.

Table 1: Land use and land cover classes.

Land Use Type	Class	Land Use Type	Class
Contiguous (indigenous) forest	1	Fallow land & old fields (trees)	4
Contiguous low forest & thicket	1	Fallow land & old fields (bush)	4
Dense forest & woodland	1	Fallow land & old fields (grass)	4
Open woodland	1	Fallow land & old fields (bare)	4
Contiguous & dense plantation forest	1	Fallow land & old fields (low shrub)	4
Open & sparse plantation forest	1	Residential formal (tree)	2
Temporary unplanted (clear-felled) plantation forest	1	Residential formal (bush)	2
Low shrubland (other)	1	Residential formal (low veg / grass)	2
Sparsely wooded grassland	2	Residential formal (bare)	2
Natural grassland	2	Residential informal (tree)	2
Natural rivers	0	Residential informal (bush)	2
Natural lakes	0	Residential informal (low veg / grass)	2
Natural pans (flooded @ observation times)	0	Residential informal (bare)	2
Artificial dams (including canals)	0	Village scattered (bare & low veg/ grass combo)	3
Artificial sewage ponds	0	Village dense (bare & low veg / grass combo)	3
Artificial flooded mine pits	0	Smallholdings (tree)	3
Herbaceous wetlands (currently mapped)	0	Smallholdings (bush)	3
Herbaceous wetlands (previously mapped)	0	Smallholdings (low veg / grass)	3
Natural rock surfaces	1	Smallholdings (bare)	3
Dry pans	3	Urban recreational fields (tree)	2
Eroded lands	5	Urban recreational fields (bush)	2
Bare riverbed material	5	Urban recreational fields (grass)	2
Other bare	5	Urban recreational fields (bare)	2
Cultivated commercial permanent orchards	2	Commercial	1
Commercial annual crops pivot irrigated	4	Industrial	1
Commercial annual crops non-pivot irrigated	4	Roads & rails (major linear)	1
Commercial annual crops rain-fed / dryland	4	Mines: extraction pits, quarries	5
Subsistence / small-scale annual crops	4	Mine: tailings and resource dumps	5
Fallow land & old fields (wetlands)	4	Land-fills	5

Table 2: Geology classes.

Igneous	Metamorphic	Sedimentary
Granite (5)	*Gneiss (3)	Sandstone (4)
Norite (4)	Marble (3)	Arenite (4)
Dolerite (4)		Conglomerate (3)
Epidiorite (4)		Shale (3)
Basalt (4)		Siltstone (3)
Tuff (3)		Mudstone (2)
		Coal (2)
		Calcrete (1)

**Gneiss is classified as medium hardness because of the wide range of mineralogy.*

The fifth factor map represents hydrography. A combination of the hydrography elements proposed by Najwer and Zwoliński (2014) and those used by Melelli et al. (2017) was used. The former did not include drainage density in their calculations. Therefore, lakes, rivers, Topographic Wetness Index (TWI), drainage density, springs and pans were used for the computation of hydrography. Pans are treated in the same manner as lakes. They are assessed based on shoreline development ratio (DL). It is important to include both rivers as presented by Najwer and Zwoliński (2014) and drainage density as presented by Melelli et al. (2017) because the two consider different aspects of rivers. Najwer and Zwoliński (2014) assessed slope while Melelli et al. (2017) assessed stream occurrence.

The final soil erodibility map is a weighted sum overlay of the five factor maps. The Multi-Criteria Evaluation (MCE) using the Analytic Hierarchy Process (AHP) was employed to calculate relative weights for each factor map. This is important to consider the potential influence of each factor on the overall soil detachability of the Soutpansberg. The MCE was done online using pairwise comparisons. The overlay was done using the raster calculator in ArcGIS.

Results and Discussion

Factor Maps

The discussion looks at each factor map individually. This allows a thorough analysis of each factor before it is overlaid on other factors. Though each layer contributes to the final map according to its relative contribution, factor focused analysis gives prominence to spatial characteristics of each factor. This exposes characteristics that are muzzled by the GIS operation of overlaying.

The soil erodibility factor map shows that the Soutpansberg range predominantly has low to moderate erodibility. Figure 3 reveals that large areas of the range have low to medium erodibility. The areas with such erodibility coincide with the highest elevation (above 1200 m.a.s.l) and medium to low-lying areas below 900 m.a.s.l. The areas above 1200 m.a.s.l. are dominated by Lithic Leptosols. The areas between 900 and 1200 m. a. m. s. l. are dominated by Eutric Leptosols. Both soils are clay loam. The soil texture triangle informs that clay loam contains between 55 and 80 % clay. Erodibility is low for clay-rich soils (Kusumandari, 2014). Water makes clay particles agglomerate into larger aggregates that resist detachment and transport. Therefore, it makes sense that areas dominated by Leptosols of clay loam texture have low to medium erodibility.

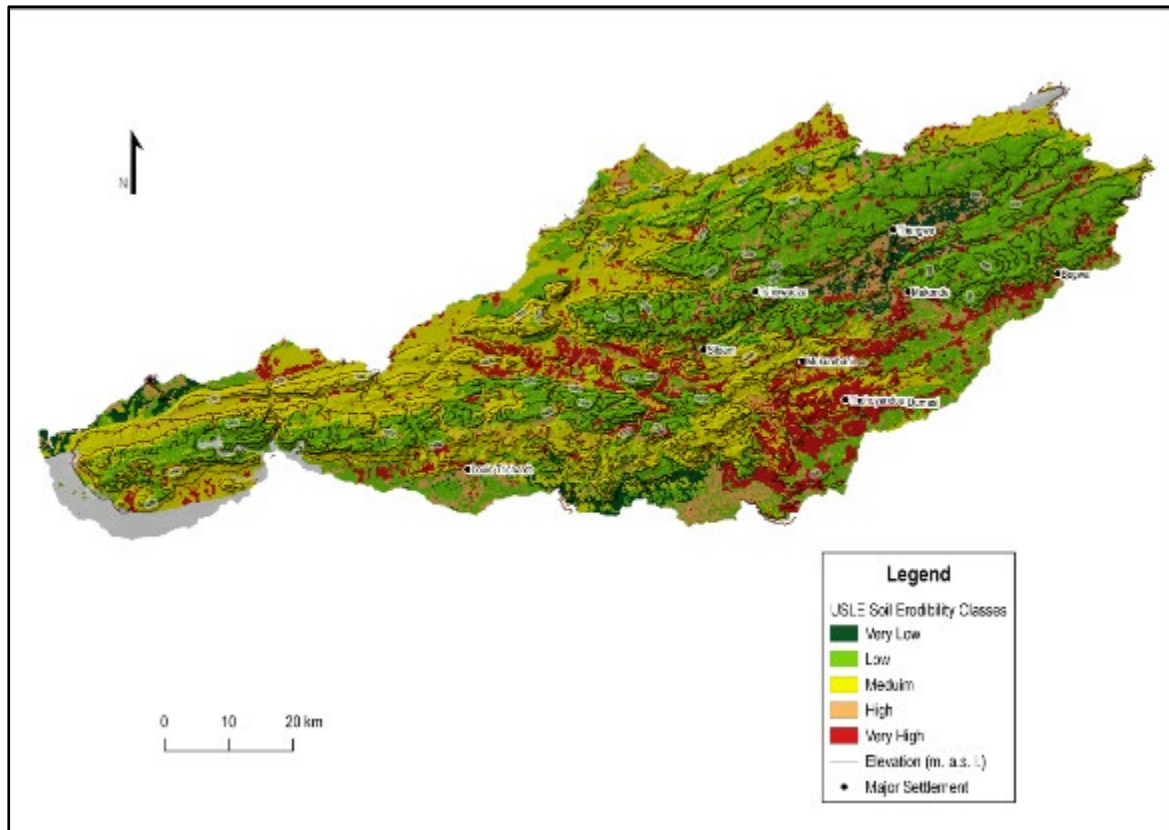


Figure 3: Erodibility factor.

The slope position factor tells a story of the dominance of open valleys and foot slopes. Cliffs and scree slopes occupy a very small portion of the mountain range. However, they are very prominent, especially at elevations above 1200 m.a.m.s.l. This is an interesting geomorphological set-up considering that the study area is a mountain range. A logical scenario would have been one of the dominances of scree slopes and cliffs.

However, the age and formation of the mountain range can give an insight into the scenario. The mountain range was formed approximately 1800 million years ago by an east-west trending asymmetrical rift or half-graben along the Palala Shear Belt (Berger et al., 2003). There is no recent history of any tectonic disturbances in the region. Therefore, it can be argued that water has had enough time to carve valleys and eat away any cliffs and steep slopes to establish rivers systems. As such, the Soutpansberg range is a major watershed in Vhembe District (Jacana Environmentals, 2015; Makungo et al., 2019). It is a source for Luvuvhu, Little Letaba, Mutale, Mutamba and Nzhelele rivers. Figure 4 presents the slope factor map.

The land use land cover factor portrays the dominance of forestry on the Soutpansberg range. Most of the range is class one and two land uses and land covers. These are natural forests, plantations, or vegetated residential areas. The Soutpansberg range is host to several private farms practicing agroforestry that has a significant effect on reducing soil detachment (Jinger et al., 2022; Kabir et al., 2021). The Tshivhase and the Mukumbani Tea Estates as well as Entabeni, Roodewal and Shefeera, among others, are large scale agroforestry projects on the range. The Levubu valley adds the banana, macadamia, and other fruits plantations to the land use map. All these have a bearing on soil detachability. Figure 5 presents the land-use-land-cover factor map.

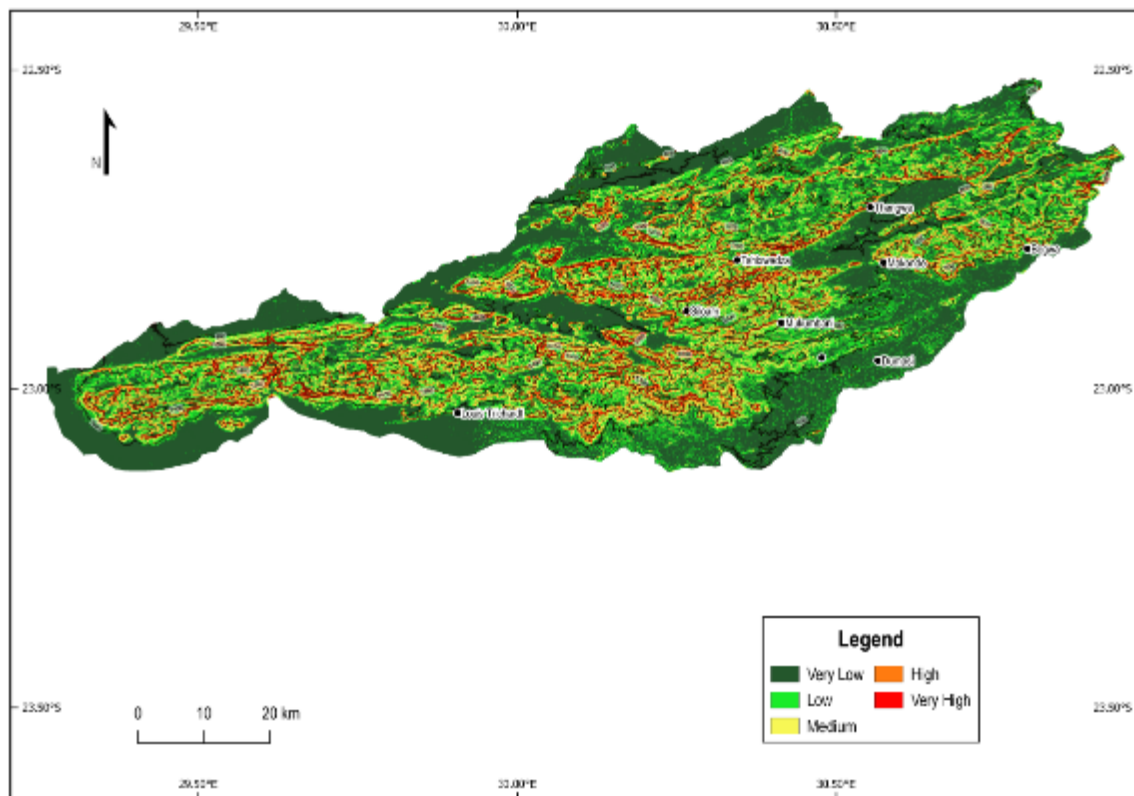


Figure 4: Slope Position factor.

