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A systematic Analysis of Water scarcity in Bari Region, Puntland State Somalia, Using Geographic Information Systems

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Abstract:

Water scarcity represents a significant challenge to sustainable development, particularly in semi-arid regions such as the Bari region of Puntland State, Somalia. This study leverages Geographic Information Systems (GIS) to comprehensively analyse the factors contributing to water scarcity within this area. By integrating diverse environmental and hydrological datasets, including well depth, pH levels, electrical conductivity, total dissolved solids, land cover, aquifer types, and historical drought occurrences, this research unveils the multifaceted nature of water scarcity in the region. The findings indicate that the Bari region hosts diverse aquifer systems with variable productivity, highlighting the necessity for differentiated water extraction policies to ensure sustainability. Historical drought data underscore the exacerbating impact of drought on water quality, emphasising the need for conservation strategies and development of drought-resistant water sources. Spatial analysis reveals a salinity concentration gradient, suggesting over-extraction of groundwater and potential saline intrusion, which could compromise water quality for potable and agricultural use.

Additionally, land cover analysis indicates that sparse vegetation, a result of arid climate conditions and anthropogenic factors such as overgrazing and deforestation, exacerbates water scarcity by affecting groundwater recharge rates. Despite these challenges, pH levels across the region generally fall within acceptable ranges for human consumption, although localised areas require monitoring. This research lays a foundation for integrated water resource management (IWRM) strategies informed by accurate GIS data, considering the region's unique environmental, socio-economic, and cultural contexts. These findings offer valuable insights for policymakers, planners, and local communities in developing targeted interventions to improve water accessibility, quality, and sustainability.

Keywords: Water Scarcity, Geographic Information Systems (GIS), Bari Region, Somalia, Aquifer Systems, Drought Impact, Water Quality, Land Cover, Integrated Water Resource Management (IWRM).

1. Introduction

Water scarcity is a critical global challenge, affecting millions of people and posing a significant threat to sustainable development (Mancosu et al., 2015). In semi-arid regions, such as the Bari region in Puntland State, Somalia, the situation is particularly dire due to the area's

vulnerability to droughts, erratic rainfall, and limited water resources management infrastructure (Oduori et al., 2003). The United Nations Development Programme (UNDP) highlights the severe implications of water scarcity, including impacts on health, food security, and regional stability (Connor, 2015). Despite these challenges, comprehensive studies leveraging Geographic Information System (GIS) technology to analyse water scarcity in these regions remain sparse. This paper aims to bridge this gap by systematically analysing water scarcity in the Bari region, employing GIS to integrate various environmental and hydrological datasets.

The importance of utilising GIS in water scarcity research cannot be overstated. GIS offers a powerful tool for integrating, analysing, and visualising spatial data from diverse sources, enabling researchers to uncover patterns and relationships that would otherwise remain hidden (Babiker et al., 2005). Previous studies have successfully employed GIS to assess water quality, availability, and distribution in various contexts (Chen et al., 2010; Feng et al., 2007). However, the application of GIS for a comprehensive analysis of water scarcity, particularly in the context of Somalia, has been limited. This study seeks to fill this research void by leveraging GIS to analyse critical factors contributing to water scarcity in the Bari region, including well depth, pH levels, electrical conductivity (EC), total dissolved solids (TDS), land cover, aquifer types, and historical drought occurrences.

The Bari region of Puntland State, Somalia, presents a unique case study due to its semi-arid climate, socio-political complexities, and the critical role of water resources in its predominantly pastoral and agro-pastoral communities (Malkowsky et al., 2022). Over the past decades, the region has experienced recurrent droughts, exacerbating the water scarcity crisis (FAO, 2014). Additionally, the lack of comprehensive water resource management strategies and infrastructure has further hindered efforts to mitigate the impact of water scarcity on the local population. By focusing on the Bari region, this study addresses a significant gap in the

literature and contributes to the development of informed strategies for water resource management in similar semi-arid regions.

The significance of this research extends beyond its academic contributions. By identifying the key factors contributing to water scarcity in the Bari region and analysing their spatial distribution and interrelations, this study offers valuable insights for policymakers, planners, and local communities. The findings can inform the development of targeted interventions to improve water accessibility, quality, and sustainability.

2. Study Area

The Bari region, situated in northeastern Somalia, forms a crucial part of the Puntland State. Bordered by the Gulf of Aden to the north and the Indian Ocean to the east, this area spans a significant portion of Somalia's coastline, offering unique geographical and climatic features that influence its hydrological patterns. Bari's strategic location and diverse topography, including coastal plains, mountain ranges, and semi-desert landscapes, presents a complex environmental setting for studying water scarcity using Geographic Information Systems (GIS). The study area map is shown in Figure 1.

