Assessing the Water Scarcity Trends in Amathole South Africa: Recommendations for Climate Adaptation Policies

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Abstract

Water is at the core of sustainable development and is critical for human survival, healthy ecosystems, and socio-economic development. South Africa is faced with unprecedented environmental changes, which can be linked to climate-related disasters such as water scarcity or drought scenarios. Several studies suggest that these changes are likely to accelerate in the future thereby causing adverse effects on the water resource availability. The Eastern Cape Province of South Africa, especially Amathole District Municipality (ADM), has recorded a high number of climate change–related phenomena including prolonged water scarcity conditions. This study assesses the water scarcity trend in Amathole District from 2017 to 2023 using selected indicators so as to suggest responsive climate adaptation policies for the region. To accomplish this, the Standardized precipitation index (SPI), Withdrawals to Availability (WTA) Ratio, Palmer Drought Severity index (PDSI) and the Normalized Difference Vegetation Index (NDVI), were utilized to access the water scarcity patterns and variations. The SPI shows that February is the only observed month for extreme wetness as the water resources fluctuate throughout the whole year. The WTA identified Mnquma, Mbhashe, and the border areas of Raymond and Amahlathi Municipalities as the areas with the highest domestic water withdrawal. The PDSI indicates that areas experiencing mild drought conditions are limited to socioeconomic development. The NDVI shows the worsening water scarcity scenario with a severity peak in 2023. Based on these results, climate adaptation policy should be targeted at promoting water harvesting & conservation and capacity building for communities towards adopting sustainable agricultural practices. The results also emphasize the need to strengthen the institutional capacity of the district water governance.

Keywords: Water Scarcity, Sustainable Development, Climate Adaptation, Amathole District Municipality (ADM), South Africa

Introduction

Water is one of the most vital resources in the world, it is on this resource that humans and ecosystems thrive. Fundamentally, water in all its forms is an essential and central resource (Urama and Ozor, 2010; Durrani 2020) in achieving sustainable development. However, climate change, a major global environmental challenge of the 21st century, poses a severe threat to water resources through increased occurrences of droughts and floods. These impacts have aggravated water stress, injustices, access and scarcity in diverse affected regions (UNECA, 2011; Ward, 2023). In Africa, where infrastructure for reliable water supply is often insufficient, the effects of climate change on water resources are particularly concerning (Cosgrove & Loucks, 2015). It has become a global priority for all countries to address the compounding impact of climate change on water resources in order to ensure their sustainability and equitable distribution.

South Africa, in particular, is highly vulnerable to climate change due to widespread poverty and inequality. Prior integrated climate assessment models show that climate change remains a critical variable to the demand and supply of water in South Africa (UN, 2016; Apraku *et al.*, 2023). The Amathole District in the Eastern Cape Province epitomizes these challenges, as it is experiencing significant water shortages and increased vulnerability as a result of the impact of climate change. The district's dependence on cattle ranching and crop production makes it especially susceptible to water scarcity issues (Popoola *et al,*.2019). To address these challenges using a localized approach, there is a need to embrace the bottom-up strategies, which considers where the risks and impacts are mostly felt (Bardosh, 2014). As climate change continues to threaten the distribution of water resources in many regions of the world, some communities are taking steps to adapt to its fluctuations. However, these measures are proving insufficient as the impacts of climate change intensifies, which underscores the need for a comprehensive climate adaptation strategy (Ziervogel, 2018). Recent studies have proven the urgency for developing policies, adaptive procedures and risk management practices for the water sector due to the threats posed by climate change (Hughes et al., 2023). The overall wellbeing and safety of communities are highly associated with water availability, which makes the need for effective climate strategies essential for successful adaptation.

Although surface water fluctuations are a visible effect of climate change, groundwater quality is a primary concern for stakeholders. Groundwater, which is essential for human consumption and agricultural irrigation, is directly influenced by the changes in rainfall and surface water (Bagdi et al., 2023). However, thorough understanding of how climatic conditions quantitatively and qualitatively affect water resource availability will help us understand the status of water availability in AMD, which implies that to effectively understand the dynamics of water scarcity in AMD, we need to take into account both the groundwater and surface water dynamics, considering its critical role in terms of human consumption and agriculture. In this regard, researchers and policymakers continue to engage in these issues and propose different policies that will enhance water accessibility. Makaya *et al*., (2020) advocated for institutional coordination to improve water provision to communities, while Palmer *et al*., (2017) proposed an adaptive integrated water resource management in South Africa's municipalities to enhance water provision. Similarly, Park *et al*., (2009) supported the policy of improving free basic water provision to the rural and vulnerable groups in communities.