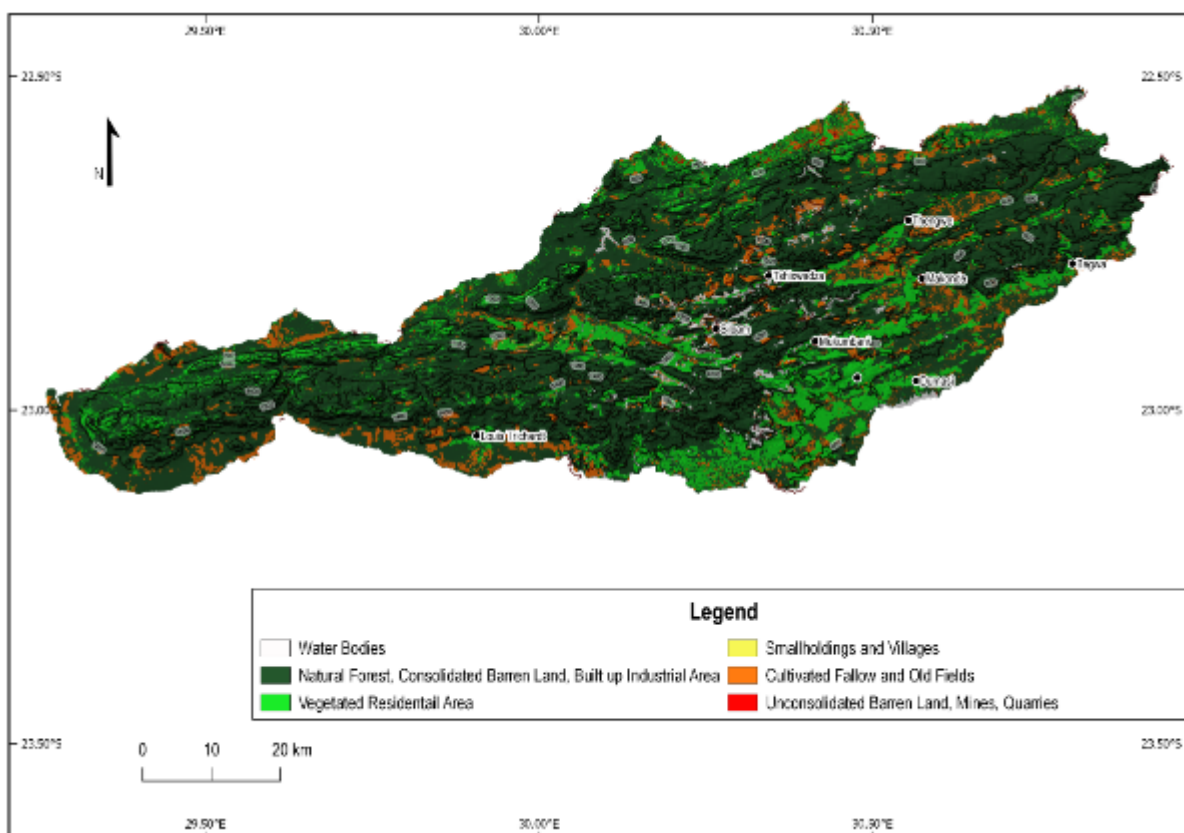


Figure 5: Land-use-land-cover factor.

The geology factor shows the dominance of hard rocks which occupy most space on the range. The rocks are predominantly igneous as shown in Figure 6. Granite is the only one in class five and occupies over a quarter of the mountain range. Arenite occupies over half of the mountain range.

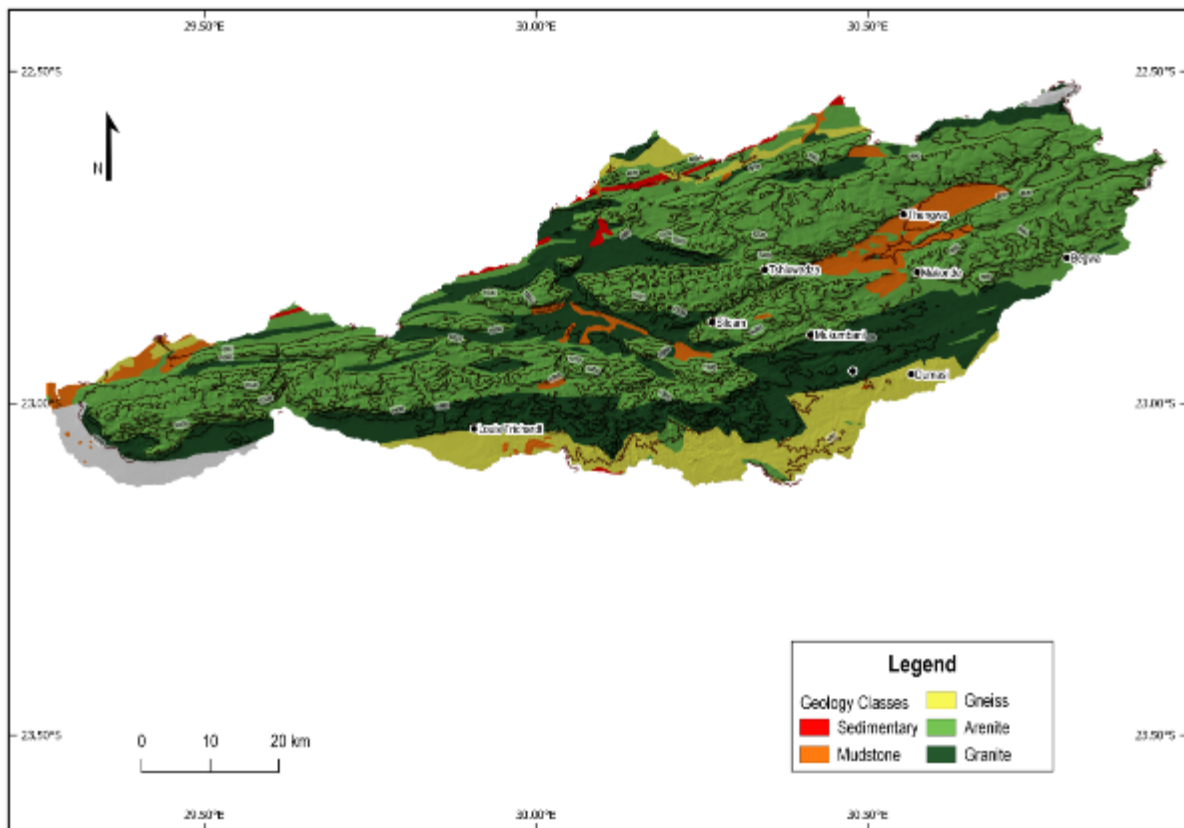


Figure 6: Geology factor.

The hydrography factor shows the interrelationship between high elevation areas, waterways, and open valleys. High hydrography represents large water bodies found in the mountain range as shown in Figure 7. However, the mountain range has a significant number of waterways that may not necessarily have a high TWI in comparison with dams and lakes. The water ways are the areas of concentrated water where all sediment is destined. Areas with high TWI indicate high soil detachability potential (Ma et al., 2010; Seutloali et al., 2017; Sharma, 2010). The north facing slopes indicate more hydrographical activity. The Sand, Mutamba, Nzhelele, Mufungudi, Luphephe and Mbodi rivers all drain to the north of the range. The implication is high erosion risk on the north facing slopes of the river.

The high risk is, however, reduced by the soils, geology, and land uses. The north facing slopes are dominated by Lithic and Eutric Leptosols. Both are clay loam and have low erodibility (Kusumandari, 2014). The rocks are mainly hard granite and arenite. Land-use-land-cover is mainly natural forest. Therefore, the hydrographical impact is contained. This is revealed by the results of the final overlay.

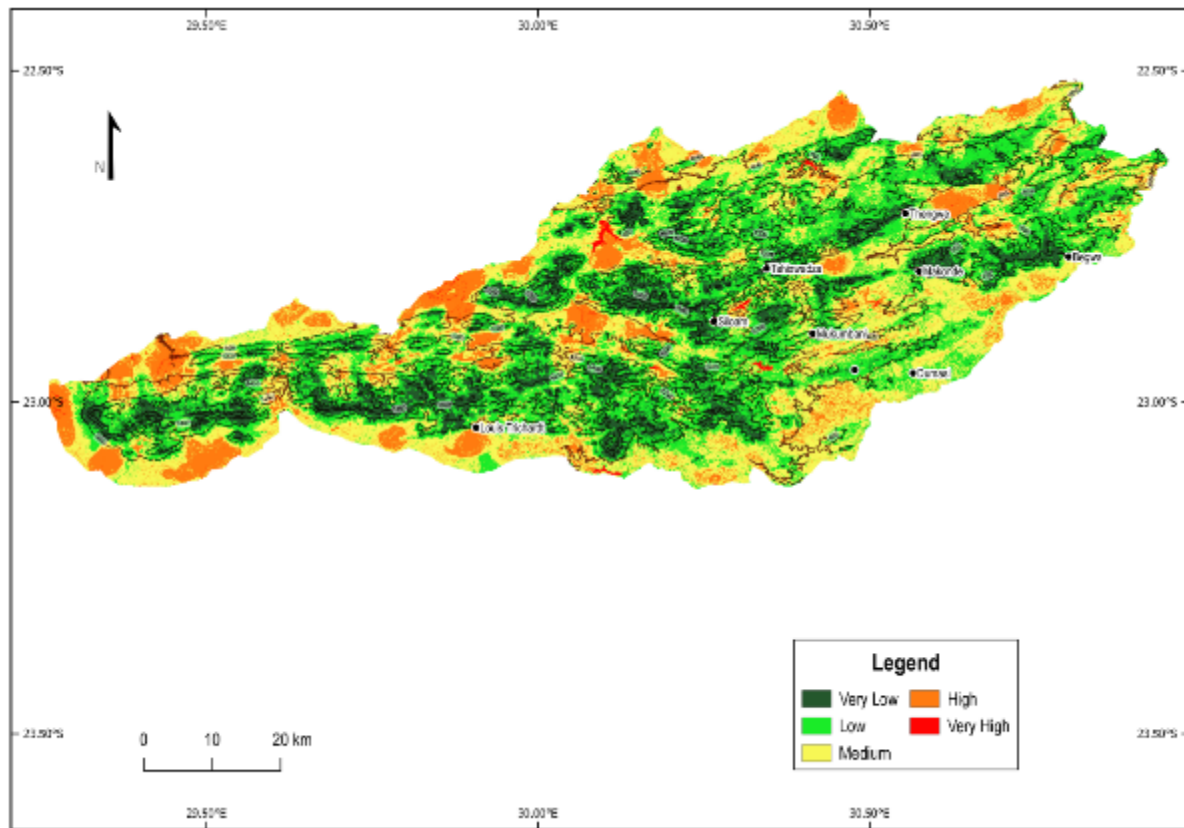


Figure 7: Hydrography factor.

The five factors were put through a factor ranking using Multi-Criteria Evaluation (MCE) of the Analytic Hierarchy Process (AHP) before overlaying them to produce the overall soil detachability map of the range. Table 3 shows that soil erodibility, land use landcover and slope carry the highest weight, in that order. Conversely, hydrography and geology carry the least weight, respectively.