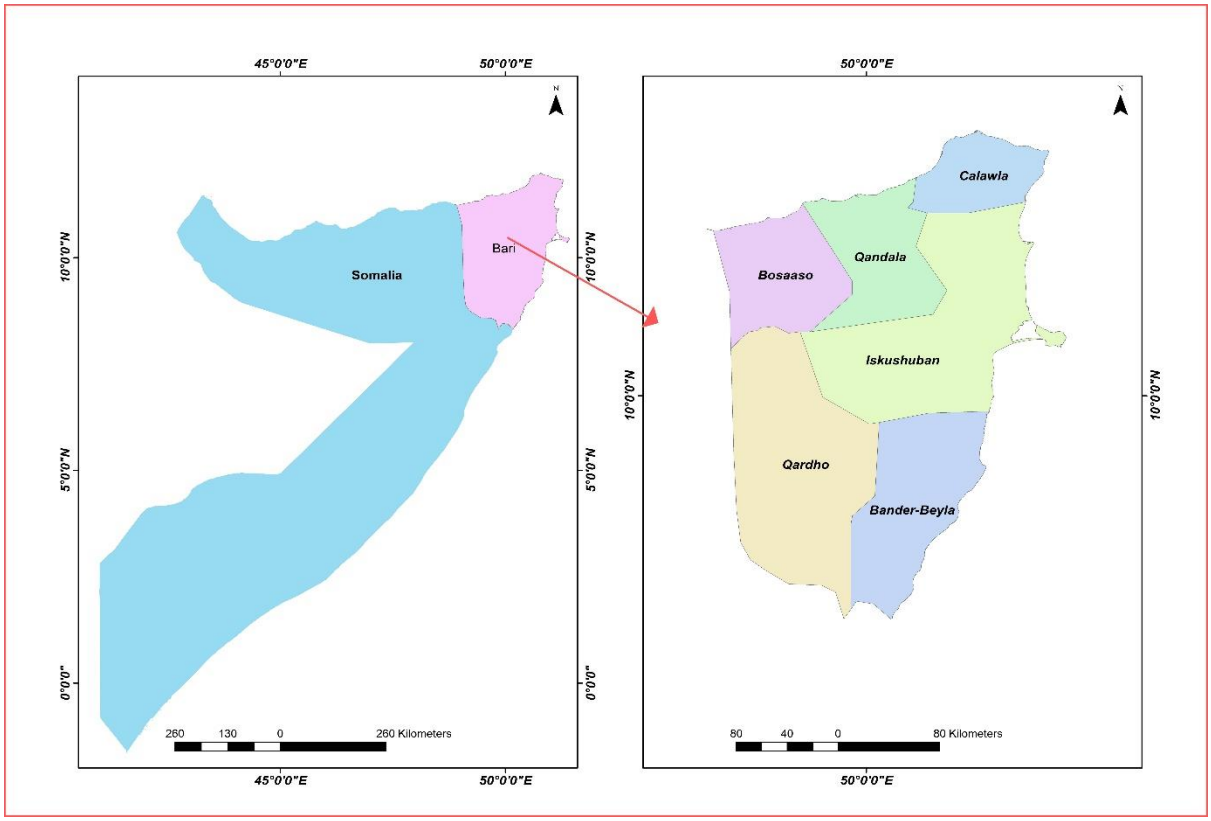

Figure 1. Location map of the study area

2.1 Geographical Characteristics

Bari region is characterised by a varied landscape that significantly influences its water availability and distribution (Behrens et al., 1994). The topographical features range from the rugged Al Madow and Golis mountain ranges, known for their potential as water catchment areas, to the expansive coastal plains and dry riverbeds that traverse the region. These geographical elements play a pivotal role in the hydrological cycle of Bari, affecting both the surface and groundwater resources critical for addressing water scarcity.

2.2 Climate and Hydrology

The climate of Bari is predominantly arid to semi-arid, with seasonal variations that influence water availability. The region experiences two main rainy seasons: the Gu (April to June) and the Deyr (October to December) (Said et al., 2019). However, rainfall is erratic and often insufficient to meet the water demands of the population and agriculture. The variability in rainfall, coupled with high evaporation rates, exacerbates the challenges of water scarcity.

Hydrologically, Bari relies on a combination of surface water sources, including ephemeral rivers, seasonal watercourses, and groundwater reservoirs (Faillace, 1983). GIS in hydrological studies has been instrumental in mapping water sources, assessing their sustainability, and identifying areas prone to water scarcity.

2.3 Socio-Economic Context

The population of Bari is predominantly rural, with livelihoods centred around pastoralism, agriculture, and fishing (Mohamed, 2022). Water scarcity significantly impacts these activities, affecting the region's food security and economic stability. The lack of reliable water sources also hinders socio-economic development, leading to challenges in health, education, and access to basic services.

2.4 Challenges and Opportunities

Addressing water scarcity in Bari presents both challenges and opportunities. The region's remote location and limited infrastructure complicate data collection and the implementation of water management strategies. However, GIS technology offers the potential to overcome these barriers, providing detailed spatial data to support decision-making processes. Moreover, Bari's unique geographical and climatic characteristics, such as its mountainous areas with potential for rainwater harvesting, present opportunities for innovative water conservation practices.

3. Methodology

3.1 Data Collection

For this study, data collection focused on integrating both primary and secondary data sources to provide a comprehensive analysis of water scarcity in the Bari region.

Primary Data: Field surveys were conducted across the Bari region to collect real-time data on well depths, pH levels, electrical conductivity (EC), and total dissolved solids (TDS). GPS coordinates for each data point were recorded to facilitate accurate spatial analysis.