Despite these contributions, there is still a notable research gap in the understanding of the trends of water scarcity in AMD to drive responsive policies that will drive climate adaptation at the community level in

Amathole district to address the water scarcity issues. The approach of this study ensures that targeted policy interventions are rooted in the reality of the locality. The significance of this study is further emphasized as the process for climate adaptation includes conducting vulnerability assessment, selecting adaptation options and evaluating these options (Goose et al., 2013). This study aims to address this gap by assessing and analyzing Water Scarcity Index (WSI) using the Standard Precipitation Index, Withdrawals to availability Ratio, Palmer drought index and Normalised Difference Vegetation Index results in order to inform policy recommendations that will promote sustainability practices and ensure long term water security for the region.

The aim of this study is to assess water scarcity trends in Amathole District and provide actionable recommendations for climate adaptation policies and strategies to ensure long term accessibility of water resources for the region. The objectives of this study are to collect comprehensive data on water availability, demand and climate variables within the Amathole District Municipality. Calculate the Water Scarcity Index (WSI) using spatial analysis framework (GIS) to quantify the severity and patterns of water scarcity in the region. Hereafter, the insights from the analysis will be used to recommend climate adaptation strategies for the district towards enhancing water resource management.

Study Area

Amathole District Municipality (ADM) in Eastern Cape Province of South Africa is located between 32°34’29.99” S and 27°12’17.40” E with an elevation of 6440 ft and a total population of 892,637 (STATASSA ,2021). The district covers a land area of 21,595 km^2 (8338 sq.mi) with approximately 200 km of coastline (SANBI ,2021) and comprises six local municipalities, which include Amahlathi, Ngqushwa, Great Kei, Mnquma, Mbhashe and Raymond Mhlaba. The district is ranked as the second richest biodiversity in South Africa (SANBI, 2021). This area is characterized by two bio-geographical regions, including the warm temperate south coast and the subtropical east coast (Nel *et al*., 2021).

ADM has a subtropical climate with rainfall peaking in the summer (Peres, 2010). The average rainfall is 400 mm/year but fluctuates between 700 and 1000 mm/year in some areas (ADMIDP, 2012; Afuye *et al*., 2020). In addition, the average monthly temperature ranges between 1.5 and 2.5 °C and the winter temperature reaching an average of 21 °C, while the summer reaches an average temperature of 28 °C, ADM comprises different eco-topographic undulating grassland and the Amathole Mountain range along the Wild Coast from diverse landscape dynamics and climate, which results in various forms of habitats (Berliner 2021; Mucina 2014). The formation of habitat in ADM varies as a result of the shifting climate and associated influencing factors including soil, topography and vegetation types across the landscape, which are crucial in vegetation distribution (Afuye *et al*., 2020).

