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Assessment of Pakistan's Water Storage Changes Using GRACE Satellite

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ABSTRACT

Pakistan is a country with diverse range of landscapes and significant agrarian economy, is heavily dependent on its water resources to support several industries and agricultural needs to the country's development. Being an agrarian country, the socioeconomic environment is greatly influenced by the availability and management of water. However, Pakistan has urgent and intricate problems with the delivery and storage of water. To tackle these obstacles, a comprehension of the spatiotemporal fluctuations in water storage throughout the country is necessary. In this context, the study delves into the assessment of Pakistan's water storage changes, specially focus on provincial levels, utilizing data of last two decades from the Gravity Recovery and Climate Experiment (GRACE) satellite. The findings showed that the level of water storage varies significantly. These variations match the mean of the Center for Space Research (CSR) data for the total water storage anomalies (TWSA), which include soil moisture, snow water, surface water and ground water. The spatiotemporal analysis revealed inconsistent TWSA trends across the country. These trends highlight the value of integrated water resource management (IWRM), especially in areas that are more likely to experience droughts and floods and have higher rates of extraction. This study advances knowledge of Pakistan's water storage changes and aids in the development of well-informed decisions for the sustainable management of water resources.

KEYWORDS: Pakistan, Water Storage, Spatiotemporal Analysis, GRACE

1 INTRODUCTION

Water is a basic, essential, and limited resource that promotes economic growth, environmental balance and the health of all living things. Indeed, water is a crucial source in Pakistan, playing a significant role in meeting the needs of agriculture, industry, and domestic consumption. Water resources are overused by sectors due to poor resource management and oversight [1]. Unfortunately, water crisis is increased day by day in Pakistan [2]. The water crisis is one of the major issues that affects many sectors (like environment, energy, food, health and economy). Further stresses on water resources can come from a variety of causes, including climate change and human activity [3]. Changes in the distribution of precipitation and temperature can have an impact on the hydrological cycle, which in turn affects water resources such as surface and groundwater [4,5]. Over-extraction of groundwater and improper management of surface water have led to decreased water levels in Pakistan, causing water balance issues when average value exceeds recharge over long

periods [6]. Pakistan's water resources face sustainability concerns, necessitating careful management to preserve them for future generations while meeting current water demands.
Research indicates that Pakistan's water storage changes are influenced by a combination of anthropogenic activities like groundwater extraction and irrigation techniques, as well as natural factors like climatic variability. Climate change and rising water demands pose significant threats to water security, particularly in arid and semiarid regions [7] like Pakistan. Pakistan's diverse hydrological landscape, climate variability, and population growth necessitate comprehensive water dynamics insights. Traditional monitoring methods lack spatially extensive and temporally continuous data, highlighting the need for spatiotemporal variations in water storage for effective management and sustainable resource planning. Developments in remote sensing technologies present viable approaches to regional water resource monitoring and assessment. Specifically, the Gravity Recovery and Climate Experiment (GRACE) satellite mission offers a means of measuring variations in Earth's gravity field, which can be used to evaluate spatiotemporal differences in water storage. The goal of the dedicated satellite project GRACE is to map the Earth's gravity field every thirty days at a spatial resolution of 400–40,000 km [8]. Based on observations of the Earth's global gravitational field, the GRACE mission gives variations in terrestrial water storage (TWS) almost every month [9]. GRACE uses twin satellites to measure gravity anomalies, which are processed into monthly anomalies with a spatial resolution of several hundred kilometres [10].
The main objective of this research is to use the GRACE satellite to examine changes in Pakistan's spatiotemporal water storage. GRACE has been used to assess regional differences in water storage during the last decade [11]. GRACE detects terrestrial water storage anomalies (TWSA) which include soil moisture, snow water, surface water and ground water; by detecting changes in Earth's gravity field due to water redistribution, distinguishing it from traditional remote sensors that measure surface electromagnetic emissions [12]. By analysing the gravity anomalies measured by the GRACE satellites from 2002-2022 and aim to quantify the changes in water storage over all provinces of Pakistan. This study focuses on provincial levels, improves knowledge of Pakistan's water storage dynamics. The research echoes the National Water Policy's demand for specific provincial policies, supports sustainable water management, and is consistent with administrative structures. By monitoring and analysing changes in water storage, policymakers and water authorities can make informed decisions about water extraction rates, sustainable use, and allocation strategies.