Table 3: Factor ranking.

Category	Priority	Rank	(+)	(-)
Soil Erodibility	36.1%	1	24.6%	24.6%
Geology	11.6%	4	11.4%	11.4%
Slope	12.8%	3	5.7%	5.7%
Land Use and Land Cover	36.1%	1	1.9%	1.9%
Hydrography	3.3%	5	1.7%	1.7%

Consistency Ratio = 7%.

The ranking is sensible because soil erodibility represents the intrinsic detachability resistance of a soil. Erodibility is determined by soil texture, structure, permeability and soil organic matter content (Kinnell, 2010; Kusumandari, 2014; Poesen, 2018; Renard et al., 1997; Wischmeier et al., 1958). The factors determine how a soil is vulnerable to particle detachment

(Kusumandari, 2014; Poesen, 2018). Slopes on the other hand influence material movement (Kinnell, 2010; Kusumandari, 2014; Renard et al., 1997; Stocking et al., 1988; Wischmeier et al., 1958). As a rule, steep slopes promote soil particle detachment. Land use and cover affects how water moves as well as soil structure. Land cover determines how raindrops travel through the atmosphere through interception (Foster et al., 1985; Li et al., 2019; Stocking & Elwell, 1976). Vegetated areas have high interception rates as opposed to bare ground. Land uses influence soil structure and characteristics. Tillage loosens soil particles and make them easily detachable. All these factors have a huge impact on the soil particle detachment processes. The effect was considered in the pairwise comparison to produce the factor ranking. The factor ranking was applied to the factors in GIS to carry out weighted overlay to produce the final map.

The final soil detachability map in Figure 8 reveals the variable strong influence of soil erodibility, slope, and land use-land cover. The factors show different influences in different places. The very high detachability shown in the south facing slopes indicate the strong influence of soil erodibility. This is the region with moderate, high and very highly erodible soils. Slope reveals its strongest influence on the edges of the south facing side of the range. This region is dominated by cliffs. Cliffs promote the fastest particle detachment. Land use-land cover exercises its dominance together with soil erodibility along the crest of the range. The region has high elevations and clay loam. The soils promote agroforestry and therefore, the areas are occupied by forests. This outcome leads to the following conclusion and recommendations.

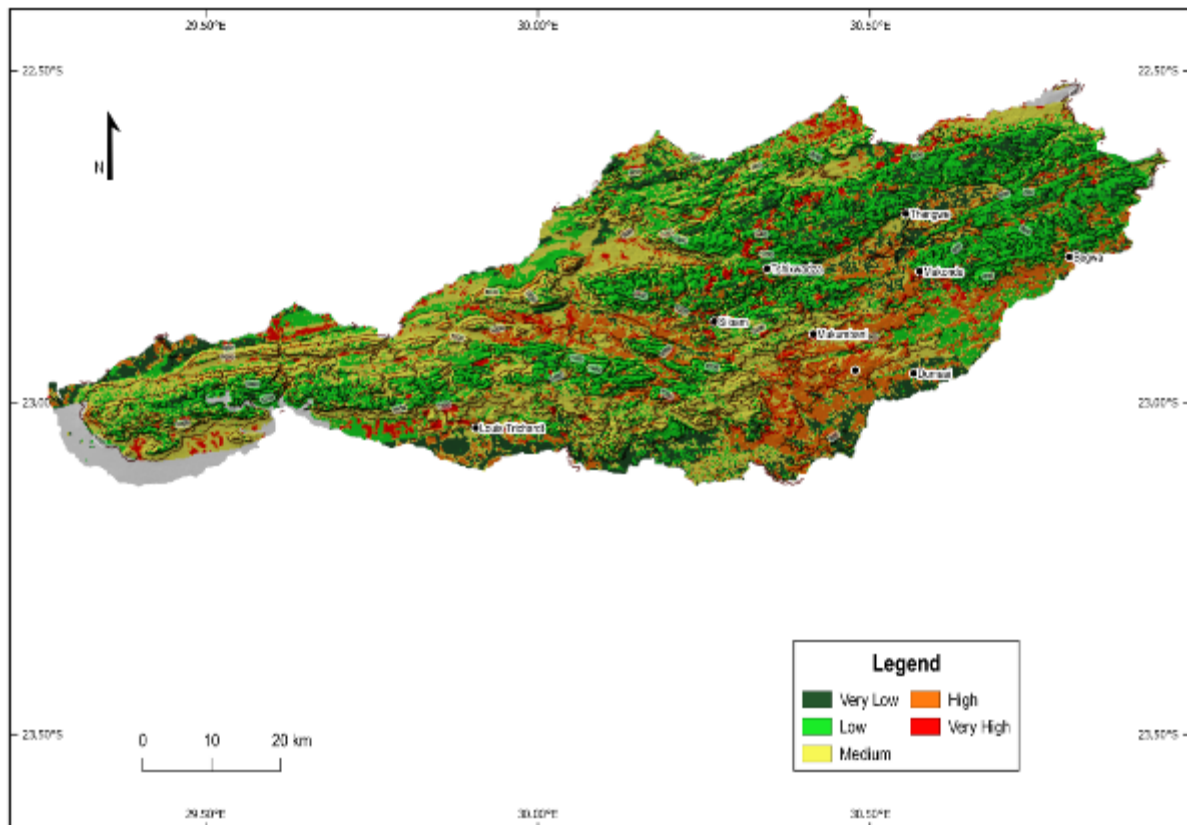


Figure 8: Total soil detachability on the Soutpansberg Range.

Conclusions and Recommendations

The Soutpansberg range is a significant landmark in the Vhembe District of South Africa. The characterisation of soil detachability considered five factors. The factors include geology, slope position, soil erodibility, land-use-land-cover, and hydrography. A factor weighting shows that soil erodibility, land-use-land-cover, and slope, respectively contribute to soil detachment considerably. Hydrography and geology have the least contribution. A weighted sum overlay of the factors reveal the variable influence of land-use-land-cover, slope and soil erodibility. Soil erodibility and land-use-land-cover show strong influence in the high elevation areas of the western parts and the crest of the range. Slope is dominant on the edges, especially the south facing slopes. Soils erodibility is also strongly influential in the southern low-lying areas.

The paper concludes that the Soutpansberg range has an intriguing soil detachability physiognomy. High and very high soil detachability occupy less than half of the mountain range. Very low and low soil detachability occupy at least 50% of the mountain range. Most of the low to very low soil detachability is found along the crest of the mountain. The crest of the mountain also coincides with areas occupied by natural forests, plantations, and clay loam soils. This reveals the interplay of intrinsic and extrinsic factors in soil detachability. Therefore, it is concluded that the Soutpansberg range is a low soil erodibility risk. This conclusion leads to the following recommendations.

The low erodibility risk status is a function of both human and natural factors. Therefore, it is recommended that the human activities that promote land-use-land-cover conditions that minimise soil detachment should continue to be promoted. The agroforestry activities should be maintained. This would maintain the mountain range in an environmentally sustainable condition.

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Declaration of Interest Statement

No interests declared.

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Terrain influences on the informal settlements of eThekweni, South Africa

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Abstract

Existing knowledge points to the fact that informal settlements are predominantly located in marginal areas which are prone to natural hazards such as landslides and floods. In most cases, this notion is based on observations made in a selected few informal settlement. Whether this perception is indeed supported by data remains largely unknown. This paper investigated whether the informal settlements in eThekweni predominantly occur in marginal areas characterised by high flood or landslide risk. Digital Elevation Model (DEM)-derived elevation, slope, and the Stream Power Index (SPI) were calculated for informal settlements to determine their risk of landslides and floods. Results show that ~30% of the informal settlements occur in flood-prone areas occurring at elevations not exceeding 100m a.s.l. In addition, the informal settlement hotspot areas also occur at elevations greater than 100m a.s.l. Further results suggest that ~36% of the informal settlement area is prone to landslides. Similarly, the SPI suggests that fewer informal settlements occur in areas that are prone to landslides. Contrary to existing knowledge, these results suggest that the informal settlements in eThekweni may not be predominantly located in marginal areas. Larger parts of the informal settlements occur in areas classified as safe from floods and landslides. These results may be used by individuals or organisations to focus their effort on high-risk areas when managing floods and landslides.

Keywords: Flood-risk, Informal settlements, Landslides, Slope, Stream Power Index (SPI)

Introduction

In most countries, informal settlements occur on state-owned land, which is either reserved for public uses or is not earmarked for any immediate developments. Typically, these areas occur, among others, along riverbanks (Dalu et al. 2018, Dangol & Carrasco 2019), in urban green spaces/city parks (Adegun 2017, Almohamad et al. 2018), railway lines (Rahmawati et al. 2020), and areas that are deemed too steep for construction (Kahanji et al. 2019). There is, thus, a growing body of literature that classifies these areas as abandoned or neglected (e.g., Khalil et al. 2018, Sibyan 2020, Sultana et al. 2020). Poverty, which is prevalent in informal settlements could drive settlement in the marginal areas since the people often fail to afford housing in the more formal parts of the city where living conditions are favourable. On the other hand, high rates of urbanisation have pushed up the demand for housing, which urban authorities fail to meet (Alzamil 2018, Hasan 2020). The settlement of people in neglected and hazard-prone areas works against the achievement of Sustainable Development Goal 11, which calls for the existence of safe and resilient cities (Nations 2016). Thus, in most cities located in low-income countries, the urban poor continue to reside in the neglected parts of the city where living conditions are deplorable.

Steep slopes ($>14^\circ$) are generally unstable and are more susceptible to landslides than those that are gentle ($<14^\circ$). It is for this reason that the areas located on steep slopes are avoided when selecting places to build housing infrastructure. A study conducted in Guatemala by Coe et al., (2004) asserted that almost all the landslides in the study area were initiated from slopes between 16° and 44° . In essence, residents have limited choices and occupy the area that are left vacant due to landslide risk. Residents further lack the resources to construct structures that are resilient to landslides. At most, the dwelling units in the informal settlements are built from temporary materials, thus, making them more vulnerable to hazards.

Literature is replete with examples of studies that point to locations of informal settlements in marginal lands, which are prone to floods (e.g., Kikwasi & Mbuya 2019, Twum & Abubakari 2019), and landslides (e.g., Castro et al. 2015, Holcombe et al. 2016), with the bulk of residents of informal settlement vulnerable to water-related hazards. An example is the report (UN-Habitat 2016), which estimated that about 40% of the non-permanent housing in the world are in disaster prone areas. Arguably, most of these assertions are based on isolated observations in few informal settlements (e.g., Desportes et al. 2016, Flower et al. 2018, Melore & Nel 2020). In addition, some of the studies base their conclusions on data collected from a selected few individuals (e.g., Ziervogel et al. 2016, Herbert et al. 2020). Observations made at the landscape scale remain few. Thus, to the best knowledge of the authors, current knowledge on the location of informal settlements in marginal areas (areas not suited for settlement) is not entirely based on empirical evidence. In fact, Muller et al., (2020), set in motion a discussion that advocates for the testing of this notion using empirical data. The authors point to the fact that, contrary to popular belief, informal settlements are not found in marginal areas. The new line of thought, questioning location of informal settlements in marginal areas, calls for a need to re-visit this discussion. Thus, the current study seeks to use landscape-scale remotely data to establish whether informal settlements are indeed located in marginal areas.

Recent advances in remote sensing technologies, which have increased the availability of free satellite data acquired at fine spatial scales, has enabled scientists to re-visit questions related to the location of informal settlements in marginal areas (e.g., Asghari Zamani et al. 2017, Müller et al. 2020, Rwanyiziri et al. 2020). In fact, questions have been asked on whether remote sensing could be used to map informal settlements at large spatial scales such as the global scale (Kuffer et al. 2016, Asghari Zamani et al. 2017). Remote sensing has an added advantage of being able to rapidly generate useful spatial data through automated algorithms (Li & Hsu 2020). Thus, its application in studies seeking to establish whether informal settlements are indeed located in hazard prone areas could provide useful insights, at large spatial scales, as opposed to point-based observations from fieldwork.