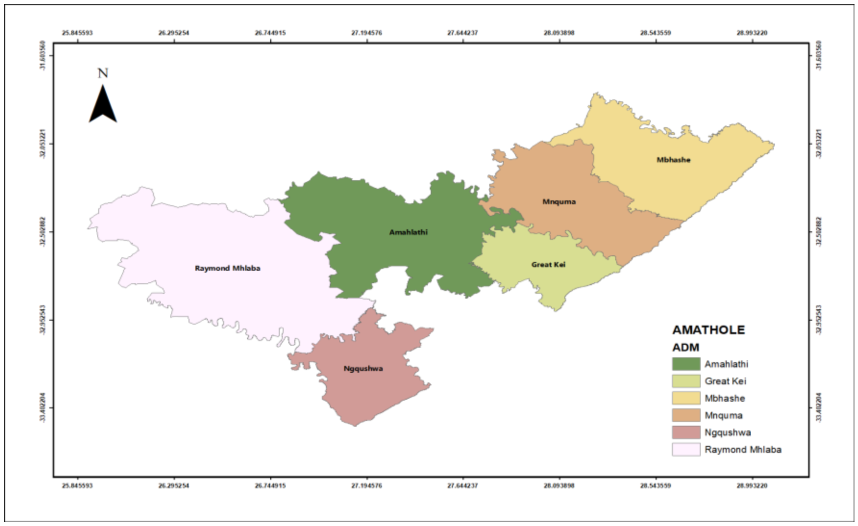

Figure 1: Study Area Map showing the local municipalities in Amathole District

Methodology

This study adopted a multi-technique approach for analysis. It is important to note that there are various tools and methods of assessing and monitoring scarcity of water or water stress patterns, which range from traditional data collection methods, statistical analysis to remote sensing techniques. However, many of the traditional methods are perceived as laborious, time-consuming and expensive (Bruntrup and Tsegai, 2017). Recently, GIS and remote sensing technologies (Chokngamwong and Chiu, 2006) have made strides in bridging this gap. Dyosi *et al.*, 2021 explored drought occurrence in Amathole District from 2007 to 2017 using remote sensing technique. Unlike ground-based conventional techniques, satellite remotely sensed data provides an up-to-date larger spatial and temporal coverage. The available remotely sensed data are easily manipulated, analyzed, interpreted and stored using GIS (Sruthi & Aslam, 2015). This chapter discusses the execution of the overall methodology in this study.

Dataset Used for This Study

The software and datasets utilized in this research are summarized in Table 1 below.

Table 1: Software and Datasets used for this study

S/N	Software	Source/Application	Website
1	Precipitation Data (SPI)	NASA	https://power.larc.nasa.gov/data-access-viewer/
2	Landsat 8 OLI	USGS	https://earthexplorer.usgs.gov/
3	ArcGIS, QGIS	Band combination, Image enhancement, Clipping, Study Area map, Data visualization and presentation of the layout	Open source
4	Microsoft Word	Project documentation	Open source
5	Math Type	Mathematical Equations Drafting	-
6	Excel	SPI chart plot	Open source
7	R-Language	SPI calculations	Open source

Water Scarcity Indices

Standard Precipitation Index (SPI)

Water scarcity can cause significant social, economic, and environmental damage. A water scarcity risk map can assist decision-makers in identifying the region's most vulnerable to drought and implementing proactive measures to alleviate its impacts.There are several widely used standardized Water scarcity/drought indices. The Standardized Precipitation Index (SPI), developed by McKee et al. (1993), enables the measurement of precipitation deficits and surpluses over various accumulation periods. It is based solely on the accumulated precipitation for a given time period (e.g. over the last 30 or 60 days), compared with the long-term average precipitation for that period (NIWA). In order to acquire a monthly temporal resolution, the SPI is computed by adding up the daily Multi-Source Weighted-Ensemble Precipitation (MSWEP) precipitation across n months (referred to as accumulation periods). The percentiles of the monthly precipitation readings are then computed and ranked. The amount of zeros is taken into account in accordance with Stagge et al. (2015) guidelines. The drought indices show that conditions are dryer than usual when their values are negative and wetter than average when their values are positive. When the drought index falls below zero, an area is deemed to be experiencing drought.

$$SPI = (P - P^*) / \sigma_P$$

Where P =Precipitation

P^*= Mean precipitation

σ_P= standard deviation of precipitation

Table 2: SPI Range and Category

SPI Range	Severity
>2.00	Severely wet
1.5-1.99	Very wet
1.0-1.49	Moderately wet
-0.99-0.99	Near normal
-1.0- -1.49	Moderately dry
-1.5 - -1.99	Severely dry
<-2.00	Extremely dry

Withdrawals to Availability (WTA) Ratio

The WTA ratio (Abubakar, Jabir & Muhammed, Ibrahim. (2020). Spatial Index of Water Scarcity in Nigeria in 2010. is a water scarcity index that compares total water withdrawals to available freshwater resources. It considers withdrawals from domestic (D), industrial (I), and agricultural (A) sectors and divides them by the annual mean river runoff (MARR). The data required for this includes runoff data from the NCA: Climate Data Guide. Land use data from Global land use/land cover with Sentinel-2 and deep learning with a resolution of 10m, Population data (OCHAcensusdatabase), Livestock Data (FAO) and Industry data (Amathole district report 2022).

Palmer Drought Severity index (PDSI)

A regional drought indicator that is frequently used for tracking drought occurrences and determining the true scope and severity of drought episodes is the Palmer Drought indicator (Palmer, 1965), also known as the Palmer Drought Severity Index. For the purpose of this study, the long-term drought was successfully identified using temperature and monthly precipitation time series data. As shown in the table below, the magnitude of PDSI shows the degree of the divergence from normal state (NIDIS, 2020).

Table 3: PDSI Values and intensity

PDSI Values	Intensity
DSI = 0	Wetness (no drought)
$0 < DSI \leq 0.99$	Mild drought
$0.99 < DSI \leq 1.49$	Moderate drought
$1.49 < DSI \leq 1.99$	Severe drought
$DSI \geq 2$	Extreme drought.