Secondary Data: Historical data on land cover, aquifer types, and past drought incidents were obtained from the Somali Water and Land Information Management (SWALIM), the United Nations Environmental Program (UNEP), and other relevant databases.

3.2 GIS Data Integration and Management

Data integration and management were handled using ArcGIS 10.8, which provided the tools necessary for the accurate merging and analysis of disparate data sets.

Data Layering: All collected data were layered over a base map of the Bari region to visualize the spatial relationship between various factors influencing water scarcity.

Data Standardization: To ensure consistency, all data were standardized to a common scale and format, with coordinate reference systems aligned for accurate overlay analysis.

3.3 Spatial Analysis Techniques

Spatial analysis was performed using several GIS-based techniques to explore the distribution and intensity of water scarcity across the region.

Interpolation: Kriging and Inverse Distance Weighting (IDW) interpolation techniques were used to predict water quality parameters (e.g., EC, TDS) in unsampled locations based on spatial patterns observed in sampled points.

4.3 Analytical Models

The study employed a variety of models to understand and predict the dynamics of water scarcity in the Bari region.

Aquifer Productivity Model: This model assessed the productivity and sustainability of various aquifer systems by correlating aquifer types with observed well depths and water yield data.

Drought Impact Model: Utilizing historical drought data, a model was constructed to evaluate the correlation between drought frequency, severity, and changes in groundwater levels and quality over the past decades.

3.5 Validation and Accuracy Checks

To ensure the reliability of the GIS analysis, several validation steps were undertaken:

Field Verification: Key findings from the GIS analysis, such as critical areas of water scarcity and pollution, were cross-checked with ground truth data from field surveys.

Accuracy Assessment: The accuracy of interpolated data was assessed using a cross-validation method where a subset of the data was held back from the interpolation process and used to compare against the predicted values to gauge the model's precision.

3.6 Ethical Considerations

All data collection and analysis procedures were conducted in strict accordance with ethical guidelines, ensuring minimal disturbance to local communities and adherence to data privacy standards.

4. Results & Discussion

4.1 Results

This study employed Geographic Information Systems (GIS) to assess water scarcity in the Bari region of Puntland State, Somalia. We integrated various layers – Well depth, pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Land Cover, Aquifer Type, and historical drought data – to create a comprehensive picture of the current state of water resources.

Aquifer Characteristics and Well depth

The Aquifer Type map indicates that the Bari region hosts diverse aquifer systems (Figure 2). Predominantly, the region features Sedimentary Fracture aquifers with low to high yields, suggesting varied levels of aquifer productivity and potential for sustainable water extraction. Notably, the sedimentary fractured aquifers, particularly the moderate to high-yield types, coincide with deeper wells. This could be due to the geological structure facilitating deeper groundwater channels, as evidenced by wells reaching depths of up to 449 meters. Areas overlying the Basement and Volcanic aquifers exhibit shallower wells, which may be less productive and more susceptible to seasonal water-level fluctuations. The depth of the Wells map is shown in Figure 3.