2 MATERIAL AND METHODS

2.1 Study Area

Pakistan is in South Asia between latitudes 23° 30′ N–33° 30′ N and longitudes 61° E–77° E. The country varied temperature and topography produce a dynamic hydrological system that affects the distribution and accessibility of water supplies. Pakistan faces a severe mismatch between the amount of water it receives and the amount it needs, much like many other South Asian countries that are water-stressed [13]. Pakistan's climate, which is primarily dry to semi-arid, means that the country is significantly dependent on its groundwater resources for a variety of purposes. The

primary cause of the use of groundwater is the variability and scarcity of surface water. However, groundwater is easier to reach than surface water [14]. In Pakistan's hydrological system, the Indus River and its tributaries are essential as they provide a significant amount of surface water and aid in groundwater recharge.

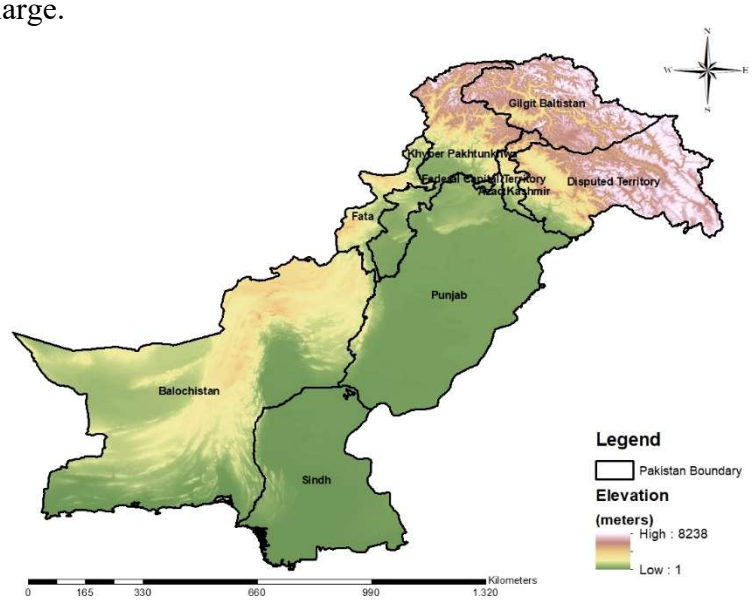

Figure 1: Elevation Map of Study Area (Pakistan).

2.2 Data

The Gravity Recovery and Climate Experiment (GRACE) and GRACE Follow On (GRACE-FO) satellites, which measure the Earth's gravity field, are the main source of data for this study. These measurements are used to calculate how much water storage has changed. Several sources, including CSR (Center for Space Research), GFZ (German Research Center for Geosciences), and JPL (Jet Propulsion Laboratory) have processed GRACE-based TWSA [15]. This study used monthly TWSA of CSR GRACE/GRACE-FO RL 06 version 02 Mascon Grids on an ellipsoidal Earth available at 1° × 1° resolution from 2002 to 2022. This is the latest version (RL-06) of GRACE data products released by CSR. GRACE Mascon solutions perform very well and better than the product based on spherical harmonics [16].

2.3 Methodology

Advancements in remote sensing technology offer promising solutions for monitoring and evaluating water resources at regional scales. GRACE offers a comprehensive view of water storage anomalies including surface water storage (SWS), snow water equivalent (SWE), soil moisture storage (SMS), and groundwater storage (GWS). The design of this study is based on an observational study utilizing satellite-based data. This research is conducting in three major steps. In the first step, the data of GRACE and GRACE-FO were downloaded and extracted covering the data period of twenty-one years from 2002 to 2022. In the second step, the mean values of TWSA for each year is individually extracted to develop a series. In the third step, spatial patterns of water

storage change and the magnitude of change are mapped using GIS and programming. In this study, spatial patterns of total water storage (liquid water equivalent thickness in cm) and changes in magnitude are displaced at each grid point. Color patterns are applied to better understand the spatial groundwater storage variations and the changes in magnitude. This study gives a visual depiction of how Pakistan's water storage has changed during last two decades by mapping and analysing the spatiotemporal patterns.

