

GIS-Based Assessment of Groundwater Depletion from Mechanical Extraction and Climate Change in Dasht-e-Barchi, Kabul

Fazalhaq Hassanzay^{✉1}, Hematullah Shirzai², Abdullah Sharifi³

¹Kabul University, Hydrometeorology Department, Geosciences Faculty, Kabul, Afghanistan

²Norwegian Afghanistan Committee (NRC), Kabul, Climate Change Officer, Afghanistan

³Climate Change and DRR Officer, World Bank Group (WBG), Kabul, Afghanistan

✉E-mail: hass.fazalhaq@gmail.com (corresponding author)

ABSTRACT

Groundwater is the primary source of water for domestic use and urban agriculture in Kabul, Afghanistan, yet it is increasingly threatened by intensive mechanical extraction and climate variability. In rapidly urbanizing areas such as Dasht-e-Barchi, groundwater decline has accelerated in recent years, while detailed spatial assessments of this process remain limited. This study aims to evaluate changes in groundwater levels over time and to examine the combined influence of mechanical water extraction and climate variability on groundwater resources in Dasht-e-Barchi. Groundwater level data from monitoring wells for 2008 and 2022 were analyzed using GIS techniques. Inverse distance weighting interpolation was applied to generate spatial groundwater depth maps, allowing comparison of temporal changes across the study area. Field surveys and questionnaire data were used to support spatial analysis and identify the dominant drivers of groundwater extraction. The results indicate a substantial decline in groundwater levels over the study period, with maximum depths increasing from approximately 45 meters to more than 95 meters in several locations. Areas with intensive greenhouse cultivation and widespread use of pumping technologies experienced the most pronounced declines. These findings suggest that unregulated mechanical extraction, combined with reduced recharge associated with climate variability, has significantly contributed to groundwater depletion. The study highlights the need for improved groundwater monitoring, regulation of extraction practices, and integration of spatial analysis into water resource management to support long-term sustainability in urban and peri-urban areas of Kabul.

To cite this article: Hassanzay, F., Shirzai, H., Sharifi, A. (2026). GIS-Based Assessment of Groundwater Depletion from Mechanical Extraction and Climate Change in Dasht-e-Barchi, Kabul. *Journal of Natural Science Review*, 4(2), 389-406. <https://doi.org/10.62810/jnsr.v4i2.408>

Link to this article: <https://kujnsr.com/JNSR/article/view/408>



Copyright © 2026 Author(s). This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.

ARTICLE INFO

Article history:

Received: January 28, 2026

Revised: March 16, 2026

Accepted: April 8, 2026

Published: June, 30, 2026

Keywords:

Climate variability; Groundwater depletion; Geographic information system; Mechanical water extraction; Urban groundwater management

INTRODUCTION

Climate change is one of the most critical global challenges, exerting profound impacts on water resources, agriculture, ecosystems, and socioeconomic systems worldwide. Rising temperatures, altered precipitation patterns, and increased climate variability have intensified pressure on groundwater systems, particularly in arid and semi-arid regions where

groundwater plays a vital role in sustaining livelihoods and food production (Zhao et al., 2019; Kala, 2017; Silva & Kawasaki, 2018). Groundwater stress has increasingly been linked not only to climatic factors but also to rapid urbanization, expansion of urban and peri-urban agriculture, and unsustainable abstraction practices. In many regions, climate-induced droughts reduce surface water availability, forcing communities to rely heavily on groundwater as a buffer resource (Ziolkowska, 2016; Mukherjee et al., 2018).

Afghanistan, a landlocked country in South Asia, is highly vulnerable to climate change due to its complex topography, limited water storage infrastructure, and heavy dependence on climate-sensitive natural resources. The country experiences multiple natural hazards, including droughts, floods, earthquakes, landslides, and avalanches, with drought being the most frequent and destructive (Usmani, 2020). Annual precipitation in Afghanistan ranges between 200 and 400 mm, making effective groundwater management and climate adaptation strategies essential for water security (Outbudin et al., 2019). Climate records indicate that since 1960, the country's average temperature has increased by approximately 0.29°C per decade, while average precipitation has declined by about 2% per decade (Aliyar et al., 2022). As surface water resources become increasingly unreliable, Afghan communities have become heavily dependent on groundwater for domestic use and agriculture. This dependency, combined with limited regulatory control over abstraction, has intensified groundwater depletion across urban and peri-urban areas (Daniell et al., 2016; Iqbal et al., 2016). FAO projections suggest that by 2040, Afghanistan will face severe water scarcity, and by 2050, nearly 90% of the country may be affected by climate change impacts (Outbudin et al., 2019).

Climate change contributes to prolonged drought conditions across large geographic areas, amplifying water scarcity and increasing competition among domestic, agricultural, and industrial water users (Seleiman et al., 2021). These compounded pressures pose serious threats to global food and water security and disproportionately affect vulnerable populations, particularly women and children (Ward et al., 2013; Enenkel et al., 2020; Ngcamu & Chari, 2020).

Kabul Province, located in central Afghanistan, has a semi-arid climate and is particularly vulnerable to climate change impacts, driven by rapid population growth and increasing water demand (Outbudin et al., 2019; Sarwary et al., 2022). Dasht-e-Barchi, one of the most densely populated areas of Kabul, receives approximately 390 mm of annual precipitation, with considerable spatial and temporal variability (Mercado, 2020). In recent years, Dasht-e-Barchi area of Kabul province has experienced rapid expansion of greenhouse-based agriculture, particularly cucumber production, which relies heavily on groundwater extracted through solar-powered pumping systems. The widespread use of mechanical pumping has significantly increased groundwater abstraction rates beyond natural recharge capacity (Kugbei et al., 2005). As a result of the combined effects of climate change-induced precipitation variability and intensive mechanical groundwater extraction, groundwater levels in Dasht-e-Barchi have declined dramatically, ranging from approximately 15 m to