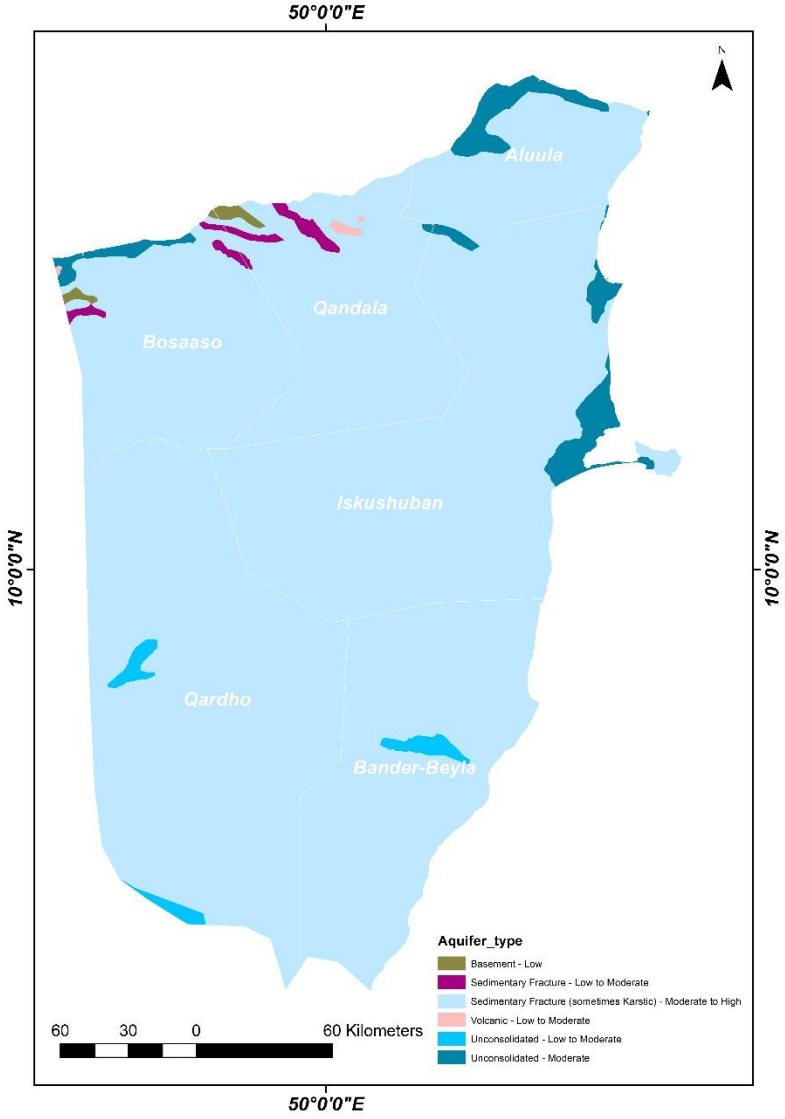

Figure 2. The Aquifer Type map indicates that the Bari region hosts diverse aquifer systems

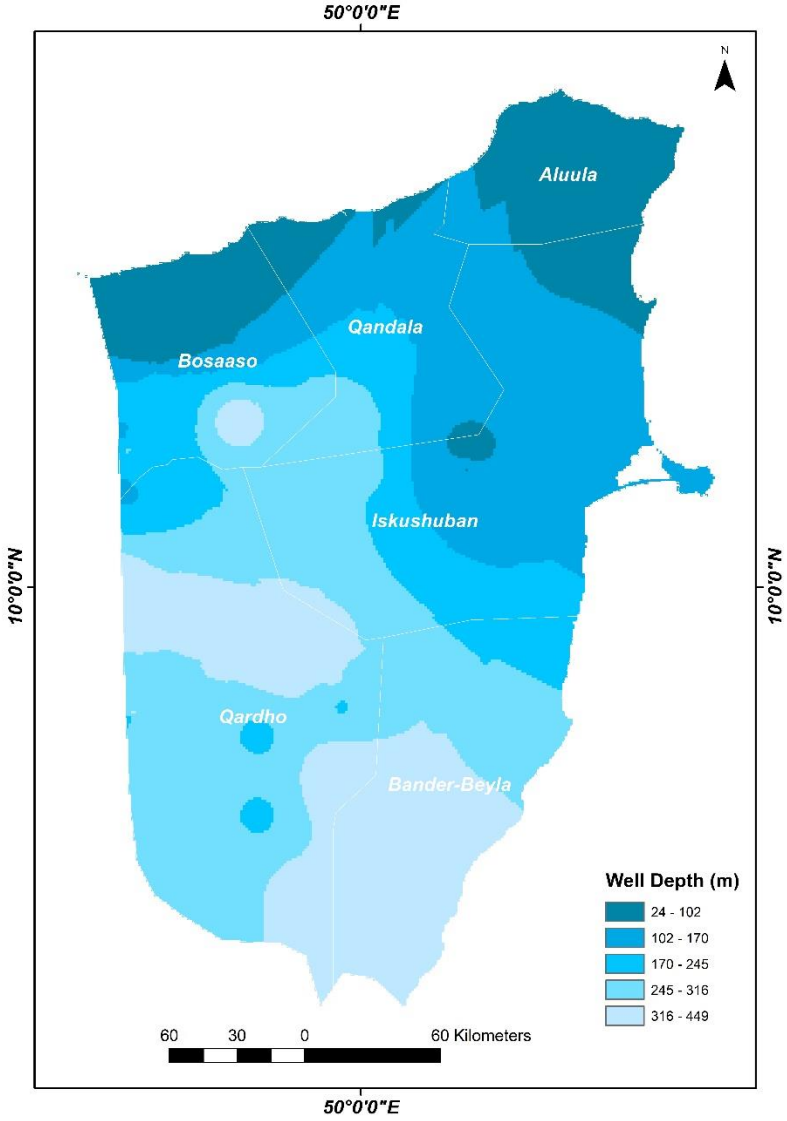

Figure 3.Well Depth map of the study area

Drought Impact

The historical drought map from 2016 underscores the extent of water stress in the Bari region (Figure 4). Severe drought conditions have predominantly affected the central and southern parts, with implications for surface and subsurface water resources. These conditions correspond with regions experiencing higher values of EC and TDS, suggesting that water quality in drought-affected areas could be compromised by increased mineralisation and possibly agricultural runoff during periods of low precipitation.