3 RESULTS AND DISCUSSION

3.1 Spatial Variations

The spatial attributes of Pakistan's water storage variations are illustrated in Figures 2 and 3. These visual representations were crafted by presenting the TWSA values associated with each grid point. These figures effectively convey that alterations in TWSA exhibit a lack of uniformity throughout the entire country. This non-uniform distribution can be attributed to a multitude of factors, including disparities in topography, land suitability for agriculture, and diverse climate conditions that span across different regions of Pakistan. Figure 2 is the TWSA for specifically chosen grid cells within Pakistan. This depiction serves as an example, showcasing the dynamic variations in TWSA over a span of twenty-one years. In this specific scenario, the range of TWSA fluctuations spanned from -10.899 cm to 0.095 cm. Negative values indicate fewer changes while positive values indicate more changes, as they are anomalies. TWSA patterns show distinct spatial distribution, especially in northern Pakistan, with highest monthly values due to significant annual rainfall.

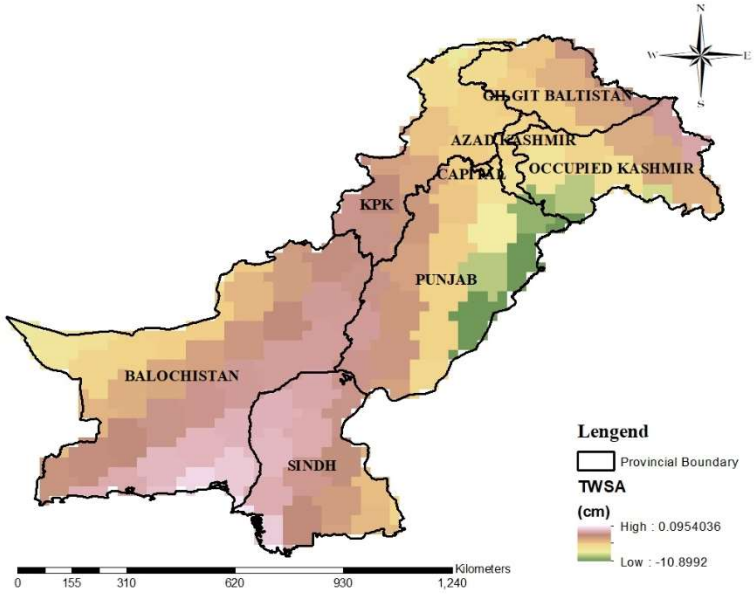

Figure 2: Spatial Mean Pattern of Total Water Storage Anomalies from 2002 to 2022.

In addition, Figure 3 presents the annual means for each year. Notably, the range of TWSA extended from -17.543 cm to +12.516 cm. This depiction offers clear insight into the fluctuations

within flood-prone regions, notably reflecting the impact of events such as the floods of 2010 and 2022, which highlight increased values due to groundwater recharge. Furthermore, areas experiencing drought conditions exhibit discernible declines in TWSA over the same period.