Elevation data derived from remote sensing is widely used in studies investigating the vulnerability of informal settlements to floods and landslides. For instance, Dalu et al. (2018) used digital elevation model (DEM) data to understand slope influences on flooding within informal settlements located in Cape Town, South Africa. The data can particularly be used in the rapid mapping of drainage features (e.g., Siddiqui et al. 2017, Imran et al. 2019), and subsequent delineating low-lying areas, which are vulnerable to floods (e.g., Ureta et al. 2020). On the other hand, slope is easily calculated from elevation data and the output could be useful in characterising landslide risk. Biswas et al (2017) used DEM-derived slope to examine vulnerability of informal settlements to landslides in Bangladesh. In addition, the Stream Power Index (SPI), a more complex computation than slope, is a reasonable proxy for erosion potential, which in turn could be useful in the delineation of landslide prone areas (Soto et al. 2017, Ahmad 2018). Although the SPI is an established proxy for erosion potential, it has not been widely used in studies that investigate the vulnerability of informal settlements to

landslides. Thus, GIS could provide useful data for testing whether the informal settlements are indeed located in marginal areas and are susceptible to floods and landslides.

The accurate identification of settlements, which are situated in hazard prone areas is an important step in the management of disaster situations. This information could guide decisions during the different stages of the disaster response cycle. For instance, warnings of floods or landslides could be issued to the communities that are likely to be affected and evacuation carried out where necessary. In most situations, resources for disaster response are inadequate. In addition, during disasters it is not possible to assist everyone at once; there may be need to set priorities in terms of who should be helped first and those to be assisted at a later stage. Thus, data on the informal settlements which are at risk of floods and/or landslides could be used in disaster preparedness and response.

Materials and Methods

Study area

The current study was conducted in the informal settlements located in the eThekweni metropolitan area in South Africa. The city is located between 30.76°-31.10°E and 29.60°-30.04°S (Figure 1). In 2011, when the last national census was conducted, the city had a total population of 595,061, with roughly 13% of the population living in informal settlements. It is generally reported that most informal settlements are in marginal areas associated with floods and landslide hazards. In the study area, these settlements are characterised by chaotic dwelling units built using makeshift materials like iron roofing sheets and other cheap materials.

Figure 1. (a) Location of eThekweni in South Africa, and (b) The informal settlements overlaid on an ASTER DEM.

eThekweni is a coastal area located at elevations ranging from 0 to 687m a.s.l. Owing to its location on the coast, the settlements on low lying areas are prone to coastal floods. Flood risk

is also higher along the major rivers like Umngeni River. The sharp variations in elevation result in steep slopes in most areas. Although these slopes are generally covered by vegetation, they still could be vulnerable to landslide risk.

Informal settlements

Informal settlements were identified on google earth images (www.googleearth.com) based on the arrangement of dwelling units. An area was classified as an informal settlement if dwelling units were arranged in no pattern (Figure 2). The perimeter boundaries of all the informal settlements identified using this approach were later digitised and stored on computer as shapefiles.



Figure 2. Chaotic arrangement of dwelling units in the informal settlement located along the New Germany Road in Recreation, EThekweni.

Although the objective was to map all the informal settlements in the study area, some could have been missed. Actual verification of the data on the ground was only done for a few settlements. In all, 210 informal settlements were digitised (Figure 1).

Digital Elevation Model

The slope data used in this study was derived from the Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model (ASTER GDEM), freely downloadable on the public domain (<https://lpdaac.usgs.gov/>). The data are acquired at the 30m spatial resolution. Three tiles cover the study area (S30E030, S30E031, S31E030). Pre-processing of the data included merging the three tiles and re-projecting from the World Geodetic System 1984 Geographic Coordinate System (WGS 84) to the World Geodetic System 1984 Universal Transverse Mercator Zone 36 South (WGS84 UTM Zone 36S). Conversion to the projected coordinate reference system enabled later extraction of area-based metrics.

The study sought to establish the average elevation at which the informal settlements occur in the study area. Thus, the average elevation within each of the 210 informal settlements was

extracted using the zonal statistics tool in ArcGIS. The tool also calculated the standard deviation, as well as the number of data values extracted. These were later used to calculate the confidence interval of elevation at the alpha level of 0.05.

To establish the area located at an altitude below 100m a.s.l., the original elevation data were reclassified into the 0-100m a.s.l. and >100m a.s.l. classes. The output from the reclassification was later clipped to exclude all areas outside the informal settlements. The informal settlement areas falling in the two elevation classes were later extracted from the attribute table of the resultant mask.

The study further sought to analyse elevation in the informal settlements classified as hotspots using the Getis Ord G_i^* statistics. The spatial statistics tool was used to classify the informal settlements as either hotspots or cold spots. All informal settlements associated with a G_i^* score of more than 1.96 were classified as hotspots. Average elevation and the size of the informal settlements occurring at elevations below 100m.a.s.l. was calculated using the procedure described earlier but this time restricted to hotspot informal settlements only.

Slope

Slope at any location in the landscape can be used to assess vulnerability to landslide hazards. Steep slopes are associated with greater landslide risk than gentler ones. Generally, areas with slope exceeding 14° are associated with higher landslide risk than those at less than 14° . These slope classes were used to classify the landscape into risk regions.

Slope was calculated using Equation 1.

$$\text{Slope (degrees)} = \tan^{-1} \left(\frac{\text{rise}}{\text{run}} \right) \quad [1]$$

This calculation was implemented in ArcGIS 10.5 using the slope calculation tool. However, prior to calculation of slope, the original elevation raster used as input was smoothed using the fill sinks tool within the hydrology tools of ArcGIS 10.5. The area of the informal settlements falling within the classes described above was extracted using the protocol that has been described for elevation data.

Stream Power index

The stream power index (SPI) was used as a proxy for erosion potential where high values represented high erosion potential and the low values are associated with low erosion potential. In essence, informal settlements located in areas of high SPI areas were regarded as more vulnerable to erosion while those in low SPI were comparatively associated with lower erosion/landslide risk. The index uses the slope and flow accumulation raster data, both of which are derived from DEM data. Prior to the computation of flow accumulation, the fill sinks procedure was implemented to get rid of local depressions in the DEM data. The flow direction and accumulation raster were later created using the hydrology tools of ArcGIS 10.5. SPI is calculated using the formula (Moore et al. 1991) (see Equation 2).

$$SPI = \ln[AS.TAN(SLO)] \quad [2]$$

where AS=specific catchment area; and SLO=slope.

However, in a GIS, the flow accumulation raster was used as a replacement for the catchment area. Instead, the following formula was implemented in ArcGIS 10.5 using the raster calculation tool using Equation 3, where \ln =natural logarithm; $facc$ =flow accumulation raster; $slope$ =slope raster (calculated as a percentage); and 0.001 is added to avoid zero values. The final SPI calculation is given in Equation 3.

$$SPI = \ln \left(("facc"+0.001) * (("slope"/100) + 0.001) \right) \quad [3]$$

The resultant raster was later reclassified using the following SPI thresholds (No erosion potential (<0); low (0-2.5); medium (2.5-5), high (5-7.5); and very high (>7.5)). In a study by Moore et al (1991), thresholding of SPI was based on equal intervals while standard deviation-based classes were also suggested. In our study, the positive SPI values were reclassified using equal intervals while negative values were generally regarded as being associated with no erosion potential.

Data analysis

Comparison of the informal settlement area located in high flood risk area (<100m a.s.l.) and that located in the low-risk zone (>100 m a.s.l.) used the chi square test. Similar comparisons were also done for the high landslide risk (slope>14°), moderate risk (slope=10°-14°) and the low risk (slope<10°). A similar analysis was performed on the SPI data. Significance of the results was inferred at the alpha level of 0.05.

Results

The total land area of informal settlements located below 100m a.s.l. covered 8.18km² (representing 29.51% of the entire informal settlement area), while 19.55km² (70.49%) was above 100ma.s.l. The area of informal settlements located on higher ground was significantly larger than that located on lower ground ($\chi^2 = 31.97, df = 1, p = 0.000$)

The informal settlements of eThekweni occur at an average elevation of 117m a.s.l. However, the lowest informal settlement was observed at the mean elevation of 8.7m a.s.l., while the highest was at 418m a.s.l. Significantly more informal settlements were located below 100m a.s.l. ($\chi^2 = 11,67, df = 1, p \sim 0.001$). In fact, 123 informal settlements (58.6%) lie below 100m a.s.l., while the remaining 87 (41.4%) are above 100ma.s.l.

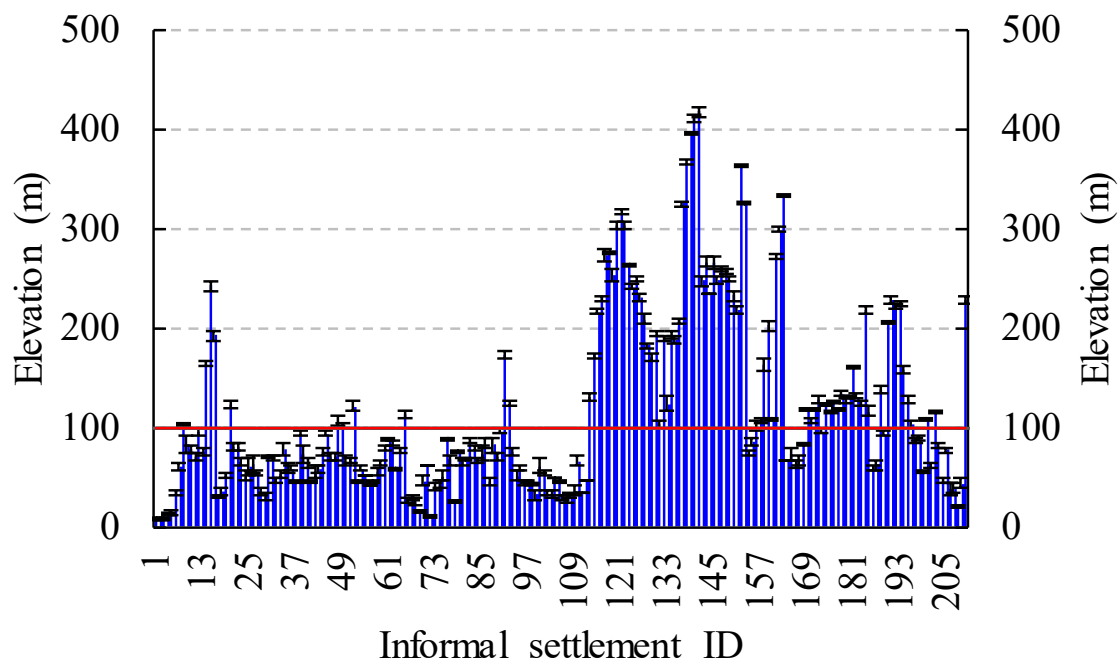


Figure 3. Variation in average elevation (error plots represent confidence interval at 95% confidence level) in the informal settlements of eThekweni. The red line is the 100 m a.s.l. elevation threshold.

Most of the informal settlements lying at elevations lower than 100m a.s.l. run parallel and close to the coastline in a south-west to north-east direction. However, the areas characterised by hotspots of informal settlements all lie at elevation greater than 100m a.s.l. (*Figure 3*).

Figure 4. Distribution of informal settlements at elevation below and above 100m a.s.l. in eThekweni, South Africa. Note that all the informal settlements hotspots occur above 100m a.s.l.

