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Study of monitoring of water bodies using remote sensing data and GIS technologies (Talimarjan water reservoir)

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Abstract. The study of water bodies using remote sensing data and Geographic Information System (GIS) technologies is crucial for effective water resource management. This research focuses on monitoring the Talimarjan water reservoir, a vital water source in Uzbekistan, by leveraging satellite imagery and GIS tools. Remote sensing offers a cost-effective and comprehensive approach to assess various parameters, including surface area, water quality, and seasonal fluctuations in water levels. By utilizing multi-temporal satellite data, changes in the reservoir's volume and surrounding vegetation were analyzed. The integration of GIS technologies facilitated the mapping and spatial analysis of these changes, enabling the identification of trends and potential risks, such as sedimentation and water loss. The combination of remote sensing and GIS provides valuable insights into the health and sustainability of the water reservoir, aiding in decision-making for water management authorities. This study demonstrates the effectiveness of these technologies in environmental monitoring, highlighting their potential for broader applications in the management of water resources in arid regions. Through accurate, real-time data, remote sensing and GIS help in ensuring sustainable water use, promoting efficient resource management, and mitigating the impacts of climate change on water bodies.

1. Introduction

Water is playing a pivotal role in maintaining the agroeconomical equilibrium, fostering economic progress, and enhancing social welfare within a Uzbekistan. However, the management and preservation of water resources have become increasingly challenging due to factors such as population growth, agricultural expansion, industrialization, and the adverse effects of climate change [1]. Consequently, the effective monitoring of water bodies, including rivers, lakes, and reservoirs, has become indispensable for sustainable management, especially in regions where water scarcity or heavy utilization prevails [2]. One such example is the Talimarjan Reservoir, situated in southern Uzbekistan, which serves as a crucial source for agricultural irrigation, fisheries, and regional water supply. Hence, the continuous monitoring of its ecological well-being and long-term sustainability is imperative to ensure that it meets the needs of local communities and ecosystems. Traditionally, the monitoring of water bodies necessitated extensive fieldwork, which was characterized by a high demand for labor, time consumption, and limitations in terms of coverage [3,4]. Nevertheless, the progress made in remote sensing and GIS technologies has brought about a revolution in the monitoring and management of water bodies. Remote sensing entails the collection of data from satellites or aerial platforms, thus

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affording a top-down perspective of the Earth's surface [4–6]. This technology permits the real-time and continuous monitoring of expansive areas, proving particularly advantageous for water bodies that are difficult to access or situated in remote locations [7–9]. Conversely, GIS technologies represent potent tools for the analysis and visualization of spatial data. They enable the integration, manipulation, and cartography of geographic data, thus yielding a comprehensive comprehension of the spatial and temporal transformations that occur within water bodies [10–13].

In the case of the Talimarjan Reservoir, remote sensing and GIS technologies offer the means to assess various parameters, including water surface area, water level fluctuations, sedimentation, and water quality. By utilizing satellite imagery in conjunction with GIS mapping, the reservoir can be continuously monitored, capturing changes in its physical characteristics and surrounding environment over time [14,15]. This approach is particularly valuable in arid and semi-arid regions like Uzbekistan, where water bodies are highly vulnerable to the impacts of climate variability and anthropogenic pressures. The use of remote sensing data, including high-resolution satellite images, allows for the analysis of the reservoir's seasonal dynamics [16–18]. For instance, by examining multi-temporal images taken at different times of the year, it becomes possible to identify changes in water volume, fluctuations in surface area, and potential indications of water loss due to evaporation, seepage, or human consumption. Remote sensing can also evaluate the ecological health of the reservoir through the analysis of surrounding vegetation and land use patterns. GIS technologies complement remote sensing by providing spatial analysis and mapping capabilities. With the aid of GIS tools, researchers can visualize and model changes in the reservoir's parameters, such as water volume and surface area, across different time periods. This spatial analysis is crucial for understanding long-term trends, identifying areas at risk of degradation, and planning effective water management strategies. The objective of this study is to explore the integration of remote sensing and GIS technologies in monitoring the Talimarjan Reservoir, with a focus on analyzing its surface area, water volume fluctuations, and the surrounding land use patterns. By leveraging these technologies, real-time data can be provided to water resource managers, aiding in the sustainability and health of the reservoir [19]. The findings of this research will contribute to a broader understanding of how modern technologies can be applied to the monitoring and management of water bodies in arid regions, promoting sustainable water usage and addressing the challenges posed by climate change and human activities.