more than 120 m in some locations (Mercado, 2020). This decline has led to reduced water availability, declining agricultural productivity, and deterioration of community livelihoods. Reports indicate that over the past six years, groundwater levels have dropped by nearly 100 m, resulting in an estimated 50% reduction in agricultural production and exacerbating poverty and food insecurity in the area (Rural & Regeneration, 2015). Dasht-e-Barchi, located in Kabul city, has become a major center of cucumber greenhouse agriculture, where groundwater is intensively extracted through mechanical pumping systems to support irrigation. The rapid expansion of greenhouse farming, together with largely unregulated groundwater abstraction, has placed substantial pressure on local groundwater resources. Simultaneously, climate change-related factors, including rising temperatures and decreasing rainfall, have reduced natural groundwater recharge, thereby accelerating groundwater depletion. This combined pressure has resulted in a continuous decline in groundwater levels, threatening the long-term availability of water for both agricultural production and domestic use, with potential consequences for ecosystem stability, agricultural sustainability, and water security. Despite the seriousness of this issue, systematic GIS-based spatial analyses that quantify groundwater level decline and examine its relationship with land-use patterns, population growth, climate variability, and mechanical water extraction remain limited in Dasht-e-Barchi. In response to this gap, the present study aims to assess the impacts of mechanical groundwater extraction and climate change on groundwater resources in the Dasht-e-Barchi area of Kabul province by applying Geographic Information System techniques. Specifically, the research seeks to quantify changes in groundwater levels between 2008 and 2022, analyze the spatial patterns of groundwater depletion, and evaluate the combined influence of climate variability and mechanical pumping on groundwater level decline, thereby providing evidence to support sustainable groundwater management and climate adaptation strategies in Kabul.

Despite increasing groundwater abstraction and growing climate stress in Kabul's urban and peri-urban districts, limited GIS-based studies have quantitatively assessed the combined impacts of climate change and mechanical groundwater extraction at the district scale. Most existing studies address climate change or groundwater depletion separately, without integrating spatial analysis to capture their interaction. Therefore, this study aims to:

Evaluate the adverse impacts of mechanical water extraction and climate change on groundwater resources in the Dasht-e-Barchi area of Kabul Province using Geographic Information System (GIS) techniques, and to propose evidence-based mitigation and management strategies for sustainable groundwater use under changing climatic conditions.

By analyzing spatial variations in groundwater levels, the study seeks to provide evidence-based insights and to propose practical mitigation and management strategies to support sustainable groundwater use under changing climatic conditions.

METHODS AND MATERIALS

This study employs an analytical–descriptive approach to investigate the impacts of mechanical water extraction and climate change on groundwater resources in the Dasht-e-Barchi area of Kabul Province. The methodology integrates spatial analysis with Geographic Information System (GIS) techniques to provide a comprehensive understanding of groundwater dynamics.

Research Design

This study adopts a mixed-method research approach, integrating quantitative spatial analysis with qualitative and survey-based data to comprehensively assess groundwater depletion in the Dasht-e-Barchi area of Kabul Province. The integration of Geographic Information System (GIS) techniques and questionnaire-based data enables both spatial quantification of groundwater changes and contextual understanding of human and climatic drivers.

Groundwater level data were collected from 100 observations and pumping wells distributed across the Dasht-e-Barchi area for the period 2008–2022. These data were used to analyze temporal changes in groundwater levels and to generate spatial groundwater depth maps in GIS.

To interpolate groundwater levels between measured wells, the Inverse Distance Weighting (IDW) interpolation method was applied due to its suitability for groundwater studies in data-scarce environments. The IDW method assumes that the influence of a known data point decreases with increasing distance from the prediction location.

The IDW interpolation was performed using the following formula:

$$Z(x_0) = \frac{\sum_{i=1}^n Z(x_i) d_i^{-p}}{\sum_{i=1}^n d_i^{-p}} \dots \dots \dots (1)$$

where:

- $Z(x_0)$ is the estimated groundwater level at an unsampled location,
- $Z(x_i)$ represents the groundwater level at known locations,
- d_i is the distance between the known point and the prediction location,
- p is the power parameter, and
- n is the number of surrounding wells used in the interpolation.

To evaluate the reliability of IDW interpolation, cross-validation was used by comparing observed groundwater levels with predicted values at selected wells. Prediction errors were assessed using descriptive error indicators, such as mean error and root-mean-square error (RMSE), which provide insight into interpolation uncertainty. Also, a power parameter of $p = 2$ was used, and the 12 nearest wells were considered for interpolation.

Quantitative data were also collected through a structured questionnaire survey, which consisted of three sections:

1. groundwater uses and pumping practices,
2. agricultural activities and greenhouse irrigation methods,
3. perceived impacts of climate variability on water availability and livelihoods.

Survey respondents included farmers, greenhouse operators, and residents. The questionnaire data were statistically summarized and directly linked to GIS results by comparing reported pumping intensity and land-use practices with spatial patterns of groundwater depletion.

Study Area

Kabul, the largest city in Afghanistan, is the capital with a population of 4.5 million and the fifth-fastest-growing city in the world (ADB). It is located in the eastern part of the country. It sits at an altitude of approximately 1,790 meters (5,873 feet) above sea level, located along the Kabul River.

Kabul city is divided into 22 municipal districts, most of which are facing drinking water scarcity due to the depletion of groundwater, which is the main source of water supply. In District 13, farmers have initiated cucumber greenhouses that rely on groundwater for irrigation.

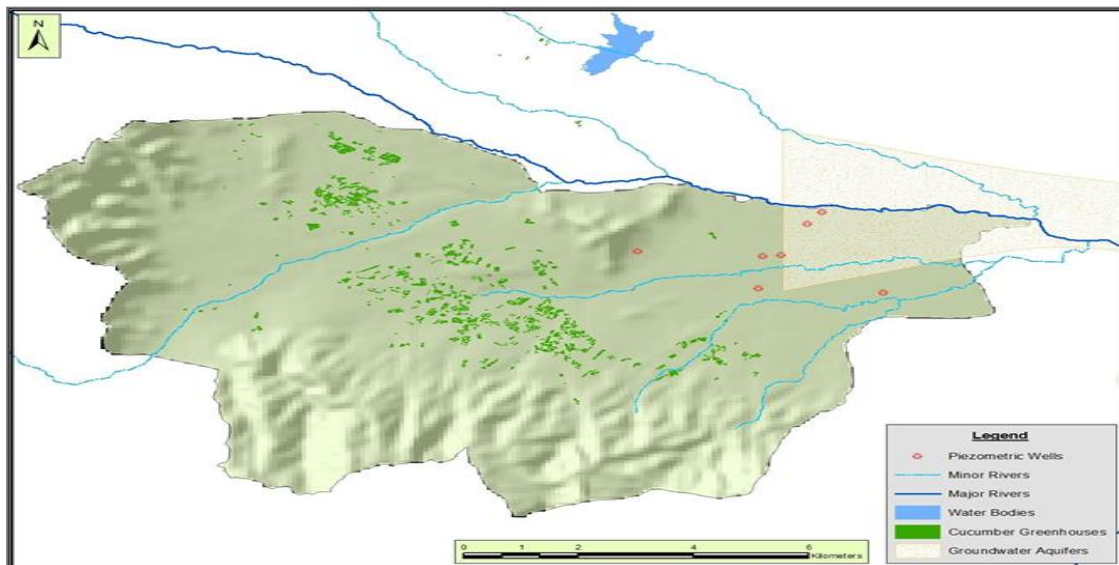


Figure 1. Study Area Map

Cucumber greenhouses are an important agricultural practice globally, significantly enhancing productivity. However, their environmental impacts are substantial, particularly regarding groundwater extraction and the potential consequences of climate change. Groundwater extraction for irrigation in cucumber greenhouses can deplete local aquifers, thereby affecting long-term water availability. Moreover, the greenhouse effect, along with changes in temperature and precipitation patterns driven by climate change, can further exacerbate water scarcity and disrupt the delicate balance of local ecosystems.