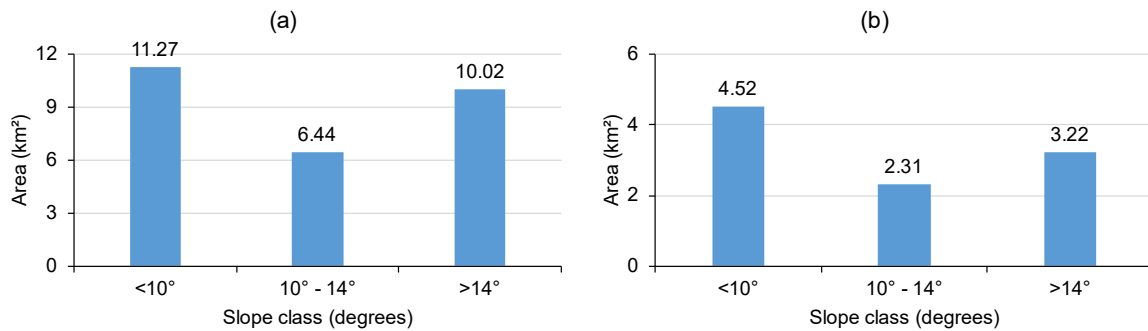


Figure 5: the size of land in the different slope classes in (a) all the informal settlements, and (b) hotspot informal settlements only.

In all the informal settlements, the areas classified as flat (<10° slope), gentle (10-14°) and steep (>14°) were found to be the same ($\chi^2=2.04$, $df=2$, $p=0.36$). The steep areas covered 10.02km² (36.13%) of the total informal settlement area, while moderate slope and gentle slope covered 6.44km² (23.22%) and 11.27km² (40.64%) respectively (Figure 5(a)). Additionally, a comparison of the steep areas to a combination of moderate and gentle slopes showed no difference ($\chi^2=3.23$, $df=1$, $p\text{-value}=0.07$).

Considering informal settlement area hotspots only, the areas in the different slope categories were found to be the same ($\chi^2 = 1.10$, $df=2$, $p\text{-value}=0.58$)

The hotspot area classifies as flat was 4.52km² (44.98%) while that classified as gentle was 2.31km² (22.99%), that classified as steep covered 3.22km² (32.04%) (Figure 5(b)).

In a similar way, the proportion of informal settlement hotspot areas classified as steep was found to be the same as that classified as flat and gentle combined ($\chi^2 = 1.36$, $df=1$, $p=0.24$).

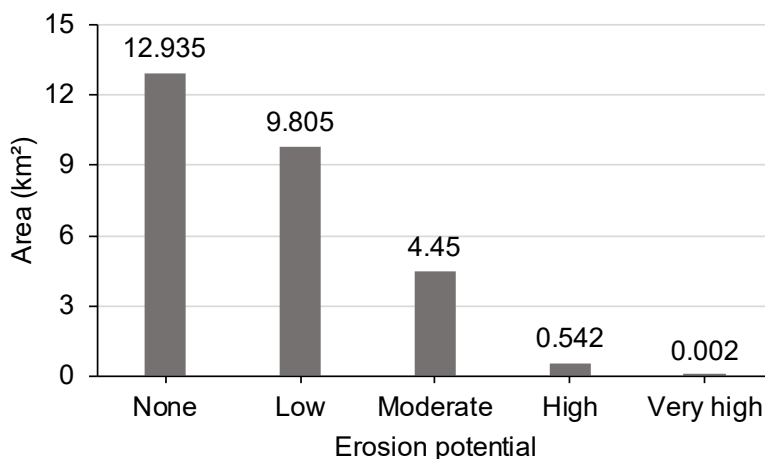


Figure 6. The size of informal settlement area classified according to erosion potential in eThekweni, South Africa (None: SPI<0, Low: SPI 0-2.5; Moderate: SPI 2.5-5, High: SPI 5-7.5; Very high: SPI>7.5).

A significantly smaller proportion of the area under informal settlements had very high erosion potential ($\chi^2 = 29.32$, $df=4$, $p\text{-value}\sim 0.000$). The area classified as having very high erosion potential covered less than 1% of the total area, while that classified as high potential covered approximately 2% of the entire informal settlement area (see Figure 6). 82% of the area had no or low erosion potential and that with low erosion potential covered a combined 82% of the area occupied by informal settlements. Moderate erosion potential was observed in the remaining 16% of the area.

Discussion

The study suggests that most of the informal settlements area is not prone to floods. In fact, only about 30% of the informal settlements occur in flood-prone areas, while the elevation >100m a.s.l., which is remaining 60% occur in areas considered safe. The hotspot areas, which occur to the northwest of the city, are far from the ocean, thus reducing the potential of coastal flooding. These hotspot areas generally occur at elevation >100m a.s.l. When interpreting these results, it must be noted that they are based on an analysis of total informal settlement area and not their total number. On the contrary, analysis using absolute numbers suggest that a bigger number of the informal settlements occur below 100m a.s.l. Arguably, the analysis based on area coverage provides more useful information compared to absolute number since some informal settlements cover extensive areas and accommodate more people. Overall, the study reports that the informal settlement area classified as prone to floods is smaller than that which is considered safe. Even the hotspot areas for informal settlements occur in areas that are safe from floods.

Further results suggest that the larger proportion of informal settlement area is safe from landslides. The area located on steep terrain (>14°) represents about a third (36%) of all the area covered by informal settlements, while the remaining two thirds are gentle to flat and are thus at low risk of landslides. Similarly, results from the analysis of SPI point to the fact that a smaller area in the informal settlements is prone to landslides.

These results suggest that the informal settlements in eThekweni may not be in marginal areas contrary to existing knowledge. Instead, a significantly bigger proportion of informal settlement area is in areas that are considered safe from floods and landslides. The finding that the informal settlements generally occur on higher ground, which as at low risk from floods may mean that the residents deliberately avoid flood-risk areas when making decisions on where to settle. Whether this is indeed the case in the study area could only be verified from interview data. Most of the less affluent areas are located further inland, and this coincides with higher elevation. However, the areas along the major rivers like the Umngeni and the Palmiet have informal settlements, which seem to be exposed to floods.

The finding that a small proportion of the informal settlement area is prone to erosion and landslides is surprising in an area like eThekweni where terrain is generally steep to very steep (Pithouse 2008, Boon et al. 2016, Mazeka et al. 2019). While findings from the current study suggest that high erosion risk is limited to small areas in eThekweni, the use of slope and SPI alone may be regarded too simplistic. The other factors which influence occurrence of landslides include high rainfall (Martha et al. 2019, Rosi et al. 2019), and bare loose soil (Okada & Konishi 2019, Sulal & Archana 2019), among others. It is, therefore, possible that in eThekweni, heavy rainfall events and soil-related issues trigger landslide events more than slope angle alone.

The finding that the informal settlements in eThekweni may not be predominantly located in marginal areas stands contrary to a large body of literature, which largely asserts that informal settlements are pushed to the less desirable and neglected areas, which are prone to floods and landslides (Vecchio 2018, Mazeka et al. 2019, Sutherland et al. 2019, Georgiadou & Loggia 2021). However, the current findings are in line with the conclusions made by Muller et al (2020).

The conclusions reached in this study are based on well-tested terrain-based metrics like elevation, slope, and the SPI. The combined use of a reliable elevation dataset (ASTER DEM) and well-established terrain metrics strengthens the conclusions reached. In addition, the SPI is a common proxy for erosion and landslides (Ahmad 2018, Andualem et al. 2020,

Chakraborty et al. 2020). However, despite its popularity in geomorphological and hazard mapping studies, evidence from literature suggests that it has rarely been used to assess vulnerability of informal settlements to landslides. Thus, the use of SPI in the current study, opens opportunities for its application in studies that would enhance knowledge on informal settlement vulnerability to landslides. An additional strength of this study is that the observations were made in an entire metropolitan area instead of being focused on one informal settlement.

Further work seeking to investigate the predominant location of informal settlements in marginal areas could benefit from replicating observations in several study sites. The findings reported here could be peculiar to eThekweni and thus not apply in other landscapes. Additional work may also include experiments that specifically measure erosion potential instead of using proxies, which limit the information they provide. For instance, factors like rainfall, land cover, and soil type all have a potential bearing on the occurrence of landslides. These were not considered in the current study. A specific focus on these factors in the future will strengthen the inferences made from the data.

Knowledge of where informal settlements occur in the landscape, as well as their vulnerability to floods and landslides may be useful in disaster risk management. For instance, the evacuation of disaster victims could benefit immensely from reliable data showing the spatial structure in vulnerability. In a similar way, warnings of disaster situations could focus on the areas associated with the highest risk. In essence, the findings of this study suggest that not all informal settlements are at high risk of floods and landslides. Thus, priority in the allocation of resources in disaster situations can be focused on the areas that need the assistance the most. This approach enables the efficient deployment of resources for the effective management of the disasters. Thus, the results of the current study may be useful to individuals, organisations, and departments that deal with the management of flood- and landslide-related disasters.

Conclusions

The current study established whether the informal settlements of eThekweni (South Africa) are in marginal areas susceptible to floods and landslides. It specifically explored the elevation, slope, and SPI in informal settlements areas to assess whether they indeed are in marginal areas.

While earlier studies suggest that informal settlements predominantly occur in marginal areas, which are susceptible to disasters, this study of informal settlements in eThekweni suggests that the informal settlements occur on higher ground where the risk of coastal flooding is low. Additional results suggest that most of the informal settlements are located on gentle slopes ($<14^\circ$), and in areas with low erosion potential. These conclusions support a new line of thinking which suggests that, contrary to popular knowledge, informal settlements of eThekweni do not predominantly occur in marginal areas. Findings from the study, therefore, point to a need to revisit the questions related to the predominant location of informal settlements in marginal areas. Results of this study have important implications on disaster management, providing important information to individuals, departments, and organisations involved in the allocation of resources in times of floods and landslide disasters.

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Understanding the role of mobile phone and Internet connectivity in rural agriculture within Sub-Saharan Africa

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Abstract

Sub-Saharan Africa (SSA) has 63% of its human population residing in rural areas, who are dependent on agricultural activities for their livelihood. The continuous transformational strides in agronomy as well as recent information communication technological (ICT) innovations (mobile phones and the Internet) have contributed to increased agricultural productivity amidst growing climatic challenges. The role of ICTs in promoting agricultural productivity has been defined in bridging the information gap to farmers in planning, planting, management, and marketing of products for adequate pricing. The fast-growing number of users of these technologies especially in SSA with currently 80% mobile phone subscription rates and 43% Internet connectivity could be interpreted as positive transformation in rural agriculture. This study sought to assess the progress and challenges in this domain for a possible way forward in fostering the integration of these technologies into rural agricultural activities in SSA. The results indicate that the use of these technologies in agricultural activities within the region has complemented the work of agricultural extension officers with information reaching farmers faster than before. However, there have been several challenges among which the high cost of connecting to the internet as well as the availability of relevant information and literacy levels of these farmers stand out. Hence, technological innovation transfer in this region and sector must take a participatory-based approach involving farmers and the various experts to establish what is relevant and applicable within specific communities for the enhancement of agricultural productivity.

Keywords: ICT; SSA; rural; agriculture; crop productivity

Introduction

According to the World Urbanisation Prospects of 2018, almost 90% of world's rural population is within Africa and Asia (AUC/OECG, 2018). The African continent is regarded as a fast-growing region in terms of human population but more so is her rural population which is estimated to add over 353 million inhabitants by 2050 from 2015 (AfDB, OECD, UNDP, 2016). The population of Sub-Saharan Africa (SSA) is usually seen to struggle with hunger despite a majority of this population being dependent on agriculture. The high dependence on agriculture and multiple challenges plaguing this sector (Bjornlund *et al.*, 2020) has made it a priority in the development agenda of this region. The agricultural activities in this region are mainly based on subsistence, with crops grown for home consumption and only excesses are sold. The continuous challenges, especially climate change, have hampered the production to satisfy home consumption let alone 'excesses' to sell (FAO, 2015; Ogundeji, 2022).