Normalized Difference Vegetation Index (NDVI)

The Normalized Difference Vegetation Index has been used to estimate the cumulative effects of rainfall and vegetation over a certain time period (Xiong and Wang, 2022). Hence, it is a relevant tool in remote sensing for assessing vegetation health, which is directly correlated with water availability. By analyzing changes in NDVI values over time, we can effectively monitor water scarcity occurrence in a region. Hence, this index was used to determine the value and distribution of NDVI in Amathole. It is one of the components in the computation of the Normalized Difference Drought Index (NDDI) to determine the drought severity in the study area. The aim is to compare NDVI values over time, to identify areas experiencing abnormal vegetation decline which will indicate potential water scarcity conditions. The NDVI calculation is important because the value and distribution of NDVI can describe vegetation cover and density, where they play an important role in maintaining the balance of ecosystems (Xiong and Wang, 2022). The calculation and mapping of NDVI in this study used Landsat 8 OLI/TIRS images of the red band (band 4) and near-infrared band (band 5) with a spatial resolution of 30 meters.

The NDVI calculation formula (Rouse *et al.*, 1973, Lazo *et al.*, 2019) is:

$$NDVI = \frac{\rho NIR - \rho R}{\rho NIR + \rho R}$$

Where ρNIR : spectral reflectance band near-infrared (band 5)

ρR : spectral reflectance band red (band 4) The NDVI value ranges from -1 to 1.

If the NDVI value is closer to 1, it indicates that the vegetation cover in the area is getting denser. On the other hand, if NDVI is closer to -1, the site has a non-vegetative surface such as built-up land or open land. Areas with high vegetation cover generally correlate positively with water stored in the soil (Lazo *et al.*, 2019) as a result, the site will be more protected against drought.

Results

Standard Precipitation Index (SPI)

In this study, four (4) SPI were taken into consideration (as shown in figure 2 below), for the analysis of water scarcity severity. The SPI 3 revealed that water scarcity situations in the months March, May, June, July, August and September in 2023 were moderate to severe, while an extreme occurrence of wetness was observed in the months of February, September and October. The SPI 6 showed a moderate to severe water scarcity pattern in the months March, April, June, July, August and September, with extreme wetness in the month of February alone. Observations from SPI 9 show moderate to severe water scarcity was observed in the months March, April, June, July, August and September with extreme wetness in February. The analyses of SPI 12 depicts, moderately to severely dry days recorded in March, April, June, July, August and September. Extremely wet days were recorded in the month of February.