Data collection

This study's primary data were collected through semi-structured interviews and focus group discussions with stakeholders, experts, and local community members to explore groundwater levels and contextual factors. In addition, secondary data collected from books, publications, and national and international articles were utilized in this study. The descriptive analysis is conducted using SPSS, while Microsoft Excel is used to generate charts and graphs. In addition, a Geographic Information System (GIS) is used to map the study area, groundwater, and IDW.

Data collection tools

- Semi-structured interviews with stakeholders, experts, and local community members to gather qualitative insights on groundwater levels and contextual factors.
- Focus group discussions to capture collective perspectives and community experiences related to water extraction and climate impacts.
- Secondary sources including books, publications, and national and international articles to provide background information and support comparative analysis.
- GIS tools for spatial mapping of the study area, groundwater distribution, and interpolation using Inverse Distance Weighting (IDW).

Data analysis

- Descriptive analysis conducted with SPSS to summarize and interpret qualitative and quantitative data.
- Microsoft Excel used to generate charts and graphs that illustrate trends and patterns in groundwater levels and climate variables.
- GIS-based spatial analysis applied to map the study area, visualize groundwater distribution, and perform IDW interpolation for spatial variation assessment.

FINDINGS

For data processing and spatial analysis, the Inverse Distance Weighting (IDW) interpolation method was applied using piezometric well observation data for 2008 and 2022 (MEW) and population data for 2022 (NSIA). The groundwater depth derived from 2008 data shows clear spatial variability across the study area, ranging from approximately 1.8 m to 30 m. Shallow groundwater levels are predominantly observed in the central and southeastern zones, while deeper groundwater levels occur in the western and northwestern areas, particularly within the PD-13 boundary.

The density of piezometric wells is higher in the central and eastern parts of the study area, resulting in greater interpolation reliability. In contrast, zones with fewer observation wells exhibit increased uncertainty. Areas with a high concentration of cucumber greenhouses within PD-13 coincide spatially with deeper groundwater levels, indicating intensive groundwater abstraction.

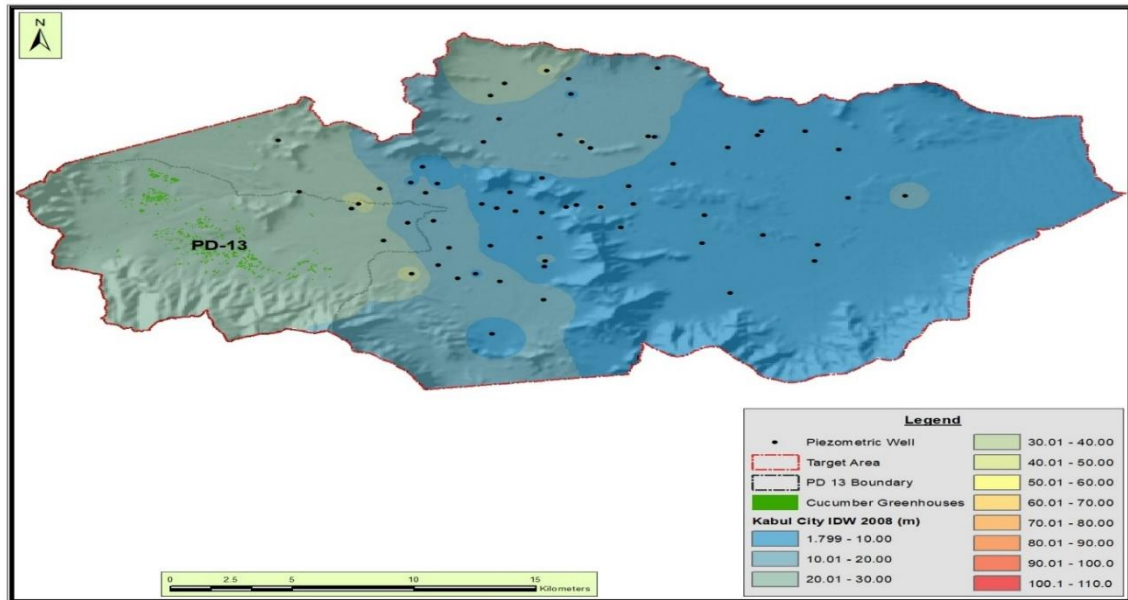


Figure 2. 13th District water level, 2008

The observed spatial pattern reflects the combined influence of mechanical groundwater pumping, land use change, and population pressure. This finding is consistent with studies (Qutbudin et al. 2019), which reported declining groundwater levels in the Kabul Basin due to reduced recharge under changing precipitation regimes (Mukherjee et al. 2018; Ziolkowska 2016), and with studies (Ziolkowska 2016) that highlighted the role of agricultural intensification in accelerating groundwater depletion in semi-arid urban environments.

Overall, the east–west gradient in groundwater depth aligns with hydrogeological conditions and increasing urban water demand, suggesting that groundwater depletion in Dasht-e-Barchi is largely driven by human activities rather than natural variability alone. Without improved regulation of groundwater extraction and strengthened monitoring networks, groundwater sustainability in the area is likely to continue to deteriorate.

The groundwater depth map for 2022, generated using the IDW interpolation method based on piezometric well data, shows substantial spatial variability across the study area. Groundwater depths generally range from approximately 4–10 m in shallow zones to more than 30 m in deeper areas. Shallower groundwater conditions are mainly concentrated in the eastern and southeastern parts of the area, while moderate to deep groundwater levels dominate the central and western sections, particularly within and around the PD-13 boundary. Several localized hotspots of deeper groundwater are evident, indicating areas of increased abstraction or reduced recharge. The higher density of observation wells in central and eastern zones enhances interpolation reliability, whereas areas with fewer wells exhibit higher uncertainty (Qutbudin et al., 2019; Mukherjee et al., 2018).