The challenge of food insecurity in the SSA has been projected to decrease as undernourishment numbers decrease from 21.4% in 2015 to 14.5% by 2030 (Alexandratos & Bruinsma, 2012). The projected decrease is due to various measures like genetically modified crops being put in place to boost food production. Furthermore, these numbers are obtained with consideration of critical resources required for food production such as land, water, economic and institutional frameworks (FAO, IFAD, UNICEF, WFP and WHO. 2017). Among these frameworks, the land availability factor is one that the SSA should not have issues with since out of the 13 countries globally owning 60% of such land, there are five (38.4%) countries from the region.

The economic and institutional frameworks have shown- greater influence on the level of agricultural production in the SSA than the land and water factors because the former controls access to the latter. In a recent review to assess why the situation is so, Bjornlund *et al.* (2020) identified among the land, water, economic and institutional factors, the high levels of borrowing within the countries of the region. Their debts are usually unaccounted for towards non-productive assets and end up draining from any local financial gains that could have been used to invest in infrastructural development. The investment in these frameworks also requires development of human capital to align with local goals.

There are several diverse approaches being implemented by individual countries as well as regional institutions to address these challenges and to foster improved food production. These interventions range from agronomic to governance of crop production (Bjornlund *et al.* 2020). The connection from these interventions to the farmers is usually through extension officers who deal directly with the farmers at local levels. However, the gap between agronomist or researchers and farmers especially in rural areas in SSA is still wide despite being in the information age (Samuel, 2010). This has been attributed to several reasons amongst which the availability of relevant expert information which is mutually beneficial to the farmers and the economy is also required (Sife & Kiondo, 2010). According to Musingafi and Zebron (2014) there have been propositions by researchers for authorities in the SSA to build capacity of food production stakeholders to enable the exchange of knowledge that can be harnessed for improved agricultural productivity.

The use of ICTs such as mobile phones and internet connectivity has been of great support to these extension workers to be able to communicate with the farmers especially considering the poor road infrastructure of the SSA (Samuel, 2010; Musingafi & Zebron, 2014). The ICTs have also helped these farmers to communicate amongst themselves for local support. Just like with the extension officers, the technologies in the hands of these farmers will play an important role in crop productivity if properly tailored. The information exchanges- could range from providing them with relevant agronomic as well as market information to receiving from them ground-based information that could be used for research. The availability of locally generated information has been identified as part of the challenge to implementing geospatial technologies for improved crop productivity in Africa (Becker-Reshef *et al.*, 2020). There have been well funded projects to implement remote sensing technologies to monitor and predict crop productivity on the African continent, but they have been hindered by availability of local data to validate developed models (Xiong *et al.*, 2017; Becker-Reshef *et al.*, 2020).

In a survey conducted by eLearning Africa across the continent in 2015⁸ to review the impact of ICT on education and development, it was conclusively revealed how beneficial these technologies were to the agricultural sector. It should be noted that the above survey did not only sample farmers but also ICT in agriculture trainers. There was no rural urban divide

⁸ www.elearning-africa.com Report available for download Accessed 12/06/2018

between those sampled. However, the results indicated a general trend, which has been used by most of the funding bodies to ascertain improved connectivity also leading to improved development across the region. While the report showed 90% of respondents agreed on the improvement of food security and sustainability through ICT, 60% did not have sufficient access to the technologies. Farming practices were also improved as agreed by 71% of respondents due to the use of ICTs, which led to a boost in yields as well as income from farming (91%). Noteworthy are the number of respondents (60%) who had insufficient access to the technologies in order to benefit fully in their sectors. The insufficient access was mostly blamed on poor connectivity, electricity supply, high cost of devices as well as services and the lack of government support.

The growth of mobile phone usage even before Internet connectivity in SSA, as all over the world, is to promote communication among humans. This rapid growth especially in Africa is of great relief to remote rural areas where movements or transmission of information is not always easy. The ownership numbers and quality of mobile phones among the population in some SSA countries like South Africa and Nigeria compares well to their counterparts in developed countries like the United States of America (Pew Research Center, 2015). In SSA, some of the phones might be without Internet connectivity or not classed as smart phones. However, just a mobile phone to read or send text messages is good enough to support rural crop productivity.

The ongoing Covid-19 pandemic with numerous lockdowns to slow its spread limited movements of humans leading to communication tools such as mobile phones and Internet connectivity became even more important. The SSA has over 61% of its rural population employed through the agricultural sector, and the connectivity made possible by ICT contributed to their survival during this time. ICT provides rural farmers the opportunity to improve productivity, enhance food security, access to markets and employment opportunities for the high unemployed population (World Bank, 2017). Yet, there is still need for increased connectivity opportunities in rural areas since many people are still without connectivity (Bjornlund *et al.*, 2020). Despite the level of mobile phone-based interventions in these rural areas, there is mixed evidence and limited investigation of their impact. This study thus seeks to understand the involvement of these ICTs (mobile phones and Internet connectivity) and their use in the agricultural sector of rural SSA. This was done through a review of mobile phone and Internet connectivity in SSA in relation to the situation globally, followed by a review of the benefits and challenges of using these ICTs in the agricultural sector to promote crop productivity and food security.

Materials and methods

This study made use of the Sub-Saharan African region as a case study. This region has been described by the United Nations as the part of the African continent that lies south of the Sahara Desert (Figure 1).

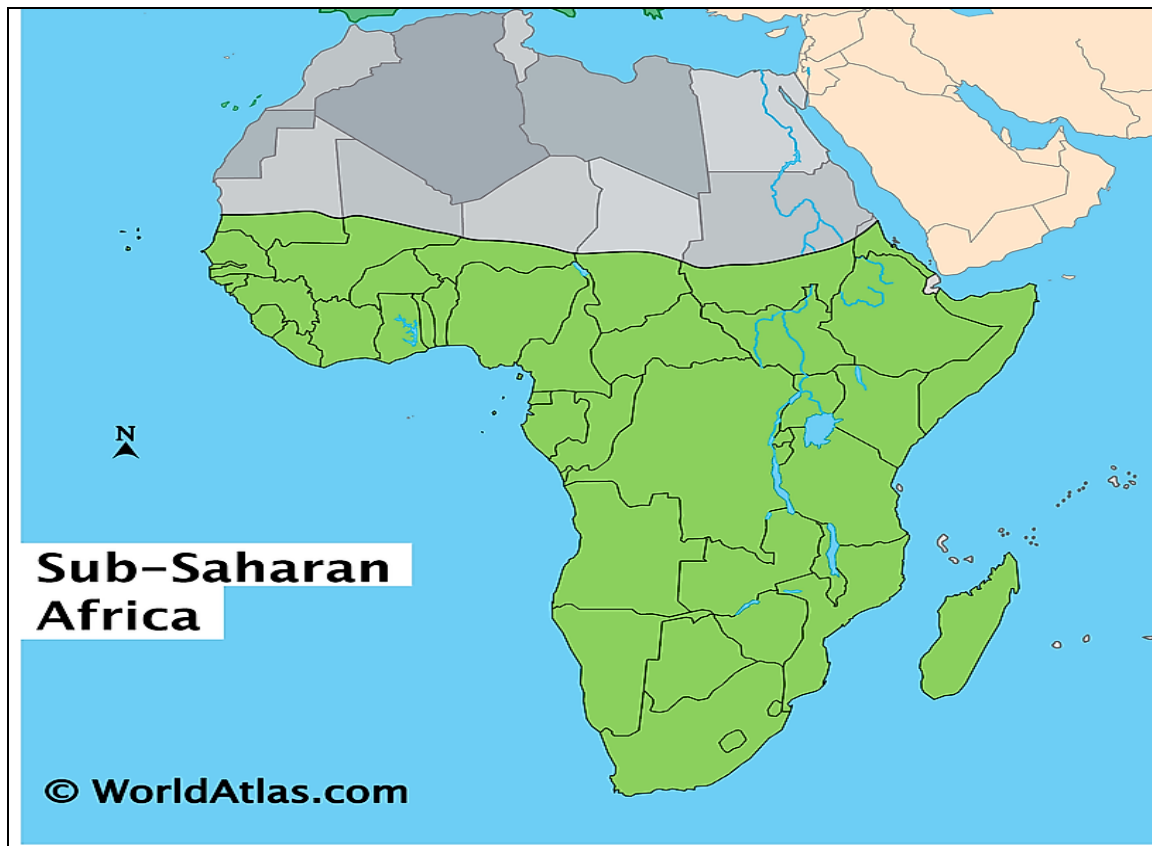


Figure 7: Geographical location of Sub-Saharan Africa shaded in green (Sourced from WorldAtlas.com)

There are several environmental challenges that affect the region, such as high soil erosion, desertification, drought, erratic changes in climatic parameters such as rainfall, temperature, and many others (Fasemore, 2017). These challenges have impacted negatively on various activities across the region but more severely on the agricultural sector where farmers in search of fertile lands keep moving away from the desert encroachments, causing various conflicts (Bjornlund *et al.*, 2020). According to the World Bank the population of this region is about 1.136 billion inhabitants and has been growing steadily and projected to reach 2 billion by 2050⁹. About two third of these inhabitants live within rural areas with farming as the major economic activity.

This study utilised a desktop approach to search for existing literature on the use of ICTs generally in the agricultural sector of this region. Then to understand if the impacts were positive or negative, the trend evolution of mobile phone as well as internet connectivity within the region were assessed. The secondary data were obtained through a survey conducted by the International Telecommunication Union (ITU) which is an agency of the United Nations charged with measuring information communication technologies globally. The data generated from the ITU surveys include connectivity trends across the world including the SSA. The available archived data were downloaded for the years 2001 to 2017 which was available for the region of interest. The ICTs of interest used in this study were mobile phone ownership and Internet connectivity. The numbers are estimated per 100 inhabitants for each ICT per country or region and globally.

⁹ <https://ccafs.cgiar.org/news/big-facts-focus-sub-saharan-africa> Accessed 19/07/2021

The relevant data to show trends of mobile phone ownership and Internet connectivity for SSA over the 2001 to 2017 period were extracted and plotted for graphical presentation. The trend analysis graphs were generated to show how the region has been evolving in connectivity over this period in terms of these ICTs. Thereafter, the average for the countries in the region was calculated to ascertain the trend for mobile and Internet connectivity.

Results and Discussion

Trend of mobile phone subscription and Internet connectivity from 2001 to 2017

The global trends of the mobile subscription as opposed to fixed-phone connectivity show the former growing tremendously from 2007 to 2017 while the latter was decreasing from 2006 (Figure 2). The case of SSA is even so especially with most of the communities not having proper electricity supply to power other information communication technological innovations such as computers (Frempong, 2010). The continuous technological innovations for mobile phones have caused most of these devices to operate like computers and support Internet connectivity. Their uses go beyond making and receiving calls or messages to searching on the internet through Google and producing as well as sharing documents.