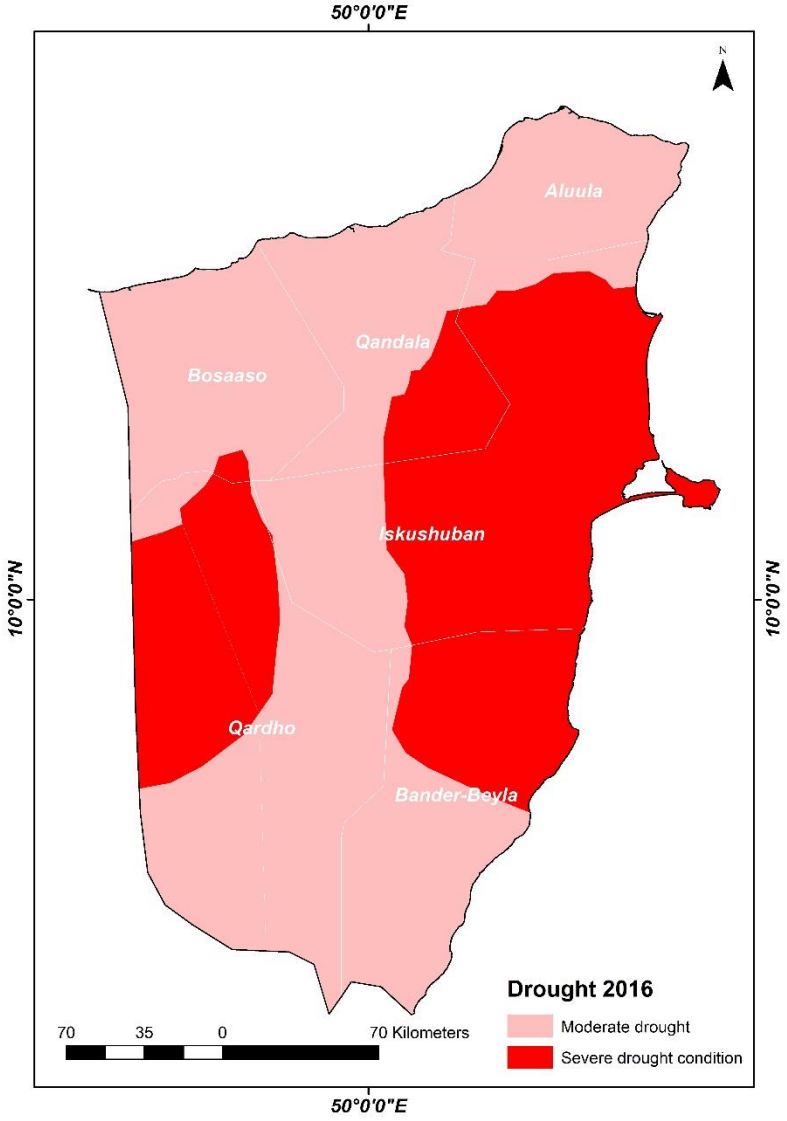

Figure 4. Drought Map of the Study Area in 2016

Water Quality Parameters

Spatial analysis of EC (Figure 5) and TDS (Figure 6) reveals a higher salinity concentration gradient in the southern part of the region, which could indicate over-extraction of groundwater and the influence of saline intrusion from the Indian Ocean. Elevated levels of TDS, particularly in areas of Qardho and Bandar-Beyla, raise concerns about the suitability of groundwater for potable and agricultural use, given the health risks associated with high salinity.