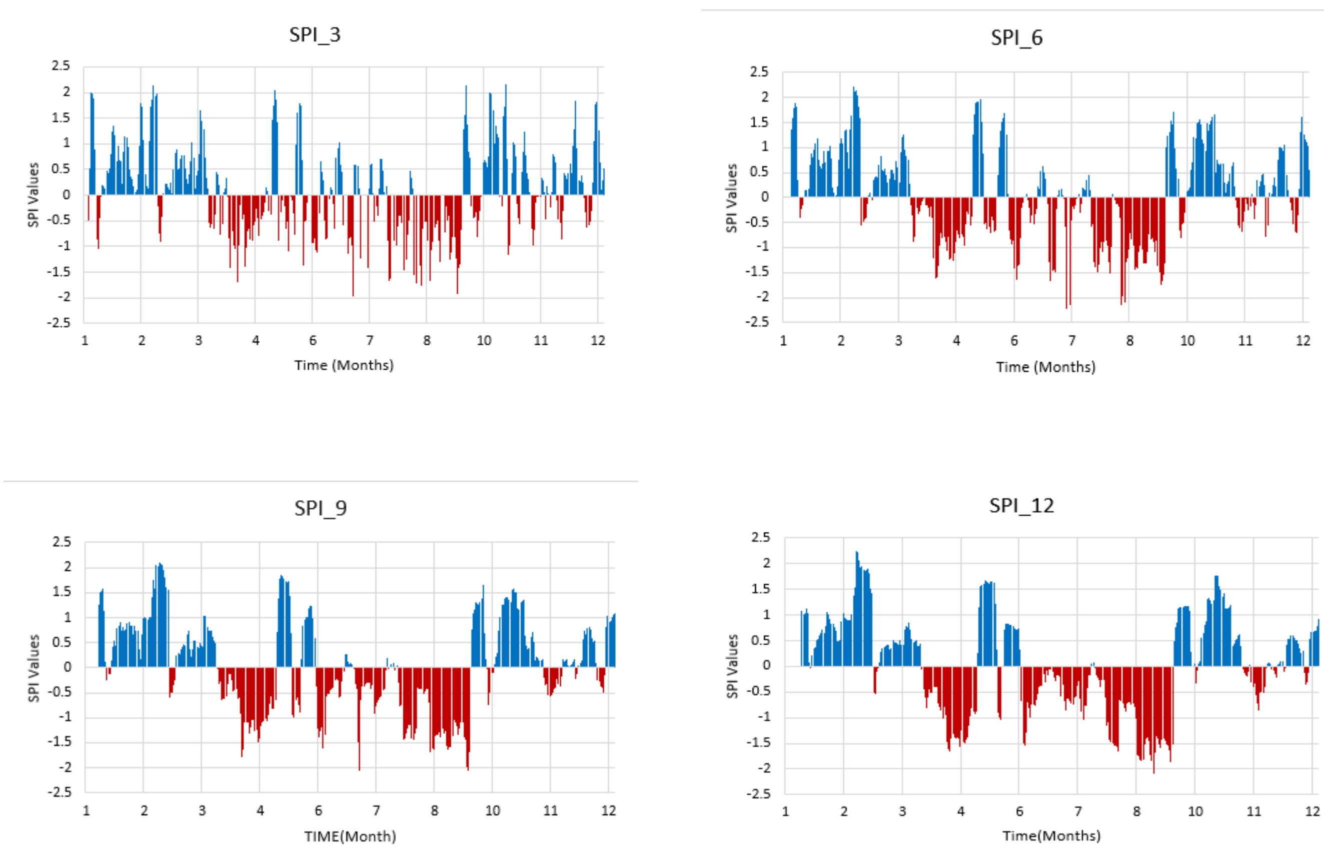

Figure 2: (Withdrawal to Water (WTA) ratio

High domestic withdrawal of water is major in Mnquma, Mbhashe, and the Border of Raymond and Amahlathi Municipalities, as shown in Figure 3, which contributed to most of the overall withdrawal in the region. This represented the high-density population in those areas directly contributing to the withdrawal, however, areas in the dataset that had zero figures for populations less than (1*1 km) grid cell and were unaccounted for. Both crop farming and livestock rearing are common in the Amathole region, but livestock farming is more prevalent. This is because Amathole is a moderately dry region and crop production relies heavily on irrigation, which makes livestock rearing a more suitable and practical choice for the region's conditions. There was moderately high total withdrawal in the Northeastern parts of Amathole where crop and livestock production are common. Figure 3 shows a high surface runoff available in the Northeastern part and central region of Amathole.

The scarcity levels in Amathole for the year 2023 according to the threshold given in Table 3 show low water stress in the majority part of the district, however, some municipalities experienced high water stress. Mnquma, Mbhashe, and the Border of Raymond and Amahlathi have shown high levels of water stress which corresponds to the withdrawal rates in those regions. This also shows a similar result with the Palmer Drought Index below showing very high drought indications in those regions.