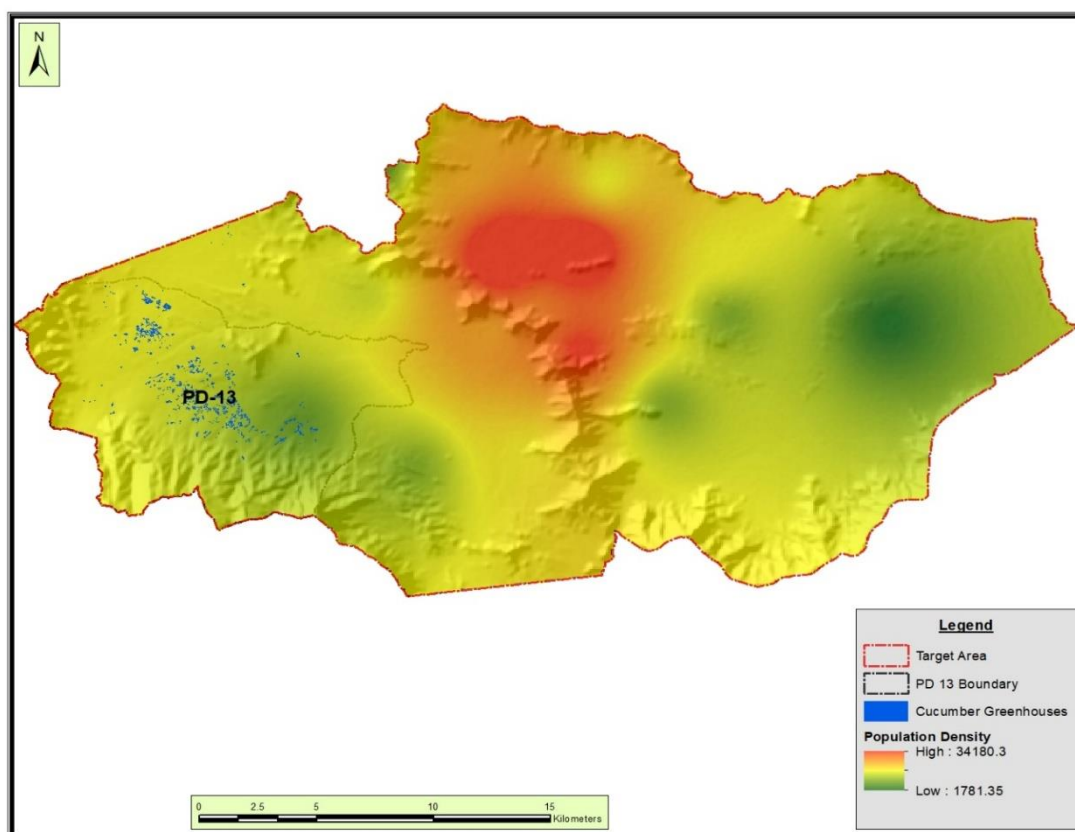


Figure 3. Population Density in the 13th District

The observed spatial patterns of groundwater depth are largely influenced by human activities, particularly intensive cucumber greenhouse cultivation, where mechanical irrigation pumps are widespread. These findings align with studies in semi-arid urban environments, which indicate that unregulated groundwater abstraction combined with reduced natural recharge accelerates groundwater depletion (Ziolkowska, 2016; Ward et al., 2013). Urban expansion and increased agricultural water demand have further constrained recharge zones, intensifying groundwater stress in Dasht-e-Barchi. Overall, the results highlight the growing risks of groundwater depletion and underscore the need for regulated pumping, improved monitoring, and sustainable groundwater management practices (Hermans & McLeman, 2021).

The GIS-based map of Dasht-e-Barchi (PD-13) illustrates significant spatial variation in groundwater depths across the district. Groundwater levels, measured via piezometric wells, range from 4.38 m to 110 m. Shallow groundwater, generally between 30–60 m, is observed in the western and central parts, whereas the northern and northeastern areas show much deeper groundwater levels, between 80–110 m. The map also indicates the locations of cucumber greenhouses, many of which are situated above shallow to moderate groundwater zones. Monitoring well distribution is denser in high extraction areas, ensuring reliable observation of groundwater trends. Overall, the GIS analysis provides essential spatial data for assessing groundwater distribution and identifying stressed zones.

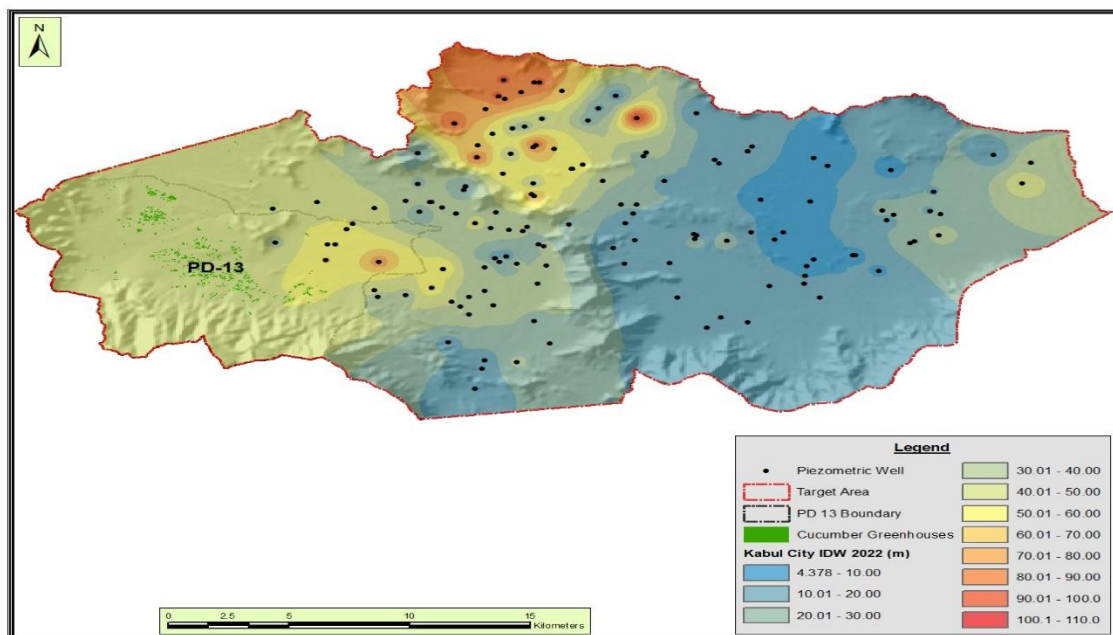


Figure 4. 13th District water level, 2022

The observed groundwater patterns are primarily influenced by intensive human activity, particularly irrigation for cucumber greenhouses. Areas with deeper groundwater likely reflect over-extraction or limited natural recharge due to geological constraints. This aligns with previous studies showing that agricultural intensification and high-water demand in semi-arid urban environments accelerate groundwater depletion (Outbudin et al., 2019; Mukherjee et al., 2018).