2. Study area

The Talimarjan Reservoir, located in southern Uzbekistan's Kashkadarya region, is a crucial water storage facility for the country (Fig.1). It was constructed on the Kashkadarya River to support irrigation, drinking water supply, and hydroelectric power generation. The reservoir plays a critical role in the region's agricultural economy, providing water for vast farmland areas that grow cotton and wheat, both essential crops for Uzbekistan's economy [20,21]. Geographically, the reservoir sits in a semi-arid to arid climate zone with hot, dry summers and cold winters. The region receives very little rainfall annually, averaging around 200-400 mm, making the reservoir a vital water source for the area. The reservoir's catchment area primarily relies on the Kashkadarya River, which experiences significant seasonal flow variations due to mountain snowmelt. With a capacity of about 1.5 billion cubic meters, the reservoir's surface area fluctuates depending on seasonal inflows and outflows for irrigation and other purposes [22].

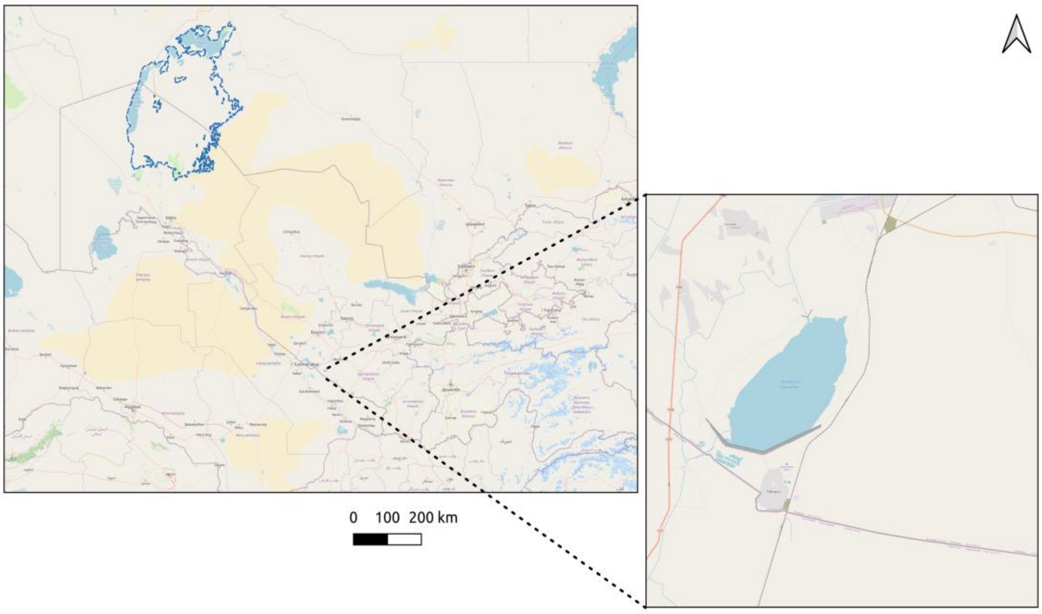

Figure 1. Study area "Talimarjan reservoir" (Source:www.osm.com, modified by QGIS).

The surrounding landscape consists mainly of desert plains with sparse vegetation, interspersed with irrigated agricultural lands. Human activities, particularly agricultural expansion, have exerted significant pressure on the water resources of the Talimarjan Reservoir. In recent years, the reservoir has also faced challenges from climate variability, raising concerns about water scarcity, sedimentation, and declining water quality. Given its strategic importance for water supply and agriculture, monitoring the Talimarjan Reservoir is crucial to ensure the region's water resources' sustainability [23]. The study area focuses on the reservoir itself, the river inflows, agricultural zones, and potential environmental hazards that could impact the reservoir's long-term health and functionality.

3. Data and methods

The monitoring of the Talimarjan Reservoir was carried out through the utilization of a combination of remote sensing data and Geographic Information System (GIS) technologies. The primary data utilized for this investigation were sourced from satellite imagery and hydrological records, thereby furnishing a comprehensive overview of the reservoir's physical and environmental parameters over time [24].

3.1. Sources of Data

Satellite Imagery: Multi-temporal satellite data were procured from platforms such as Landsat 8, Sentinel-2, and MODIS. These satellites offer high-resolution images that enable the examination of the reservoir's surface area, changes in water volume, and the vegetation surrounding it. The images employed spanned multiple time periods in order to capture seasonal and interannual fluctuations in water levels and land usage patterns.

Hydrological Data: Historical and current hydrological data from the Kashkadarya River, including records of water inflow and outflow, were gathered from local water management authorities. This data was crucial for establishing correlations between observed alterations in the reservoir and patterns of river discharge.