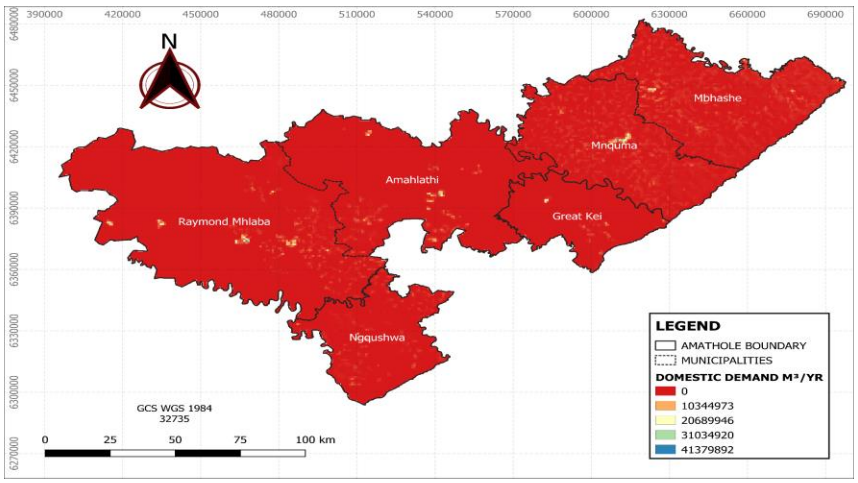

Figure 3: The domestic withdrawal of water in Amathole District

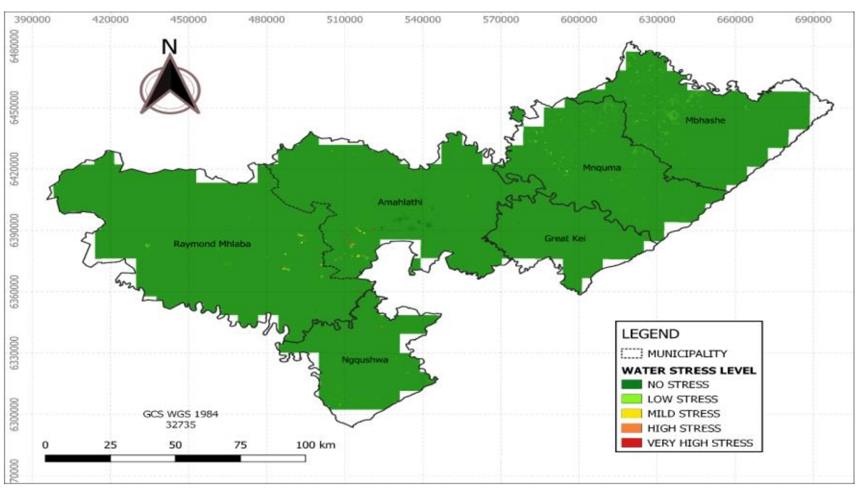

Figure 4: Water stress levels from the WTA ratio for Amathole

Palmer Drought Severity Index (PDSI)

The PDSI raster map (as shown in Figure 5 below) categorized the Amathole district into areas with different levels of water scarcity severity. The map indicates a spatial variation in drought conditions across the district. The PDSI values vary significantly across the Amathole District, suggesting heterogeneous water scarcity conditions. The southern portion of the Amahlathi sub-district is experiencing mild drought conditions (-0.8 PDSI), while the central region, encompassing Raymond Mhlaba, Amahlathi, and Mbashe, shows moderate drought relief (1.79 PDSI). The northern parts of Amahlathi, Mnquma, and Mbashe were shown to be experiencing significant drought relief, with PDSI values ranging from 2.725 to 3.66, indicating relatively wet conditions.

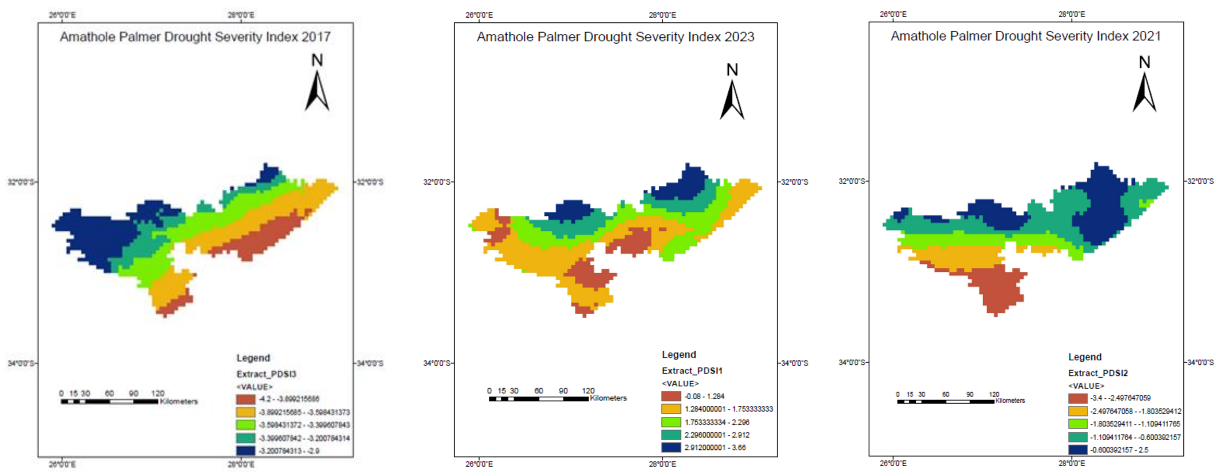

Figure 5: Palmer Drought Severity Index (a) 2017 (b) 2021 (c) 2023.

Figure 4. Normalized Difference Vegetation Index (NDVI)

The analysis of the NDVI indicated that there was a distinct difference in water pattern within the study period. The negative values of NDVI (depicted in orange color) increased significantly from the year 2017 to 2023, which means that the water scarcity scenario peaked in the year 2023. Spatially, the regions of Raymond Mhlaba and Amahlathi had the most visible change over time. In the figure 7 below a graphical overview of the spatial trend and pattern of the water availability and scarcity scenario is shown revealing the intensity and severity of the water scarcity from year 2017 to 2023.