The concentration of monitoring wells in high-extraction zones supports accurate tracking of vulnerable areas but highlights the need for expanded observation networks in less-monitored regions. Sustainable groundwater management, including regulated irrigation and water-saving practices, is essential to preserve water resources in Dasht-e-Barchi. Similar findings in South Asian semi-arid regions emphasize the combined impact of human extraction and climate variability on groundwater stress (Ziolkowska, 2016; Ward et al., 2013).

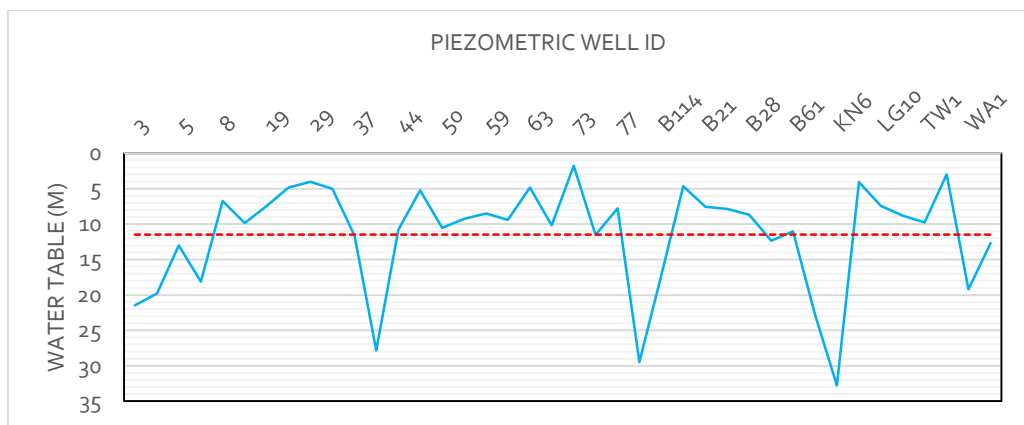


Figure 5. Groundwater Depth Variation by Well (2008 - 2022)

Figure 5 presents groundwater levels measured from various piezometric wells in Dasht-e-Barchi. Groundwater depths range from approximately 10 m to 95 m, showing substantial spatial variation across the district. Shallow wells, at depths of 10–30 m, are mainly located in central and western areas. In contrast, deeper wells, up to 95 m, are found in other zones, potentially indicating intensive water extraction or naturally deeper groundwater. The average water table, indicated by a red dashed line, is approximately 42–43 m, distinguishing shallow from deeper groundwater. Overall, the graph highlights areas where groundwater may be under stress due to depth variations.

The variation in groundwater depth reflects both human-induced and natural factors. Shallow groundwater areas may be more vulnerable to intensive irrigation, such as from cucumber greenhouses, while deep wells indicate regions of over-extraction. This pattern is consistent with findings by Outbudin et al. (2019), who reported that unregulated groundwater pumping, combined with reduced recharge under changing precipitation regimes, accelerates groundwater depletion in the Kabul Basin. (Mukherjee et al. 2018; Ziolkowska 2016) emphasize that semi-arid urban regions with intensive agriculture are particularly prone to groundwater stress.

Identifying areas of deep and shallow groundwater is crucial for targeted management, including regulated pumping, monitoring, and sustainable irrigation practices, to prevent further depletion and maintain long-term water security in Dasht-Barchi.

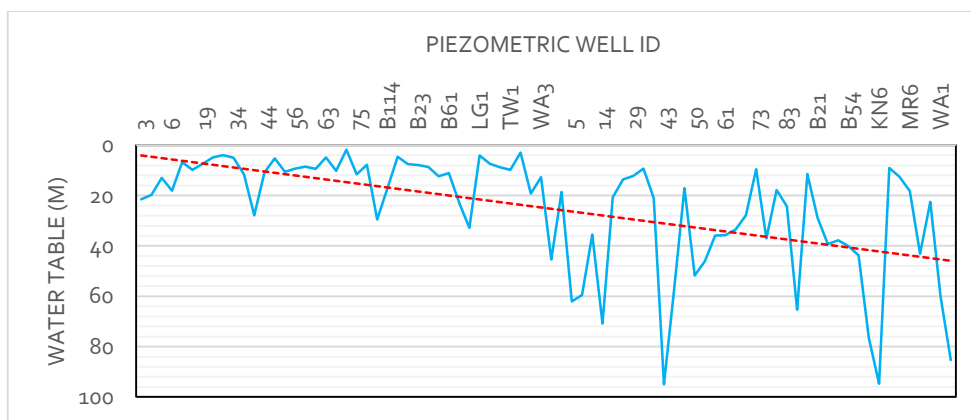


Figure 6. Water Table Depth Trend in Piezometric Wells (2008 - 2022)

Figure 6 illustrates groundwater levels (water table depth in meters) measured at various piezometric wells in Dasht-e-Barchi. The horizontal axis shows the well IDs, and the vertical axis shows water table depth. Shallow groundwater, approximately 5–20 m deep, is observed in the initial wells (left side of the graph), whereas deeper, more variable water levels, reaching 80–95 m, are recorded in later wells (right side). The red dashed line indicates the overall trend, showing a gradual increase in depth from left to right, reflecting a decline in groundwater levels across the study area.

The observed pattern indicates increasing groundwater stress from wells with shallow to deeper water tables. Deeper wells likely correspond to areas of high extraction or limited natural recharge, while shallower wells are more susceptible to intensive irrigation, such as in cucumber greenhouses. The downward slope of the trend line confirms a spatial gradient of groundwater depletion, which may result from a combination of geological variations, unregulated pumping, and reduced recharge.