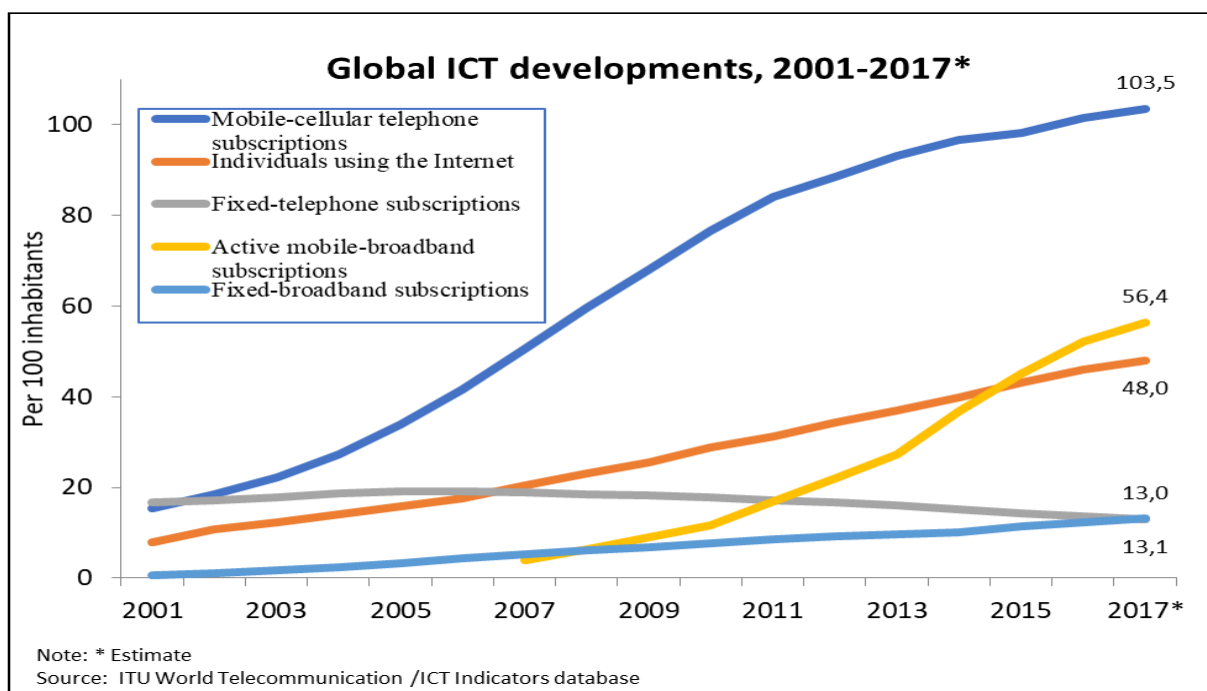


Figure 8: Global trends of mobile phone subscription and internet connectivity

Within the global trend it was necessary to see what the pattern/trend was for mobile phone subscriptions for the regions of the world, including the African continent. The number of persons who were subscribed to a mobile phone network on the continent stood at 77.8% in 2017 per 100 inhabitants sampled (Figure 3).

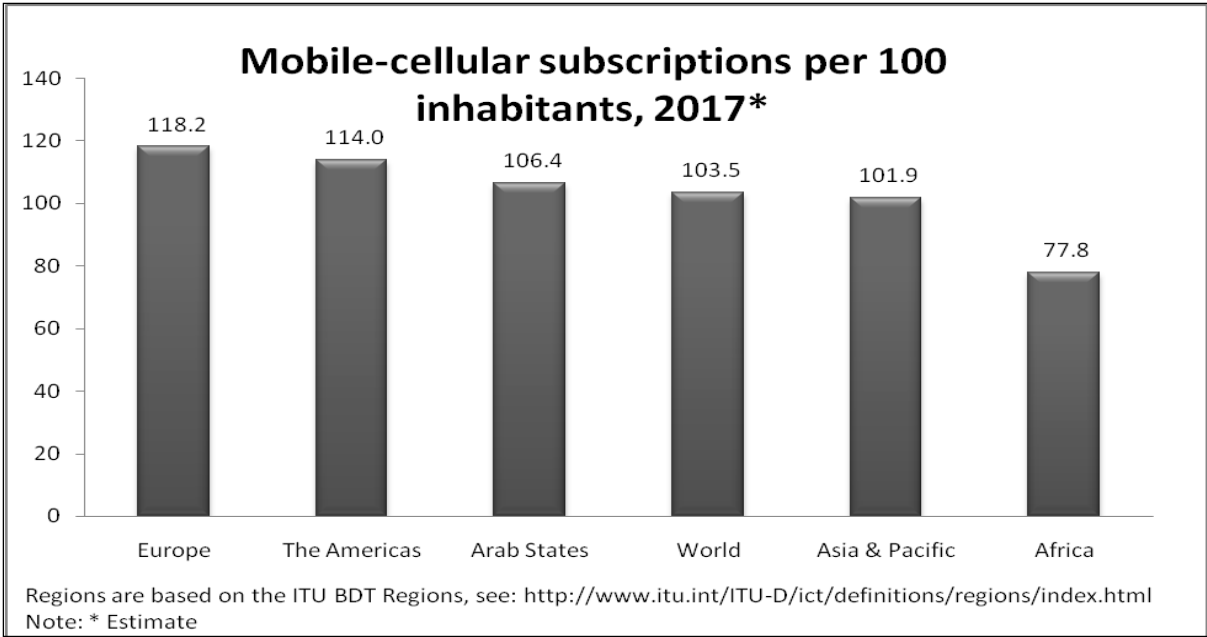


Figure 9: Mobile phone subscriptions by regions of the world

The next aspect of the ICTs in this study was Internet connectivity as a contribution to information exchange for improved crop productivity in these rural areas of SSA. The ITU statistics measure Internet connectivity by the household and individual connectivity (Figure 4; Figure 5). The numbers for the region reflected are dependent upon the economic situation of inhabitants at household and individual levels. The number was quite low at 18 persons per 100 persons sampled compared to the rest of the regions.

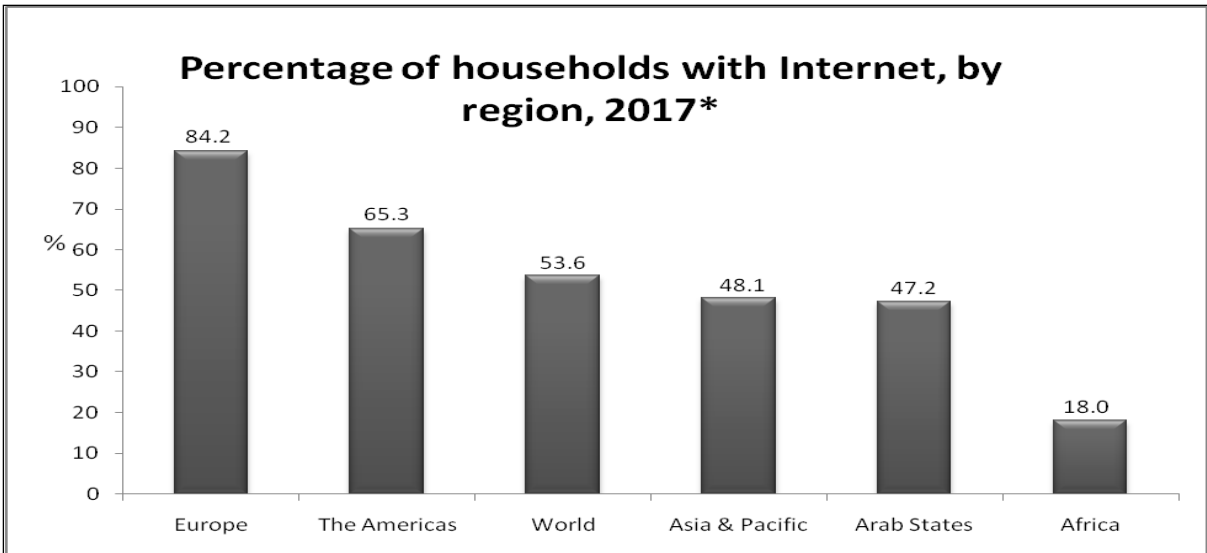


Figure 10: Household internet connectivity by different regions of the world

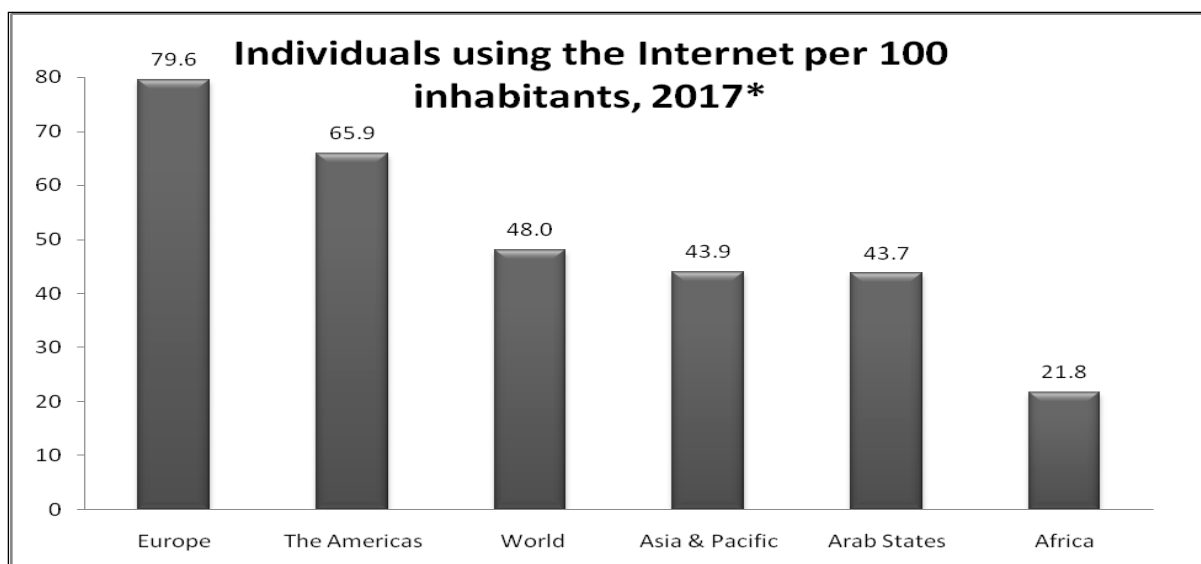


Figure 11: Individuals with Internet connectivity by different regions of the world

To understand exactly what the trends of mobile phone subscriptions and Internet connectivity were for the region during this period, the numbers were extracted for each country in the region according to the World Bank listing. An arithmetic average was calculated for all countries per year to plot the values by years. The generated trend shows an increase below the global values but growing steadily (Figure 6).

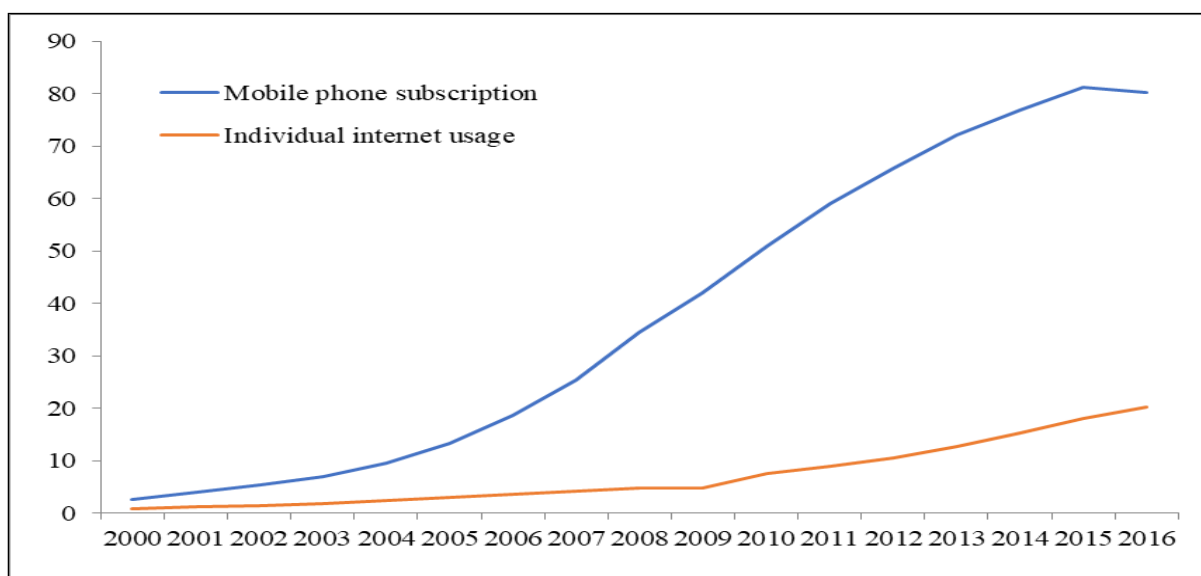


Figure 12: Trend of mobile phone and Internet connectivity across SSA from 2001 to 2016 source?