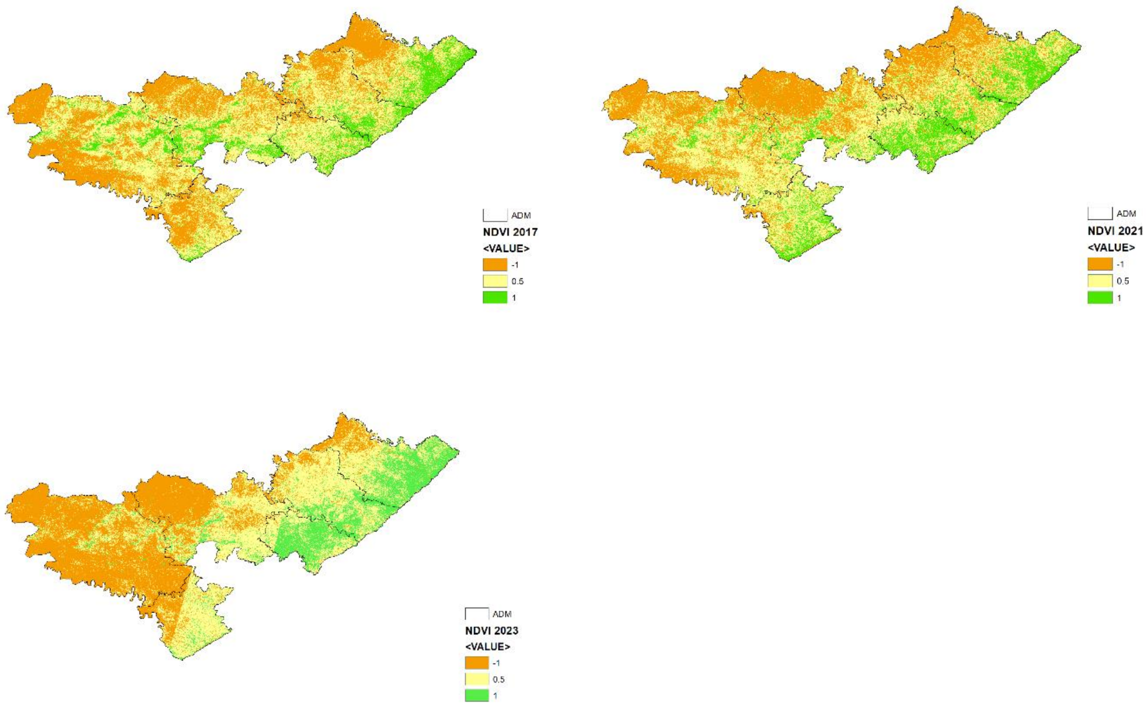

Figure 6: Spatial Distribution of Water Scarcity based on NDVI (a) 2017 (b) 2021 (c) 2023.

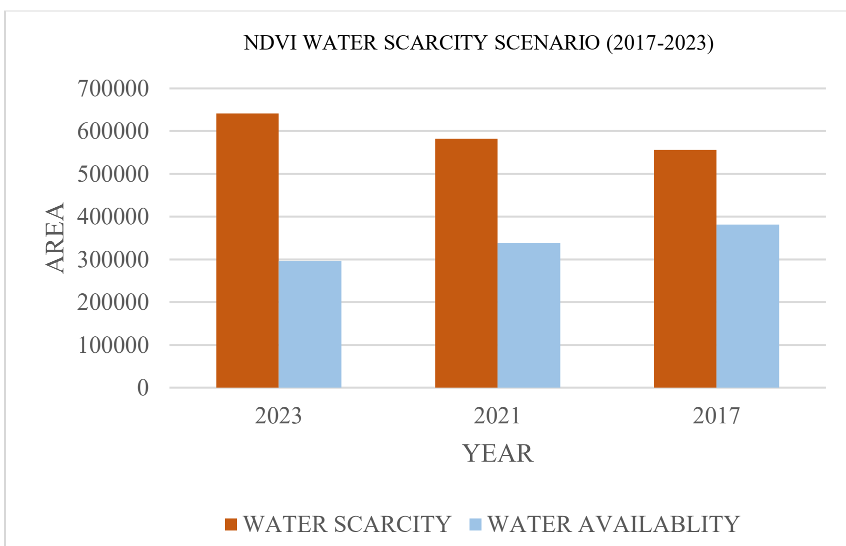

Figure 7: Graph showing the spatial extent of Water scarcity and availability (2017-2023)

Discussion and Implications

The study revealed a varying water scarcity condition in the Amathole district, South Africa. The SPI results showed that the water scarcity issue is moderately prominent in the months of March, April, June, July, August, and September. February is the only observed month for extreme wetness. The seasonal variations indicate the challenges with water resources as they fluctuate throughout the year. Interventive measures must become adaptive and consider the variability of water availability. This variability implies that adaptation measures must be responsive to the changing water availability especially in the month of february for communities to prepare ahead of recurring dry months.