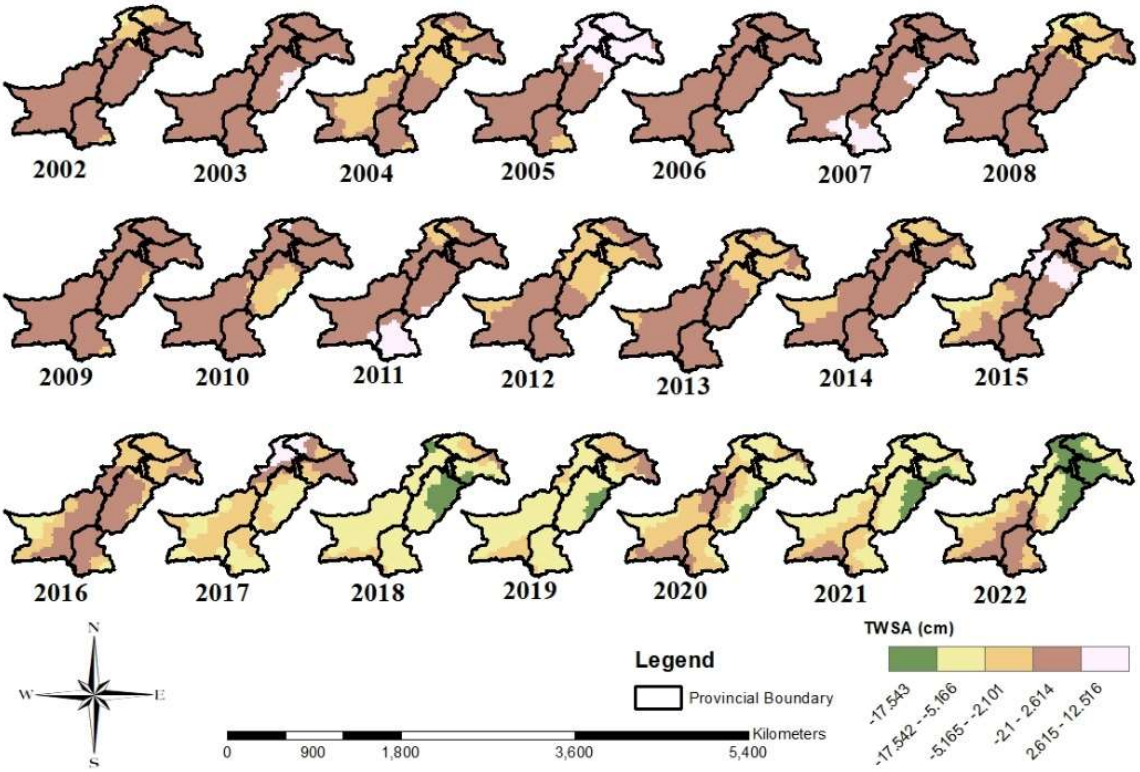

Figure 3: Spatial Annual Patterns of Total Water Storage Anomalies.

3.2 Temporal Variations

The results for provinces Punjab, Sindh, Balochistan, Khyber Pakhtunkhwa, Gilgit Baltistan and the Kashmir regions showed more significant outcomes. The results revealed declines across all locations, strongly suggesting that consumption of surface water increased and groundwater extractions were surpassing recharge. Figure 4 illustrated the annually variations in TWSA. Significant increases in TWSA were observed, particularly during flood events such as the ones in 2010 and 2022. These floods led to a notable rise in water levels in the lower Indus Basin, which had a considerable impact on all provinces. Similarly, substantial declines in groundwater storage were particularly evident during drought events, influenced by the El Niño-Southern Oscillation (ENSO) conditions [17]. These droughts were exacerbated by a lack of precipitation. A significant decreasing in precipitation trend was found in the country which cause droughts [18]. Noteworthy distinctive shifts experienced by Punjab and Sindh, where TWSA exhibits significant variations, including notable declines, while the other provinces show fluctuations that lack uniformity, emphasizing the complexity and heterogeneity of water storage dynamics within the country.