Table 1. Groundwater Level in Kabul City (2008-2022)

Groundwater Level in Kabul City				
2008		2022		
Lowest	Highest	Lowest	Highest	
45.3	1.78	95	6.13	

Groundwater levels in Kabul City as it shown in table 1, have undergone significant changes between 2008 and 2022, reflecting a clear trend of depletion. In 2008, the lowest groundwater level was 45.3 m, and the highest was 1.78 m, indicating relatively accessible groundwater across most parts of the city. By 2022, the lowest level had risen to 95 m, and the highest reached 6.13 m, demonstrating a dramatic decline in groundwater availability over 14 years. The sharp rise in minimum groundwater depth highlights areas of intensive extraction, particularly in high-density urban zones.

Both human and natural factors drive the observed decline. Over-extraction from residential, commercial, and agricultural wells, coupled with urban expansion, has increased water demand. Reduced recharge due to changes in precipitation patterns, decreased infiltration, and encroachment on natural recharge zones has further exacerbated groundwater depletion. The moderate rise in the highest water levels suggests some shallow aquifers remain, but they are increasingly limited.

As shown in Figure 7, the analysis of Kabul’s average annual precipitation from 1979 to 2022 reveals substantial interannual variability and two distinct periods. During 1979–1999, precipitation was relatively stable, fluctuating between approximately 230 mm and 420 mm per year, with an average around 305–310 mm. In contrast, the period 2000–2022 experienced extreme variability, characterized by a sharp decline in 2000–2001, when precipitation dropped to nearly 125 mm—a decrease of about 175 mm, or roughly 57% below the long-term average—followed by recovery and occasional high precipitation events reaching nearly 485 mm in 2020. Overall, while the long-term average precipitation remains similar between the two periods, the second period shows intensified drought conditions, greater fluctuations, and increased vulnerability to water scarcity, highlighting the growing challenges in water resource management in Kabul.

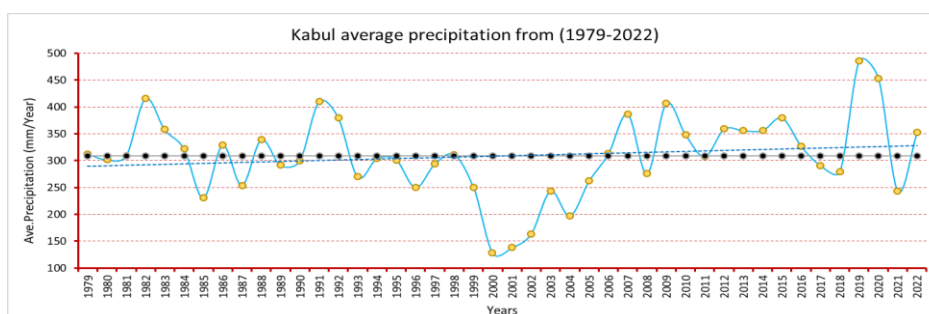


Figure 7. Kabul average precipitation from (1979-2022).

Figure 8 shows the analysis of Kabul’s mean annual temperature from 1979 to 2022, which indicates a clear warming trend, with the annual average temperature rising from approximately 15 °C in the early 1980s to around 17.5 °C by 2022. During the period 1979–1999, temperatures fluctuated around a lower mean of roughly 15.5 °C, with intermittent peaks and dips, reflecting relative stability with minor warming. In contrast, the period 2000–2022 shows a more pronounced and consistent increase in temperatures, averaging around 16.5 °C, with several years exceeding 17 °C, indicating an accelerated warming trend. The linear trend line shows a steady upward slope, suggesting Incremental increase of roughly 2 degrees over the 44-year period. This comparison between the two periods indicates that the post-2000 era has experienced a sharper and more sustained rise in annual temperatures, signaling intensified climatic warming in Kabul over recent decades.

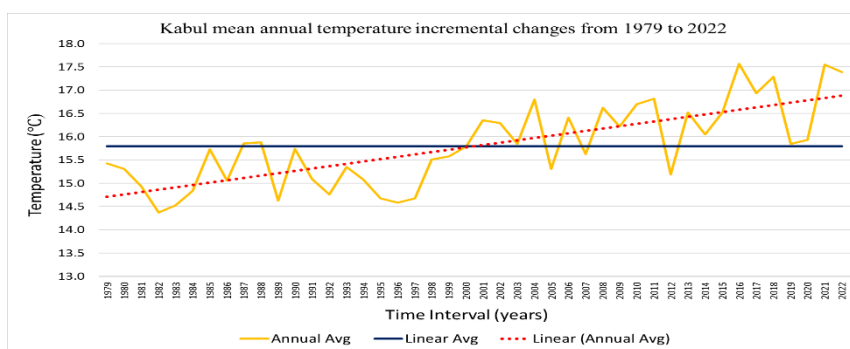


Figure 8. Kabul mean annual temperature incremental changes from 1979 to 2022.

DISCUSSION

The GIS-based assessment of groundwater in Dasht-e-Barchi, Kabul, demonstrates a marked decline in groundwater levels between 2008 and 2022, with depths increasing from 45.3 m to 95 m in the lowest zones and from 1.78 m to 6.13 m in the shallowest areas. This trend highlights severe aquifer depletion, primarily driven by intensive mechanical extraction and insufficient natural recharge. These findings directly address the study's objective of assessing the impacts of water abstraction and climate change on groundwater resources, while also revealing broader environmental and socio-economic consequences.

The results are consistent with Outbudin et al. (2019), who identified changing precipitation patterns and unregulated pumping as major contributors to aquifer stress in the Kabul Basin. Similarly, Mukherjee et al. (2018) emphasized that urban growth and agricultural intensification accelerate groundwater depletion, aligning with the observed pressures from cucumber greenhouses and urban water demand in Dasht-e-Barchi. Beyond Afghanistan, Aliyar et al. (2022) reported that farming households perceive drought as a critical threat, often adopting short-term coping strategies rather than sustainable water management. This resonates with the current study's findings, where communities rely heavily on groundwater without long-term conservation measures.

International comparisons further reinforce these conclusions. For instance, Antwi et al. (2022) showed that effective communication of water availability improved conservation behavior in Ireland, suggesting that public awareness campaigns could play a similar role in Kabul. Likewise, Hermans & McLeman (2021) highlighted the linkages between drought, land degradation, and migration, raising concerns that unchecked groundwater depletion in Kabul could exacerbate rural–urban migration and socio-economic instability.

The deterioration of water quality, with elevated TDS, nitrates, and salts, mirrors findings by Sarwary et al. (2022), who reported similar contamination trends in Ghazni City. Reduced vegetation cover and ecosystem health observed in Dasht-e-Barchi also align with Seleiman et al. (2021), who documented drought stress impacts on plant systems. Socially, the rising costs and limited access to groundwater echo Jawid & Khadjavi (2019), who found that external interventions often fail to adequately support vulnerable communities in adapting to climate change.