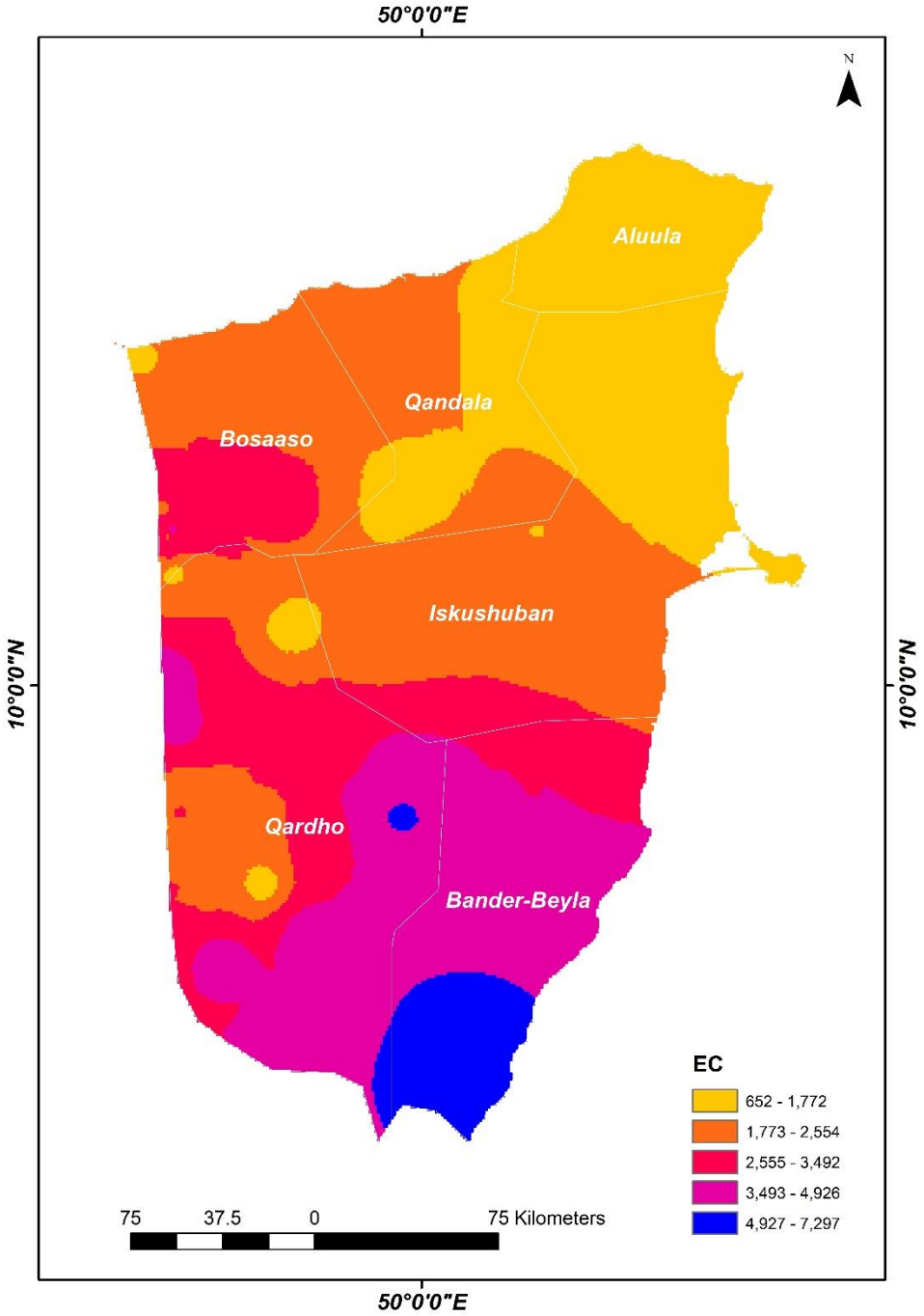

Figure 5 EC map of the study area

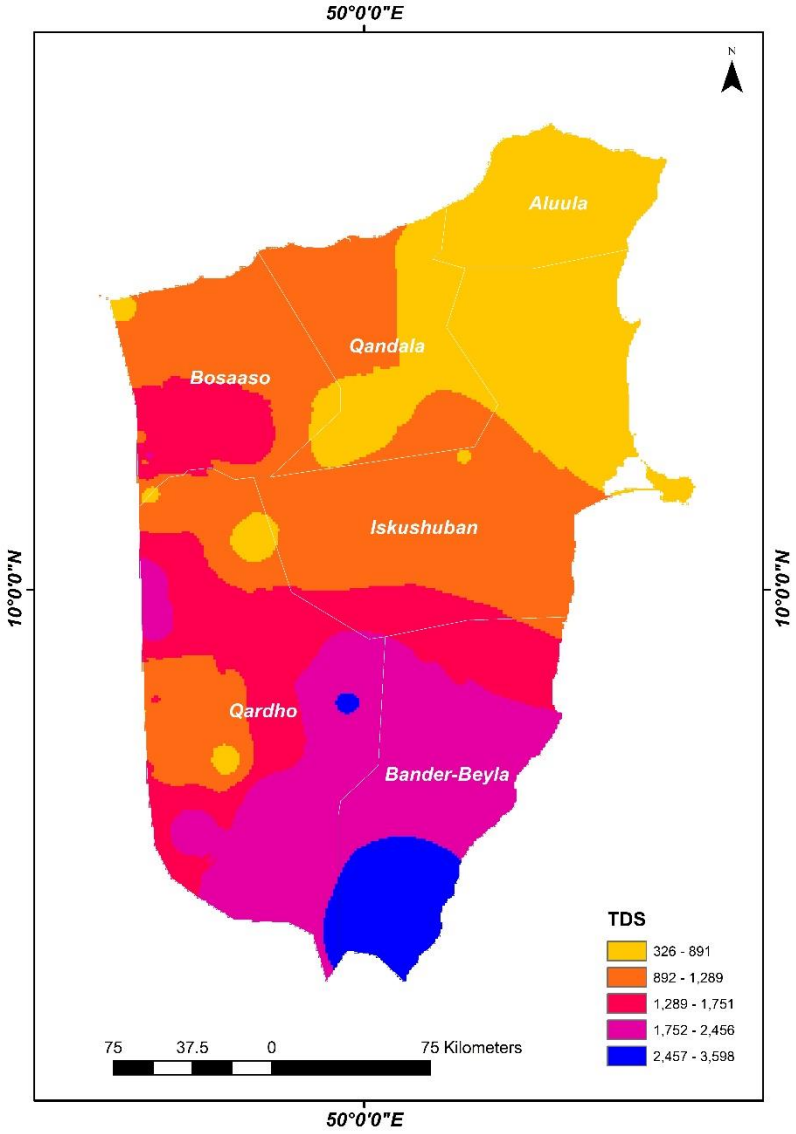

Figure 6 TDS map of the study area

Land Cover Correlation with Water Availability

The Land Cover map illustrates a landscape predominantly covered by sparse vegetation and shrubland, with some grassland areas (Figure 7). This type of coverage is less effective at retaining soil moisture and supporting groundwater recharge than denser woodlands or mangrove systems. Moreover, the prevalence of sparse vegetation is likely a consequence of the arid climate and anthropogenic factors such as overgrazing and deforestation, further exacerbating water scarcity.