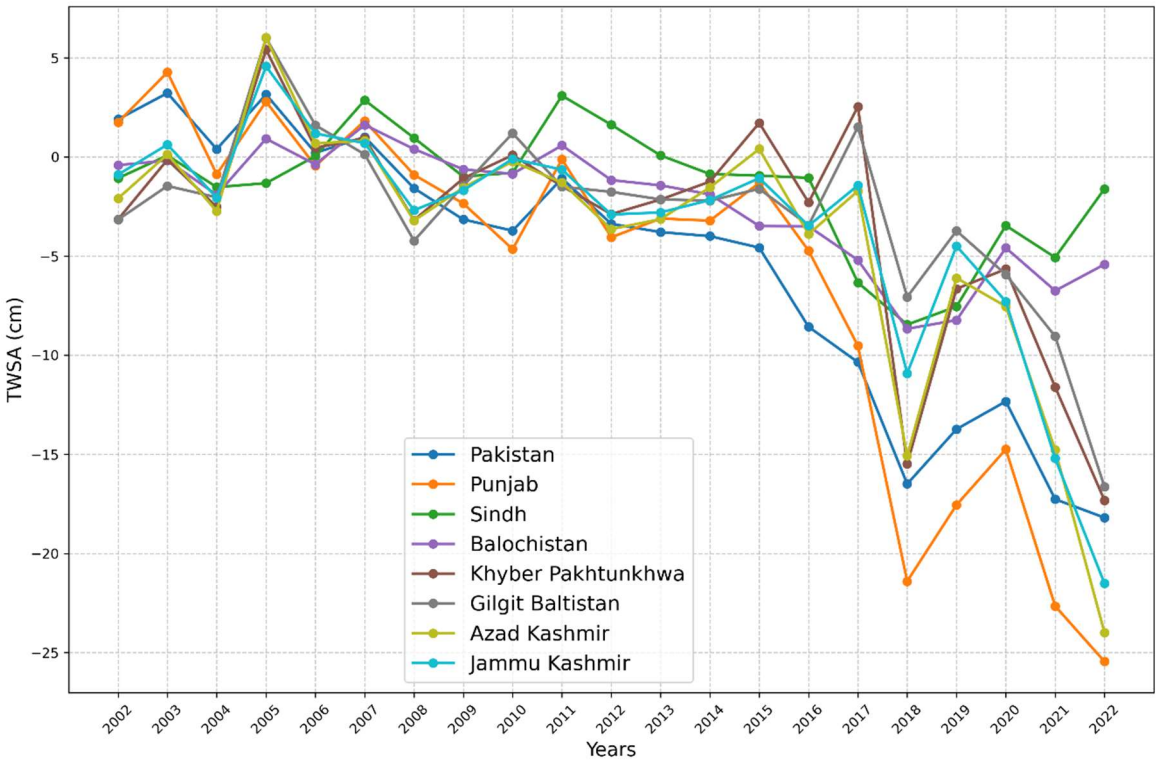

Figure 4: Annual Variation in Total Water Storage Anomalies of Different Regions.

4 CONCLUSION

Precise knowledge of water storage changes is crucial for reliable and integrated water resource management (IWRM), especially in arid and semi-arid areas like Pakistan. In such regions, human activities and spatiotemporal climate shifts influence the water storage dynamics. The study's findings provide strong evidence of a significant and fast-paced decrease in the amount of water storages in Pakistan. The water storages are being depleted at a notable rate, and this reduction has been substantiated by the study's analysis and data, highlighting the pressing concern of diminishing water resources in the country. Notably, the most significant declines in water storage were observed over the last decade. This suggests that factors such as changing weather patterns and agricultural practices play a vital role in shaping water dynamics in the country, with recent years seeing the most pronounced impact on resources. The spatial patterns revealed non-uniform variations in TWSA across the entire country. The data analysis underscores considerable fluctuations in TWSA across all provinces of Pakistan. Notably, Punjab and Sindh exhibit particularly pronounced changes when compared to other regions. However, other provinces show fluctuations that lack uniformity. The results substantiate the critical importance of taking action to mitigate the overuse of water resources, with the aim of preventing an impending crisis in the near future. The study underscores the urgent need for management plans and policy changes to ensure Pakistan's long-term sustainability of its water resources.