While the study provides valuable insights, several limitations must be acknowledged. First, the reliance on semi-structured interviews and focus groups introduces potential biases, as perceptions may not fully capture hydrogeological realities. Second, secondary data availability was limited, particularly for long-term climate records, which may affect the precision of predictive GIS modeling. Third, the study focused on Dasht-e-Barchi, and while findings are indicative of broader Kabul Basin trends, they may not fully represent other regions with different hydrogeological conditions.

Future research should expand spatial coverage to include other districts of Kabul and neighboring provinces, enabling comparative analysis across diverse aquifer systems.

Incorporating advanced modeling techniques, such as coupled climate–hydrology models, could improve predictions of groundwater responses under different climate scenarios. Moreover, integrating socio-economic vulnerability assessments, as demonstrated by Dumitrașcu et al. (2018), would provide a more holistic understanding of community resilience. Policy-oriented studies should also explore the feasibility of artificial recharge, rainwater harvesting, and regulated extraction, building on frameworks proposed by Freire-González et al. (2017).

CONCLUSION

The combined effects of intensive mechanical extraction and climate variability drive the observed decline in groundwater levels in Dasht-e-Barchi. The expansion of cucumber greenhouse agriculture and the widespread use of deep and tube wells have caused abstraction rates to exceed natural recharge. In contrast, urban expansion and concrete infrastructure have reduced soil permeability and limited infiltration, further constraining recharge zones.

Climate change has amplified these pressures by altering precipitation patterns, reducing snowfall, increasing evaporation, and shortening rainy seasons, making aquifers more vulnerable during dry periods. The rapid decline in groundwater has also led to deterioration in water quality, with increased levels of nitrates, salts, and other contaminants.

Analysis of Kabul's climate data from 1979 to 2022 reinforces these observations. Average annual precipitation exhibited substantial interannual variability and two distinct periods: 1979–1999 showed relatively stable precipitation around 305–310 mm per year, while 2000–2022 experienced extreme variability, including a sharp drop to nearly 125 mm in 2000–2001 and occasional high precipitation events reaching 485 mm. Similarly, mean annual temperatures indicate a clear warming trend, rising from approximately 15 °C in the early 1980s to around 17.5 °C by 2022, with accelerated and sustained warming particularly after 2000. These trends highlight intensified drought conditions, greater rainfall fluctuations, and increased climate change, which exacerbate water scarcity and groundwater stress in Kabul.

From a socio-environmental perspective, residents face higher water costs, limited access, and disproportionate impacts on vulnerable groups. At the same time, ecosystem health is threatened through reduced vegetation, shrinking green spaces, drying springs, and altered microclimates. Overall, current groundwater practices in Dasht-e-Barchi are environmentally and socially unsustainable. This study highlights the urgent need for regulated groundwater extraction, artificial recharge, sustainable urban planning, and climate-adaptive water management strategies to ensure long-term water security, protect livelihoods, and preserve ecosystem stability in Kabul City.

In light of the study's findings, it is recommended that the Ministry of Energy and Water regulate groundwater extraction through strict licensing and regular monitoring of deep and tube wells to prevent overuse, while promoting aquifer recharge measures such as artificial

basins, rainwater harvesting, and permeable pavements to enhance replenishment during dry periods. The Ministry of Agriculture, Irrigation, and Livestock should adopt water-saving irrigation technologies, including drip irrigation in cucumber greenhouses, to improve water productivity and reduce stress on groundwater resources. The use of solar-powered irrigation pumps should also be encouraged to lower energy costs and greenhouse gas emissions. Finally, the Ministry of Energy and Water, in coordination with the National Environmental Protection Agency, should implement GIS-based monitoring systems to track groundwater levels, land use changes, and climate variables, enabling early warning and informed decision-making for sustainable water management.

Authors Contributions

Fazalhaq Hassanzay, Hematullah Shirzai, and Abdullah Sharifi contributed equally to the conception, execution, and completion of this study. Fazalhaq Hassanzay analyzed rainfall and temperature data, examined the relationship between groundwater depletion and climate change, and coordinated the manuscript structure to meet the target journal's scientific and formatting requirements. Hematullah Shirzai conducted the overall data analysis, supported interpretation of results, and contributed to the methodological framework of the study. Abdullah Sharifi conducted spatial analysis using a geographic information system, developed groundwater depth maps, and assisted with visualization of results. All authors actively participated in manuscript revision, critically reviewed the content, and approved the final version for submission.

Acknowledgements

We extend our appreciation to the Ministry of Energy and Water (MEW) of Afghanistan for providing relevant groundwater and long-term hydrometeorological data used in this study. We also gratefully acknowledge the National Statistics and Information Authority (NSIA) for supplying population and supporting statistical information essential to the analysis. The authors further thank the Journal of Natural Sciences Review (JNSR) for providing the publication platform and editorial framework that supported the dissemination of this research.

Funding Information

No external funding was received to support the research, authorship, or publication of this manuscript. All activities related to data collection, analysis, and manuscript preparation were conducted without financial support from any public, commercial, or non-profit funding agencies.

Conflict of Interest Statement

The authors declare that they have no conflict of interest associated with this manuscript. There are no financial, personal, institutional, or professional relationships that could be perceived as influencing the research process, data interpretation, or the presentation of

results. The study was conducted independently, and all conclusions are based solely on the analyzed data.

Data Availability Statement

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request. These data include groundwater level measurements, climate variables, and geographic information system–based spatial datasets. Access to the data may be subject to institutional guidelines and ethical considerations.