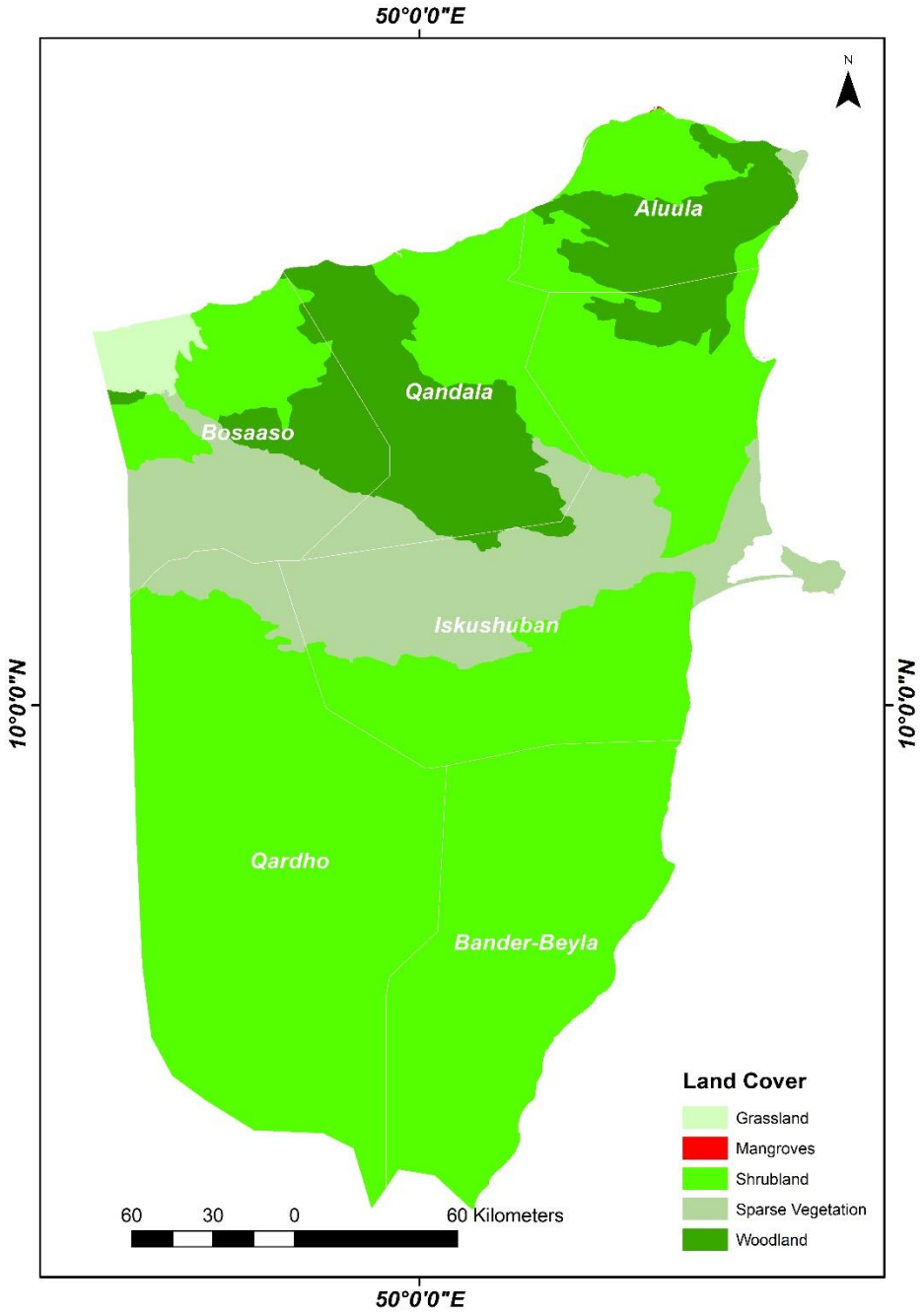

Figure 7 Land Cover map of the study area

pH Levels and Suitability for Consumption

Across the region, the pH levels, as illustrated by the pH map (Figure 8), generally fall within the WHO's recommended range for drinking water (6.5 to 8.5). This suggests that the water's acidity is not immediately problematic; however, localised areas, particularly in and

around Qardho, show pH levels that verge on being unsuitable for human consumption without treatment.