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REFERENCES

1. Salem, G. S. A., Kazama, S., Komori, D., Shahid, S. & Dey, N. C. Optimum Abstraction of Groundwater for Sustaining Groundwater Level and Reducing Irrigation Cost. *Water Resources Management* **31**, 1947–1959 (2017).
2. Akbar, M., Ali Khan, S., Dilawar, S. & Tahir Hassan, M. *WATER CRISIS IN PAKISTAN: PROSPECTS AND IMPLICATIONS*. *PROSPECTS AND IMPLICATIONS PJAEE* vol. 18 (2021).
3. Moghim, S. Assessment of Water Storage Changes Using GRACE and GLDAS. *Water Resources Management* **34**, 685–697 (2020).
4. Liuzzo, L., Noto, L. V., Arnone, E., Caracciolo, D. & La Loggia, G. Modifications in Water Resources Availability Under Climate Changes: A Case Study in a Sicilian Basin. *Water Resources Management* **29**, 1117–1135 (2015).
5. Moghim, S. Impact of climate variation on hydrometeorology in Iran. *Glob Planet Change* **170**, 93–105 (2018).
6. Cheema, M. J. M., Immerzeel, W. W. & Bastiaanssen, W. G. M. Spatial quantification of groundwater abstraction in the irrigated indus basin. *Groundwater* **52**, 25–36 (2014).
7. Hu, Z. *et al.* Groundwater depletion estimated from GRACE: A challenge of sustainable development in an arid region of Central Asia. *Remote Sens (Basel)* **11**, (2019).
8. Tapley, B. D., Bettadpur, S., Watkins, M. & Reigber, C. The gravity recovery and climate experiment: Mission overview and early results. *Geophys Res Lett* **31**, (2004).
9. Strassberg, G., Scanlon, B. R. & Chambers, D. Evaluation of groundwater storage monitoring with the GRACE satellite: Case study of the High Plains aquifer, central United States. *Water Resour Res* **45**, (2009).
10. Seyoum, W. M., Kwon, D. & Milewski, A. M. Downscaling GRACE TWSA data into high-resolution groundwater level anomaly using machine learning-based models in a glacial aquifer system. *Remote Sens (Basel)* **11**, (2019).
11. Xiao, R., He, X., Zhang, Y., Ferreira, V. G. & Chang, L. Monitoring groundwater variations from satellite gravimetry and hydrological models: A comparison with in-situ measurements in the mid-atlantic region of the United States. *Remote Sens (Basel)* **7**, 686–703 (2015).
12. Katpatal, Y. B., Rishma, C. & Singh, C. K. Sensitivity of the Gravity Recovery and Climate Experiment (GRACE) to the complexity of aquifer systems for monitoring of groundwater. *Hydrogeol J* **26**, 933–943 (2018).
13. Qureshi, A. S. *Improving Food Security and Livelihood Resilience through Groundwater Management in Pakistan Scaling up Small Scale Irrigation Technologies to Improve Food Security in Sub-Saharan Africa View Project ICBA-RAMSAP View Project*. http://garj.org/garjas/home (2015).

14. Salam, M. *et al.* GROUNDWATER STORAGE CHANGE ESTIMATION USING GRACE SATELLITE DATA IN INDUS BASIN. *Big Data in Water Resources Engineering (BDWRE)* **1**, 10–15 (2020).
15. Arshad, A., Mirchi, A., Samimi, M. & Ahmad, B. Combining downscaled-GRACE data with SWAT to improve the estimation of groundwater storage and depletion variations in the Irrigated Indus Basin (IIB). *Science of the Total Environment* **838**, (2022).
16. Neves, M. C., Nunes, L. M. & Monteiro, J. P. Evaluation of GRACE data for water resource management in Iberia: a case study of groundwater storage monitoring in the Algarve region. *J Hydrol Reg Stud* **32**, (2020).
17. Ullah, I. *et al.* Recent and projected changes in water scarcity and unprecedented drought events over Southern Pakistan. *Front Earth Sci (Lausanne)* **11**, (2023).
18. Naz, F., Dars, G. H., Ansari, K., Jamro, S. & Krakauer, N. Y. Drought trends in Balochistan. *Water (Switzerland)* **12**, (2020).