*environmental sciences proceedings*

MDPI

*Proceeding Paper*

# Comparing the Water Storage Changes in Iran and Its Six Neighboring Countries with Gravity Recovery and Climate Experiment Satellite Data on Google Earth Engine †

**Sahand Tahermanesh, Behnam Asghari Beirami * and Mehdi Mokhtarzade**

Department of Photogrammetry and Remote Sensing, Faculty of Geodesy and Geomatics Engineering, K. N. Toosi University of Technology, Tehran 19967-15433, Iran; tahermanesh@gmail.com (S.T.); m_mokhtarzade@kntu.ac.ir (M.M.)

* Correspondence: behnam.asghari1370@gmail.com

† Presented at the 5th International Electronic Conference on Remote Sensing, 7–21 November 2023; Available online: https://ecrs2023.sciforum.net/.

**Abstract:** Water plays a vital role in sustaining life and meeting the water needs of various sectors, such as agriculture, industries, and households. As water resources continue to be depleted, several hazards arise for communities. Declining water quality, a declining water table, reduced plant growth, droughts, diminished agricultural productivity, and the underutilization of power generation stations are some of the hazards associated with these conditions. Therefore, it is crucial to monitor the changes in water resources. The traditional methods used for measuring water storage face various challenges, including limited spatial coverage, low temporal resolution, high cost and resource requirements, and accuracy limitations. To address these challenges, remote sensing sensors such as the GRACE satellite provide rich sources of information that can be used to evaluate water reserves. Moreover, the Google Earth Engine provides access to a wide range of satellite imagery and geospatial data for various applications, making geospatial information more accessible and enabling informed decisions. This study analyzed the GRACE satellite time series data from 2002 to 2017 to investigate and compare water storage changes in Iran and six neighboring countries: Turkey, Iraq, Saudi Arabia, Turkmenistan, Pakistan, and Afghanistan. The final statistical analyses indicate a decrease in water reserves in almost all mentioned countries. The analysis of the results shows that Iran ranks second in terms of water reserve consumption after Iraq, which had the worst performance. Our study concludes with a concerning outlook on water storage in Iran, primarily attributed to inefficient water resource management, reduced rainfall, drought, and excessive withdrawals.

**Keywords:** water storage; GRACE; Google Earth Engine



**Citation:** Tahermanesh, S.; Beirami, B.A.; Mokhtarzade, M. Comparing the Water Storage Changes in Iran and Its Six Neighboring Countries with Gravity Recovery and Climate Experiment Satellite Data on Google Earth Engine. *Environ. Sci. Proc.* **2024**, *29*, 28. https://doi.org/10.3390/ECRS2023-16295

Academic Editor: Riccardo Buccolieri

Published: 6 November 2023



## 1. Introduction

The accurate monitoring and effective management of water resources in arid and semi-arid regions, such as Iran, are of great importance. Implementing precise spatial and temporal monitoring techniques and appropriate water storage strategies can significantly contribute to sustainable water resource management. Water reserves are vital to various freshwater sources and are pivotal in global economic and social development [1]. Using satellite imagery and station data, the Climate Hazards Group Infrared Precipitation with Station dataset generates detailed grids that contain rainfall information for analyzing long-term patterns and conducting drought surveillance. It employs sophisticated interpolation techniques and high-resolution cold cloud duration observations to provide precise estimates of long-term rainfall [2]. Investigating changes in equivalent water thickness using traditional methods poses challenges due to the need for hydrologic data and the large spatial scales involved [3]. Satellite observations enable the monitoring and study of water storage changes through remote sensing technology. The GRACE satellite establishes a relationship between monthly variations in the Earth's gravity field and water level fluctuations by estimating the Earth's gravity field [4]. Monthly GRACE satellite data enable a comprehensive water storage assessment, encompassing underground water, soil moisture, surface water, and snow equivalent water.