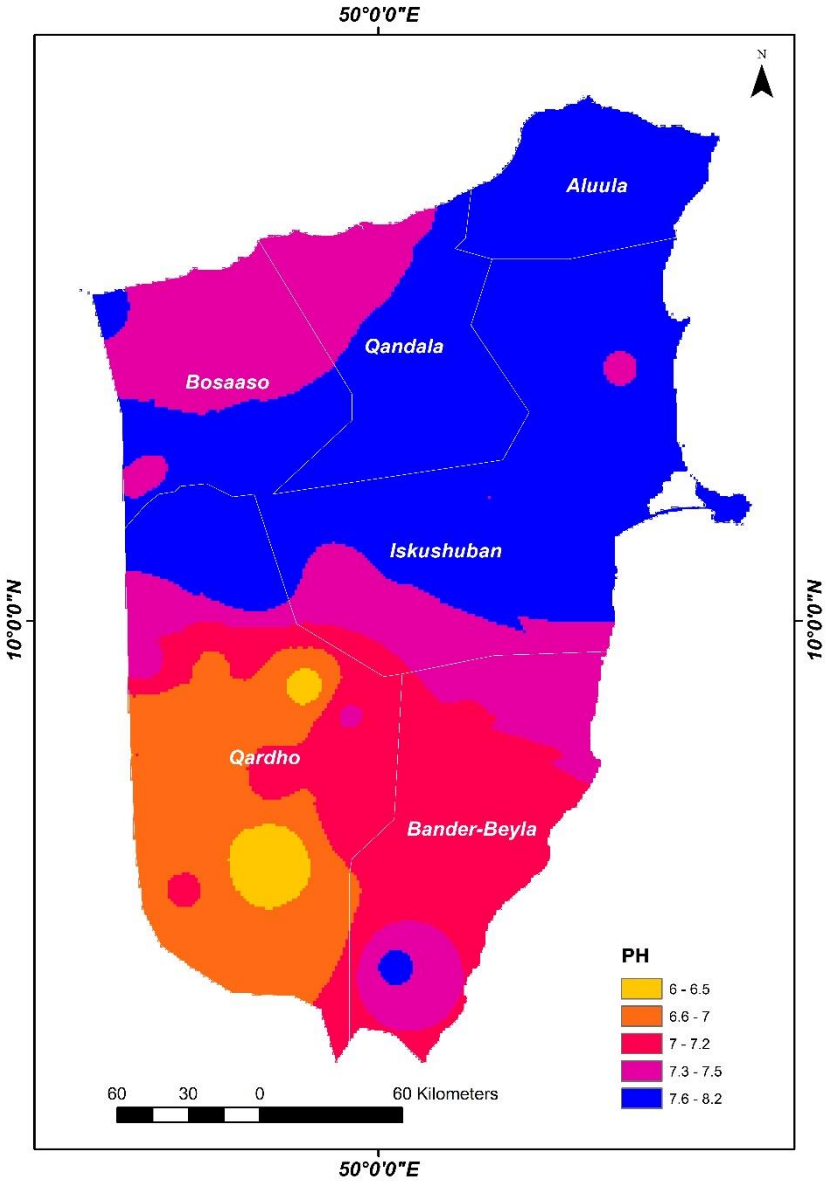

Figure 8 pH map of the study area

4.2 Discussion

The GIS layers have illuminated a complex picture of water scarcity in the Bari region, which is affected by many interacting natural and anthropogenic factors. The significant correlation between aquifer types and well depths suggests that more profound aquifers are

associated with sedimentary structures. These findings advocate for differentiated water extraction policies that consider the sustainability of each aquifer type, emphasising the protection of high-yield sedimentary fracture aquifers from overuse.

The exacerbating impact of drought on water quality calls for implementing conservation strategies and developing drought-resistant water sources. Artificial recharge projects, rainwater harvesting systems, and water-saving irrigation practices could mitigate some of the adverse effects of drought conditions on water availability and quality.

The observed salinity gradient indicates the urgent need for a management framework that addresses natural processes and human activities contributing to saline intrusion and groundwater contamination. Implementing regulated water extraction limits, monitoring well depths, and establishing desalination plants may be necessary to ensure sustainable water use.

Land cover patterns further underscore the critical role of vegetation in water conservation and soil stabilisation. Reforestation efforts, sustainable land management practices, and protecting remaining woodland and mangrove areas are essential in enhancing groundwater recharge rates and reducing runoff during sporadic rain events.

Despite the extreme environmental conditions, the relatively stable pH levels across the Bari region are encouraging. However, regular monitoring and assessment are imperative to promptly identify any detrimental changes due to environmental degradation or industrial activities.

This study has provided a scientific basis for understanding Bari's intricate dynamics of water scarcity. It underscores the pressing need for integrated water resource management (IWRM) strategies that are informed by accurate GIS data and consider the region's unique environmental, socio-economic, and cultural contexts. These strategies must be adaptable to

future challenges posed by climate change, population growth, and socio-economic development, ensuring sustainable water access for all communities in the Bari region.

4.3 Future Work

To build on the findings of this study, future work should include continuous monitoring and evaluation of water resources in the region, employing GIS tools for dynamic and adaptive management. Moreover, a more comprehensive analysis incorporating socio-economic data could reveal the human dimensions of water scarcity, including demand-side challenges and opportunities for community-based management interventions. Collaboration with local communities and stakeholders will be vital in developing practical and sustainable water management practices that align with the region's long-term environmental and developmental goals.

5. Conclusion

The study reveals that water scarcity in the Bari region is exacerbated by both natural and human factors. It shows diverse aquifer systems with varied productivity, highlighting the need for tailored water extraction policies to ensure sustainability. The detrimental effects of drought on water quality emphasize the necessity for conservation strategies and the development of resilient water sources. High salinity and groundwater contamination suggest urgent implementation of a management framework to regulate water extraction and prevent saline intrusion. Land cover analysis underscores the importance of vegetation in conserving water and enhancing groundwater recharge. Although pH levels are generally within acceptable ranges, localized areas require monitoring to ensure water safety for human consumption. Overall, the findings support the need for integrated water resource management (IWRM) strategies that account for environmental, socio-economic, and cultural factors, ensuring sustainable water access for the region's communities.

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