REFERENCES

- Aliyar, Q., Zulfiqar, F., Datta, A., Kuwornu, J. K. M., & Shrestha, S. (2022). Drought perception and field-level adaptation strategies of farming households in drought-prone areas of Afghanistan. *International Journal of Disaster Risk Reduction*, 72(September 2021), 102862. <https://doi.org/10.1016/j.ijdr.2022.102862>
- Antwi, S. H., Rolston, A., Linnane, S., & Getty, D. (2022). Communicating water availability to improve awareness and implementation of water conservation: A study of the 2018 and 2020 drought events in the Republic of Ireland. *Science of the Total Environment*, 807, 150865. <https://doi.org/10.1016/j.scitotenv.2021.150865>
- Cheung, K. K. C., & Tai, K. W. H. (2021). The use of intercoder reliability in qualitative interview data analysis in science education. *Research in Science and Technological Education*, 00(00), 1–21. <https://doi.org/10.1080/02635143.2021.1993179>
- Daniell, J., Wenzel, F., & Schaefer, A. (2016). *The economic costs of natural disasters globally from 1900-2015 : historical and normalised floods , storms , earthquakes , volcanoes , bushfires , drought and other disasters*. 18, 2016.
- Ding, Y., Hayes, M. J., & Widhalm, M. (2011). Measuring economic impacts of drought: A review and discussion. *Disaster Prevention and Management*, 20(4), 434–446. <https://doi.org/10.1108/09653561111161752>
- Dumitrașcu, M., Mocanu, I., Mitrică, B., Dragotă, C., Grigorescu, I., & Dumitrică, C. (2018). The assessment of socio-economic vulnerability to drought in Southern Romania (Oltenia Plain). *International Journal of Disaster Risk Reduction*, 27(September 2017), 142–154. <https://doi.org/10.1016/j.ijdr.2017.09.049>
- Enenkel, M., Brown, M. E., Vogt, J. V., Mccarty, J. L., & Bell, A. R. (2020). *Why predict climate hazards if we need to understand impacts ? Putting humans back into the drought equation*. 1161–1176.
- Freire-gonzález, J., Decker, C., & Hall, J. W. (2017). The Economic Impacts of Droughts : A Framework for Analysis. *Ecological Economics*, 132, 196–204. <https://doi.org/10.1016/j.ecolecon.2016.11.005>
- Guo, H., Wen, X., Wu, Y., Wang, J., & Liang, Q. (2022). Drought risk assessment of farmers

- considering their planting behaviors and awareness: A case study of a County from China. *Ecological Indicators*, 137(February), 108728. <https://doi.org/10.1016/j.ecolind.2022.108728>
- Guo, Y., Huang, S., Huang, Q., Wang, H., Fang, W., Yang, Y., & Wang, L. (2018). Assessing socioeconomic drought based on an improved Multivariate Standardized Reliability and Resilience Index. *Journal of Hydrology*. <https://doi.org/10.1016/j.jhydrol.2018.11.055>
- Hermans, K., & McLeman, R. (2021). Climate change, drought, land degradation and migration: exploring the linkages. *Current Opinion in Environmental Sustainability*, 50, 236–244. <https://doi.org/10.1016/j.cosust.2021.04.013>
- Iqbal, M. W., Donjedee, S., & Kwanyuen, B. (2016). *FARMERS ' PERCEPTION OF WATER MANAGEMENT UNDER DROUGHT CONDITIONS IN BADAKSHAN PROVINCE , . November*, 6–8.
- Jawid, A., & Khadjavi, M. (2019). Adaptation to climate change in Afghanistan: Evidence on the impact of external interventions. *Economic Analysis and Policy*, 64, 64–82. <https://doi.org/10.1016/j.eap.2019.07.010>
- Kala, C. P. (2017). *Environmental and Socioeconomic Impacts of Drought in India : Lessons for Drought Management*. 5(2), 43–48. <https://doi.org/10.12691/aees-5-2-3>
- Kochhar, N., & Knippenberg, E. (2023). *Droughts and Welfare in Afghanistan*. January. <http://www.worldbank.org/prwp>.
- Kugbei, S., Gregg, B. R., Wassimi, N., & Van Gastel, A. J. G. (2005). Socioeconomic features, food security status and seed needs of farming households in Afghanistan. *Journal of New Seeds*, 7(1), 53–70. https://doi.org/10.1300/J153v07n01_05
- Mercado, R. (2020). Are capital inflows expansionary or contractionary in the Philippines? *Journal of Asian Economics*, 67. <https://doi.org/10.1016/j.asieco.2020.101176>
- Mukherjee, S., Mishra, A., & Trenberth, K. E. (2018). *Climate Change and Drought : a Perspective on Drought Indices*. 145–163.
- Ngcamu, B. S., & Chari, F. (2020). Drought influences on food insecurity in africa: A systematic literature review. *International Journal of Environmental Research and Public Health*, 17(16), 1–17. <https://doi.org/10.3390/ijerph17165897>
- Outbudin, I., Shiru, M. S., Sharafati, A., Ahmed, K., Al-Ansari, N., Yaseen, Z. M., Shahid, S., & Wang, X. (2019). Seasonal drought pattern changes due to climate variability: Case study in Afghanistan. *Water (Switzerland)*, 11(5). <https://doi.org/10.3390/w11051096>
- Rural, R., & Regeneration, E. (2015). *Regional Rural Economic Regeneration Strategies (RRERS) GRM*. 1–5.
- Sarwary, M. N., Behzad, M. H., & Rahimi, M. L. (2022). *Analysis of Groundwater Quality in Ghazni City, Ghazni, Afghanistan*. 1–12. <https://doi.org/10.32996/bjes>

- Seleiman, M. F., Al-Suhaibani, N., Ali, N., Akmal, M., Alotaibi, M., Refay, Y., Dindaroglu, T., Abdul-Wajid, H. H., & Battaglia, M. L. (2021). Drought stress impacts on plants and different approaches to alleviate its adverse effects. *Plants*, 10(2), 1–25. <https://doi.org/10.3390/plants10020259>
- Silva, M. M. G. T. De, & Kawasaki, A. (2018). Socioeconomic Vulnerability to Disaster Risk : A Case Study of Flood and Drought Impact in a Rural Sri Lankan Community. *Ecological Economics*, 152(May), 131–140. <https://doi.org/10.1016/j.ecolecon.2018.05.010>
- Social, A., Akademik, S., & Ara, S. (2022). *Asya Studies*. 6, 301–314.
- Switzer, D., & Vedlitz, A. (2017). Investigating the determinants and effects of local drought awareness. *Weather, Climate, and Society*, 9(4), 641–657. <https://doi.org/10.1175/WCAS-D-16-0052.1>
- Usmani, M. A. (2020). *A short Overview of Afghanistan*. June.
- Ward, F. A., Amer, S. A., & Ziaee, F. (2013). *Water allocation rules in Afghanistan for improved food security*. 35–53. <https://doi.org/10.1007/s12571-012-0224-x>
- Zhao, M., Huang, S., Huang, Q., Wang, H., Leng, G., & Xie, Y. (2019). Assessing socio-economic drought evolution characteristics and their possible meteorological driving force. *Geomatics, Natural Hazards and Risk*, 10(1), 1084–1101. <https://doi.org/10.1080/19475705.2018.1564706>
- Ziolkowska, J. R. (2016). *Socio-Economic Implications of Drought in the Agricultural Sector and the State Economy*. 1–11. <https://doi.org/10.3390/economies4030019>