Climate Data: Meteorological data, encompassing metrics such as precipitation, temperature, and evaporation rates, were also obtained for the purpose of assessing the impact of climate variability on the reservoir's water levels [25].

3.2. Methods
Image Processing and Classification: Remote sensing data were processed using software QGIS. The images were preprocessed to correct for atmospheric distortions, followed by image classification techniques such as supervised classification to identify water bodies, vegetation, and land use changes around the reservoir.

Change Detection Analysis: Multi-temporal analysis was conducted to monitor changes in the surface area of the Talimarjan Reservoir. Techniques such as Normalized Difference Water Index (NDWI) were applied to delineate water boundaries and quantify fluctuations over time.

$$NDWI \frac{(Green-NIR)}{(Green+NIR)} \tag{1}$$

GIS Mapping and Spatial Analysis: GIS tools were employed to map the spatial distribution of water bodies, land use changes, and environmental risks such as sedimentation. Spatial analysis techniques were used to identify patterns and trends in water level changes and correlate them with climatic and hydrological data [26]. This integrated approach provided a comprehensive understanding of the dynamics affecting the Talimarjan reservoir.

4. Results
The Talimarjan Reservoir is utilized year-round, with periods of intensive use coinciding with the peak agricultural demand for water. During the growing season, when irrigation is essential for crops such as cotton and wheat, substantial amounts of water are withdrawn from the reservoir to satisfy the needs of the surrounding farmland. During other times, particularly in the off-season, the reservoir functions as a storage facility, accumulating water for future use. To effectively manage these fluctuating demands, an optimal operation strategy is developed that balances water usage for irrigation with the reservoir's secondary function of power generation. To ensure efficient and sustainable reservoir management, continuous monitoring of water levels is crucial. Geographical Information System (GIS) technologies, in combination with remote sensing data, offer an effective solution for this purpose. By utilizing satellite imagery and real-time data, GIS enables accurate tracking of water quantity, surface area changes, and potential risks such as sediment buildup or evaporation losses. Remote sensing facilitates real-time monitoring of the reservoir, providing valuable insights into water availability and allowing for swift responses to any critical fluctuations. This technology guarantees optimal management of water resources, thereby supporting agricultural activities, meeting power generation needs, and ensuring the long-term sustainability of the reservoir.

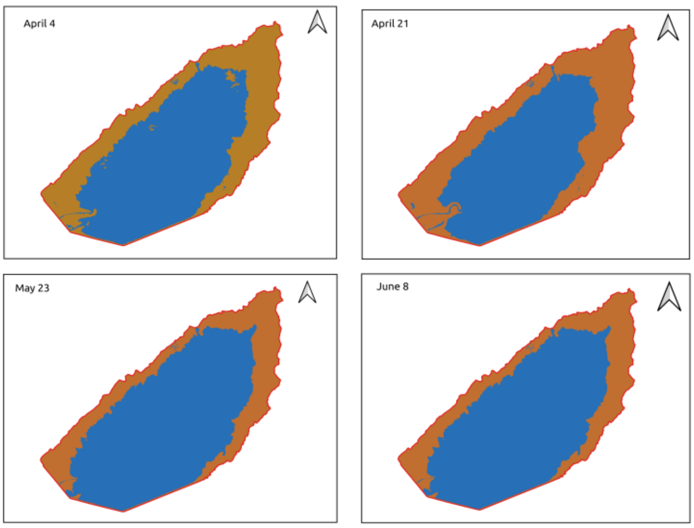

Figure 2. Map of water volume changes in reservoir (Aprel to June).