The WTA ration analysis identified the regions with high domestic water withdrawal, particularly in Mnquma, Mbhashe, and the border areas of Raymond and Amahlathi Municipalities. The regions exhibited the highest levels of water stress which correlates with the high population density observed in these regions. In an article written by Sibom (Amathole District Municipality, 2023), the 2015 Drought Disaster declared in Amathole exhibited severe water stress in Mbhashe and Mnquma local municipalities which is also evident in the results. The prevalence of livestock farming in Amathole over crop production is evidence that the dry conditions experienced in the region make irrigation dependent agriculture less viable. Adaptive measures must be targeted at improving water efficiency and access. Strategies that are targeted at encouraging sustainable farming practices can promote crop farming in the face of climate variability. Additionally, the adoption of livelihoods that are not water intensive or embracing sustainable practices could alleviate some pressures that are on the water resources.

The PDSI results indicated that the impacts of drought were not uniform across the district, with some areas being more vulnerable than the others. The varying drought conditions have different implications for agriculture as areas with lower PDSI values might face challenges such as reduced crop yields, while regions with higher values may experience favorable conditions for crop growth. The prevalence of livestock and crop production in drought-relief areas suggests that regions experiencing mild droughts such as the southern portion of Amahlathi are limited to socioeconomic development which underscores the need for water resource allocation in those areas. Areas like this should be prioritized for drought adaptation measures for long term sustainability.

The NDVI indicated the worsening water scarcity scenario over time. The NDVI results showed that the regions of Raymond, Mhlaba and Amahlathi had the most severe water scarcity experience. The spatial trends revealed the intensity and the severity of water scarcity with a peak in 2023. The water availability patterns observed shows that the current adaptation measures are insufficient, which necessitate the need for more responsive strategies.

Conclusion and Policy Recommendations for Water Resource in Amathole District

The assessment of the water scarcity trend in Amathole district shows the worsening water scarcity for the region. The application of various indices, including the Standard Precipitation Index (SPI), Withdrawal to Water Availability (WTA) ratio, Palmer Drought Severity Index (PDSI), and Normalized Difference Vegetation Index (NDVI), reveal significant spatial and temporal disparities in water availability across the district. The data indicates that certain regions, particularly Mnquma, Mbhashe, and the borders of Raymond and Amahlathi municipalities, are experiencing higher levels of water stress and drought conditions, which conform with increased water withdrawals and lower precipitation levels. As water challenges are being worsened by the impact of climate change the ideal scenario for these areas would be efforts towards climate adaptation that are focused on enhancing water conservation which could include implementation of more efficient water resource management frameworks that are specific to each region. Real time monitoring using NDVI and SPI could improve responsiveness of water distribution systems to changing climatic conditions.

Responsive climate adaptation plans need to be achieved with society and individuals working together (SADC, 2011). It has become important to incorporate culture specific practices into national climate change policies to better understand the local strategies that can be used to adapt to its impact (Cooper et al., 2008). It is essential to strengthen the institutional capacity of water governance in the district to encourage effective water management strategies which will involve multi stakeholder collaboration between community, local government, and experts to design water harvesting plans especially in february and efficient water management strategy. Policies should be targeted at encouraging sustainable agricultural practices to make their farming practices resilient in the face of climate vulnerability. Climate adaptation policies that encourage the capacity building and education of the Amathole populace on sustainability practices for households and training local officials in adaptive management techniques would play a vital role in ensuring the long-term sustainability of water supplies.

Unless concerted efforts are undertaken to utilize the harvest of rainwater and adopt sustainability practices that will encourage efficient use of these resources, the water scarcity issue will continue to be a major problem for the district. This necessitates the need to act swiftly and adopt measures that can improve water accessibility for people, especially those in water scarce regions. Further studies are needed to understand the socio-economic factors that influence water use and adaptation behaviors among community members in the Amathole District.

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