Benefits and challenges of ICTs usage in the agricultural sector of rural SSA

These recent ICT innovations (mobile phone and Internet connectivity) are expected to boost agricultural productivity in many ways. According to the United Nations Food and Agricultural Organisation research based on information search or sharing can support this boost (FAO, 2013). One of the searches is for market prices with mobile phones by farmers within rural

areas. The cost of these searches through data for connectivity without any government subsidy becomes high. Even in cases where the search is not on the internet but through the services of third parties involved in order to cover transport cost to reach these areas is charged to these farmers (Nzie *et al.*, 2016). The contribution of ICT innovations has also been seen as response to environmental sustainability with facilitated virtual communication which reduces vehicle transportation to farmers (Asongu *et al.*, 2013). Furthermore, the benefit of mobile phone usage among urban traders in Cameroon is a good tool for economic development (Ngange & Beng, 2017). The conditions surrounding the use of the device in urban areas might not be the same as in rural areas in terms of power or network connectivity and other factors.

Increased agricultural productivity because of the use of mobile phones and Internet connectivity has been established for information sharing (Lio & Liu, 2006). In a similar study it was established within a community that the lack of phone devices among farmers translated to no information about the type of crops grown or production practices (Fafchamps & Minten, 2012). In another study, Tadesse and Bahiigwa, (2015) found that few farmers in India used their mobile phones to search for relevant information because the link to agricultural production is not available. This finding was contrary to a similar one on fishermen where information sharing through their mobile phones enabled increase fish productivity in the same country (Mittal *et al.*, 2010). In Zimbabwe the challenge of mobile phone support to enhance agricultural productivity was linked to literacy levels (Masuka *et al.*, 2016). Therefore, from the above studies there are three fundamental requirements for mobile phones to increase agricultural productivity *viz*: ownership of a relevant/suitable device, literacy level and relevant information to search. The bottom line to the above factors is connectivity to the Internet which excludes many of these communities because of no network coverage e.

The usage of mobile phones in rural areas is mostly through phone calls or short messaging services (SMS) which are considered as cheaper options. Communication linked to their agricultural activities is generally during planting and harvest periods when they need farming inputs and searching markets respectively (Musingafi & Zebron, 2014). It would be of interest to find out the reason for low levels of communication from these farmers during their crop growth stages which could be considered critical for improved yield or maximal productivity. The facilitated communication with ICTs among these farmers has also enabled cooperation at different levels of their activities but more especially in marketing. In the marketing cooperation, these farmers have gathered their produce to bulk quantities which could easily be moved by dealers (who could be farmers too) to bigger markets in urban centres or even exported internationally.

The idea of seeking market prices before marketing their produce has also translated into better price bargains by these farmers. The farmers are also able to search for more lucrative markets where their produce could be sold. The price bargaining and lucrative market search have resulted in improvements in the rural economies as well as livelihood of the people (Masuki *et al.*, 2010), through relatively higher incomes from sales. Elsewhere, including Zimbabwe, farmers make and receive payments as well as to insure crops using mobile services. By consulting remotely on mobile phones for supplies and product markets prices, for advice as well as by using mobile financial transactions, farmers save time and finances that would have been used on travelling (Nyamba & Mlozi, 2012).

Nonetheless, these benefits have not been without challenges that while some rural communities in SSA break through others have not been able to overcome these challenges. One of the underlying challenges has been the levels of illiteracy and ICT language comprehension among these rural farmers within the region. Some studies identified high

illiteracy levels as a challenge to successful application of mobile phones in their agricultural activities in Kenya and Ghana (Frempong *et al.*, 2007; Baumüller 2016).

The results from a random evaluation of rural households in Niger showed that they were unable to improve sales even using the farm-gate prices received on their devices, and therefore no improved livelihood (Aker & Ksoll, 2016). In such communities the rural population has remained poverty stricken despite their efforts in agricultural activities. This also indicates the relevance of the information shared through these connections as to what crops are grown, how they are managed for improved yields and subsequent marketing. The empirical research into this has also established that most rural farmers do not have access to relevant information. A study evaluated their knowledge of integrated pest management on farms and realised that low literacy levels amongst the farmers and scarce visits or support from extension officers caused poor identification of pests and pesticide to be applied (Abang *et al.*, 2014). The information gap has been the reason why mobile phone connectivity in Zimbabwe boosted rural agricultural activities from farm management to supply of produce in the markets thereby reducing losses at pre- and post-harvest (Masuka *et al.*, 2016). Another scenario in Cameroon showed no available information on pesticide application levels, times, dosage or toxicity to the health of either crops or environment as a whole and humans inclusive (Sonchieu *et al.*, 2017).

It has been ascertained that ICTs generally have a role to play in agricultural productivity and rural development (Goyal & Gonzalez-Velosa, 2013). While the connection to agronomic information relevant for crop production is provided, there is also an opportunity to close transactional cost for the farmers which will boost their crops reaching competitive markets with better prices. One of the experiences in rural agriculture has been to have dealers or middlemen to market their produce in urban markets without adequate knowledge upon which the farmers are guided (Mujeyi *et al.*, 2021). Nowadays with a simple phone call, these farmers can find out the selling prices and other vital information to guide them in deciding on marketing their produce or in some cases deal directly without these middlemen. In this, the economic power of rural areas is achieved (Jha, 2013; Chhachhar *et al.*, 2014). ICTs have thus improved rural agricultural marketing, has brought them new products as well as principles to improve yields through new cultivars or engaging in consumer needs and trying to be relevant (Lashgarara *et al.* 2011).

Some challenges of mobile phone usage in agriculture within rural SSA

There have been projects like Esoko (<https://esoko.com/>, accessed on 05 November 2022) undertaken around SSA to facilitate the use of these ICTs for their benefits because of identified challenges. The level of illiteracy among these rural communities is one of the aspects since the necessary information will not reach target audience. Training on using other functionalities of the devices effectively such as loading airtime, voice note records, and texting through local languages have been conducted like the Esoko example above. There are also issues of connectivity with poor signals within some of these rural areas with mobile phone servers from various providers (Masuka *et al.*, 2016).

Also identified was the issue of electricity availability to charge mobile phones, which is common across the region with low electricity connection. There have been experiences by the researcher in rural areas of Cameroon where people must travel to nearby towns with electricity connections just to recharge power to their mobile phones. Others travel or must position themselves at specific locations in their villages to get mobile phone signals to receive or make a call or send an SMS. The core of these challenges has been identified as the lack of appropriate policies and regulations within these countries to create competitive environments for other operators of better services to be provided to their populations (Gillward & Stork,

2009; Frempong, 2010; Gillward, 2010). These policies should regulate implementation of relevant services by the providers without discrepancies in signal strength and cost. The benefits of ICTs in upgrading the socio-economic developments can be achieved through necessary regulations as well as implementation within the countries (Etwire *et al.*, 2017). Some of the countries are embracing the open markets for telecommunications by selling most shares in state-owned companies as in Ghana; others such as Kenya are doing the opposite and through inadequate management have allowed the end-users to bear the higher prices (Waema *et al.*, 2010), thereby keeping poverty-stricken rural farmers unable to access these facilities. In a more recent review of the adoption of these ICTs innovations in the agricultural sector of Africa, the lack of adequate ICT policies is listed among the challenges (Ayim *et al.*, 2022).

What is the way forward or possible opportunity to exploit?

The rural parts of SSA are highly dependent on agriculture which requires a lot of information (agronomic or market) in addition to taking care of the other challenges to be successful. The positive trend shown by the number of mobile phone subscriptions and Internet connectivity in the region is a medium for transmitting more accurate and relevant information to farmers. These farmers usually rely on extension workers to bring or take agronomic information with the aim to improve productivity. These extension workers usually must take the information to or from researchers as well (Oladele, 2015), or in the case of market related information, the use of dealers or middlemen. In all of these, for improved agricultural activities and more specifically crop productivity, the information flow chain must be considered and shortened as it could hinder or prevent the goal of improving crop productivity from becoming a reality.

The transmission of this information must be correct and done in time to be able to obtain correct results. Using extension workers to assist farmers through rural SSA with difficult road systems to navigate could pose a risk of delayed information missing the target or objective (Mittal & Mihar, 2012; Nyamba & Mlozi, 2012). For instance, most of the crop production in this region is rainfed and understanding seasons can be vital to appropriately implement planting or crop management activities. During the planting season some days might be more suitable for planting than others if the weather conditions are rightly monitored. When weather forecasters envisage such information and transmit it through extension officers it might reach the farmers too late. Similarly, the outbreak of a crop disease could be readily stopped with timeous intervention before it ravages the area if the information could reach the farmers in time.

However, with the use of mobile phone, Internet as well as other ICTs the above transmission hitches could easily be addressed. With the information chain almost like a feedback mechanism, the farmers as end-users of the information can also be made partners in the chain to give feedback on their experiences which will validate suggestions or models. Then a library of local information will be created that can be useful over a long run and can be integrated with other multidisciplinary approaches or interventions such as geospatial sciences or specifically remote sensing to support productivity. The library will also serve as base information for other technological models such as artificial intelligence (AI) (Becker-Reshef *et al.*, 2020). Through AI not only will there be quick access to information by farmers but also - despite their literacy levels - creative ways to access it through colour signal messages for each cropping activity.

There is also the opportunity of easily rallying farmers to distribute information provided by these ICTs. In the past, farming groups had their meeting days to disseminate information but with an emergency need, rallying these members can be futile (Masuki *et al.*, 2010). However, mobile phone communication does improve this. There are also established telecentres within

these rural areas with teleconferencing capability that farmers can use to benefit from information sharing from experts without them physically travelling to them, as in the case of Uganda (Masuki *et al.*, 2010). Such sessions become interactive with these experts and the farmers to gain more valuable information which might have been distorted along transmission chains with extension officers.

Empirical studies have also established that the relationship between these technological innovations and agricultural activities in terms of transactional cost (airtime or Internet data cost) will increase production cost in the beginning of implementation (Masuka *et al.*, 2016; Nzie *et al.*, 2017). This shows a negative relationship that improved technological innovations lead to increase cost which translates to increased cost of agricultural activity for the farmers. However, the use of mobile phones still illustrated a positive relationship overall since they are useful without airtime or data to receive calls or text messages including multimedia (Masuka *et al.*, 2016; Nzie *et al.*, 2017; Ayim *et al.*, 2022). Challenges exist in terms of searching market prices, as well as adequate information on sustainable planning and management of the farms and produce getting to final destinations or markets in good conditions as discovered in Zimbabwe (Masuka *et al.*, 2016).

Conclusion

This study has revealed a positive trend of ICTs and connectivity among the population of the region and hope that this trend will continue in the future. The challenges identified should also be addressed to enjoy the benefits of these ICTs in crop productivity. This will not only boost rural economies but also improve food security to the growing population of this region. Along with the positive trend of amongst farmers, there is room for this to be leveraged to improve crop productivity. However, some of the challenges identified also need to be considered especially in policies as well as infrastructural support and building capacity of these farmers. The Covid-19 pandemic has made it even more imperative for governments to consider developing more of the communication infrastructure and this could not be more urgent than it is already for SSA which is hunger-stricken but can no longer afford to wait on imported food aid. These developments will create platforms to stimulate not only growth in crop productivity but also economic growth.

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