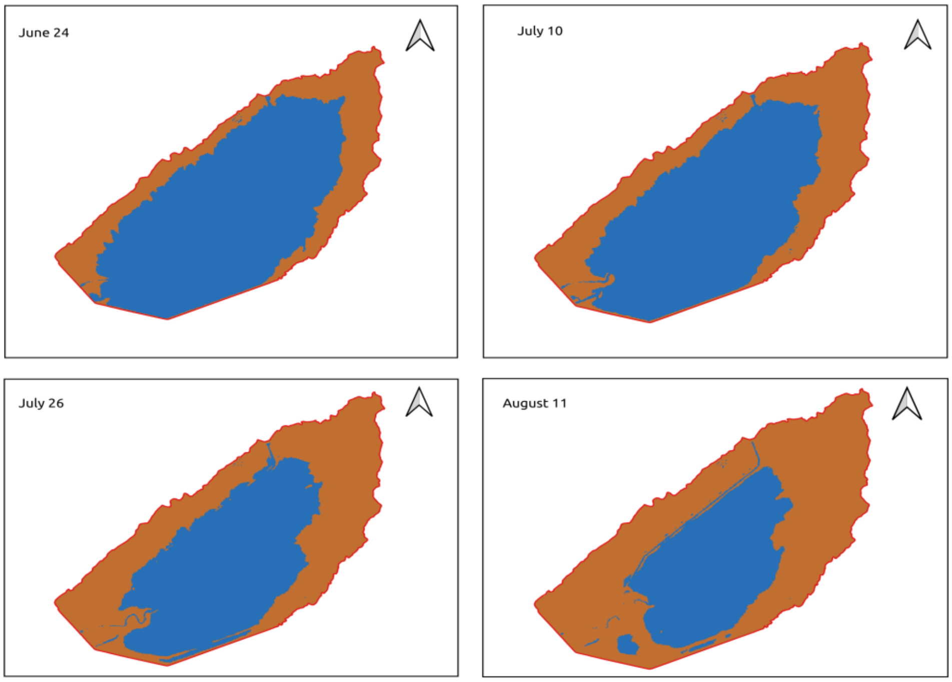

Figure 3. Map of water volume changes in reservoir (June to August)

The Talimarjan Reservoir was analyzed over the vegetation period, spanning from April to December, a critical time when water is most needed for agricultural activities. During this period, the reservoir experienced significant fluctuations in water levels, influenced by irrigation demands and climatic factors. The lowest water levels were observed in July and September, coinciding with peak water withdrawals for crop irrigation. In these months, the high demand for water to support the growth of crops such as cotton and wheat caused substantial depletion in the reservoir (Fig.3).

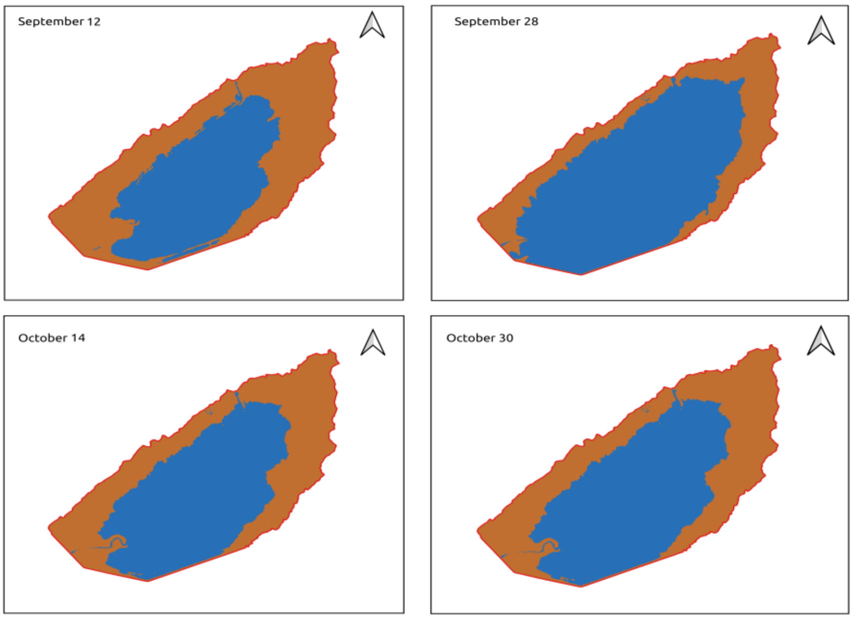

Figure 4. Map of water volume changes in reservoir (September to October)

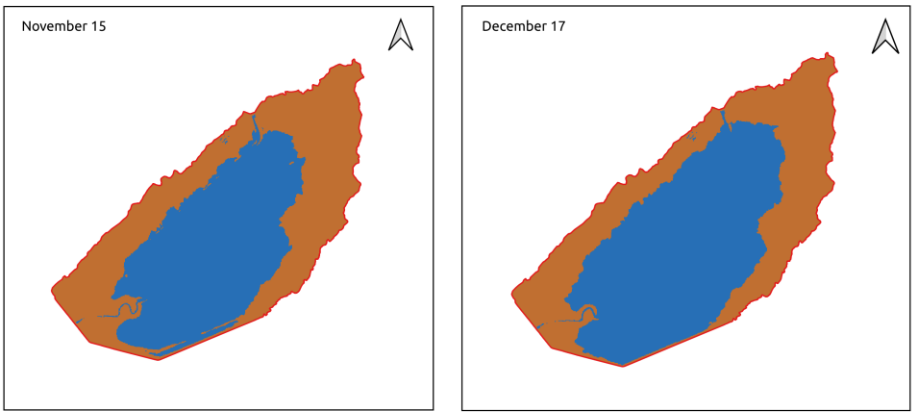

Figure 5. Map of water volume changes in reservoir (November to December)

Interestingly, a brief recovery in water levels was noted in September, possibly due to reduced irrigation demand or increased inflows from upstream sources, such as the Kashkadarya River. However, this increase was temporary, as the water level began to decline again in October. This reduction in water levels towards the end of the year reflects the continuous use of the reservoir's resources to meet irrigation needs, as well as the natural reduction in river inflows during the autumn months(Fig.4).

The analysis of these fluctuations highlights the importance of careful water management, particularly during the peak growing season, to ensure the reservoir can meet both agricultural and environmental needs. Continuous monitoring using remote sensing and GIS technologies is essential to understand and manage these seasonal changes effectively (Fig.5).

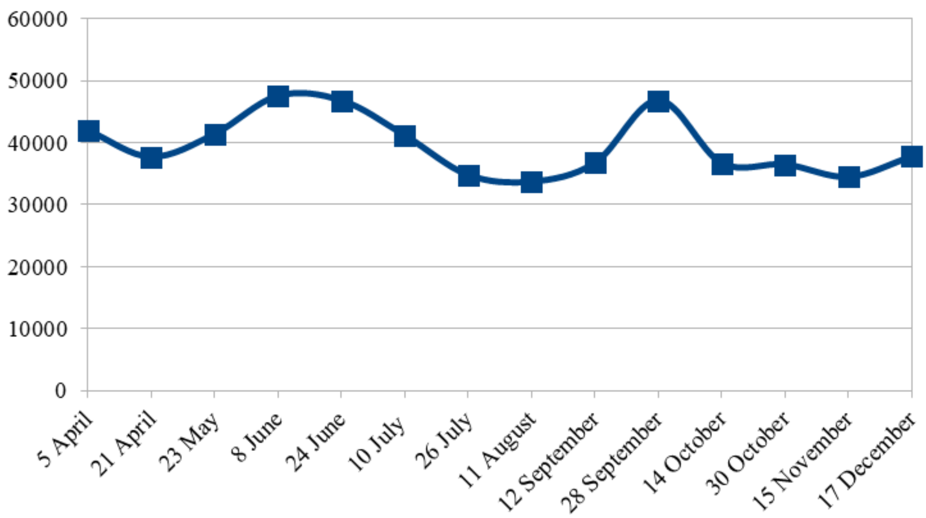

Figure 6. Dynamic of map of water volume changes in reservoir in vegetation period

Talimarjon Reservoir, holds prominent significance in the realm of regional water management and agriculture. The reservoir primarily serves as an irrigation system, providing essential support to the agricultural endeavors undertaken in the surrounding vicinity. Moreover, it plays a pivotal role in flood prevention and water provision. Throughout the vegetation period, spanning from April to December, the water levels within the reservoir display considerable fluctuations. Notably, the nadir is often observed in the months of July and September, potentially exerting adverse effects on irrigation schedules and crop yields (Fig.6). Subsequently, if the water levels rise in September, a subsequent decrease is typically witnessed from October onward. This recurrent pattern holds paramount importance in the context of agricultural planning and the efficient management of water resources.

5. Conclusion

The study of the Talimarjan Reservoir using remote sensing data and GIS technologies has yielded significant findings regarding the seasonal dynamics of water levels, particularly during the critical vegetation period from April to December. The analysis has revealed that the lowest water levels were observed during the months of July and September, which align with the peak irrigation demand. Such a pattern is expected given the substantial water requirements for the surrounding agricultural land during the peak growing season, specifically for water-intensive crops such as cotton and wheat. The integration of remote sensing and GIS technologies has proven to be highly effective in tracking these fluctuations in real-time. Satellite data has allowed for continuous monitoring of the reservoir's surface area and water levels, while GIS tools have facilitated spatial analysis and visualization of these changes. This real-time capability is particularly advantageous for the management of water resources in arid regions like southern Uzbekistan, where efficient water utilization is critical to meet the demands of agriculture, industry, and power generation. The study emphasizes the significance of utilizing remote sensing and GIS for the purpose of sustainable water resource management. These technologies provide accurate and timely information that can assist water managers in making informed decisions regarding the allocation of water for irrigation, monitoring the health of reservoirs, and promptly responding to fluctuations in water levels. By ensuring a harmonious balance between water supply and demand, these tools contribute to the long-term sustainability of vital water bodies such as the Talimarjan Reservoir, particularly in the face of escalating water scarcity and climate variability.

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