Various investigations have been carried out to scrutinize equivalent water thickness and water retention by employing remote sensing technology and GRACE satellites. Khaki et al. [5] investigated changes in various water storage components in the Middle East, including groundwater, surface water, and soil moisture. The study achieves its objective by generating a comprehensive long-term reanalysis of a land's hydrologic water storage elements from 1980 to 2019. This process involves integrating multiple satellite remote sensing observations with an advanced data assimilation approach, considered state of the art in hydrological modeling. In another study, Lezzaik et al. [6] applied a distributed ArcGIS model and utilized gridded datasets to estimate water storage in the Middle East and North Africa. This estimation was achieved by generating estimates for an aquifer's saturated thickness and effective porosity. Additionally, monthly gravimetric datasets (GRACE) and land surface parameters (GLDAS) were utilized to quantify changes in groundwater storage between 2003 and 2014.

The primary objective of this study is to employ GRACE data to explore and compare changes in water storage within Iran and six adjacent countries, namely Turkey, Iraq, Saudi Arabia, Turkmenistan, Pakistan, and Afghanistan, from 2002 to 2017 using the Google Earth Engine (GEE) platform. The key findings reveal a widespread decrease in water storage across most countries, with Iran ranking second in significant depletion. Our study is expected to contribute to understanding water storage dynamics in the East Asia region and highlight the pressing need for sustainable water management strategies.

The present study consists of several distinct sections. The Section 2 presents the research study areas and utilized data. Section 3 offers an overview of the methodology employed. Section 4 presents the experimental results in detail and discusses the obtained results. Finally, Section 5 summarizes the essential findings and conclusions.

## 2. Study Area and Dataset

As previously mentioned, in this study, we investigated the water storage changes in seven countries: Iran, Turkey, Iraq, Saudi Arabia, Turkmenistan, Pakistan, and Afghanistan. Figure 1 displays the geographical location of the study area.

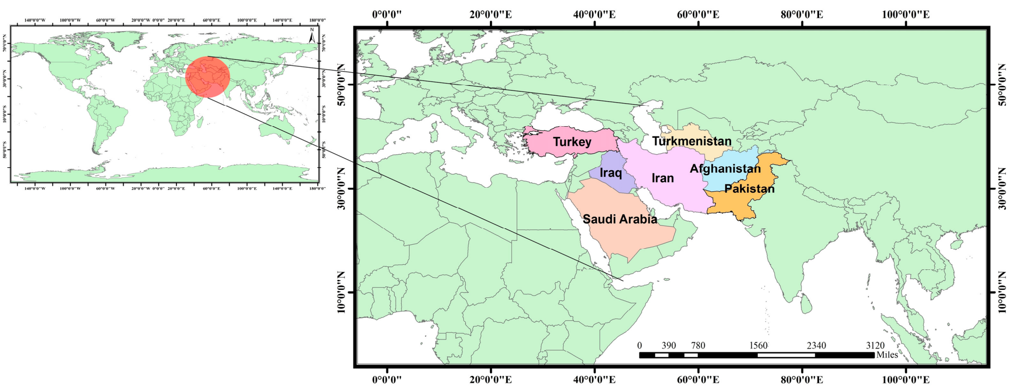


**Figure 1.** The geographical location of the study area.

Considering their geographical location, these regions have fragile water resources, making them highly prone to fluctuations. Analyzing the variations in water reserves can improve our comprehension of their sensitivity and vulnerability. Additionally, these areas experience significant economic and social effects due to water scarcity. Water resources play a vital role in the local economy and daily livelihoods of people, and the importance of evaluating changes in water resources is essential to understand economic and social consequences.

The Gravity Recovery and Climate Experiment (GRACE) is a collaborative satellite mission by NASA (National Aeronautics and Space Administration) and the University of California. Its primary objective is to investigate Earth's gravitational changes and their influence on water resources and climate. This mission employs co-orbiting satellites to measure the planet's gravity field variations accurately. GRACE enables the modeling and prediction of water storage changes in diverse regions worldwide, including oceans, rivers, lakes, and underground reservoirs. In this study, we obtained GRACE's "lwe_thickness_gfz" products from the GEE platform, covering the period from 2002 to 2017 across seven countries.

## 3. Methodology

This paper utilizes GRACE satellite time series data to investigate the water storage depletion in the study areas.

The flowchart depicted in Figure 2 outlines the methodology. The following steps are conducted within the GEE environment to investigate changes in water resources.

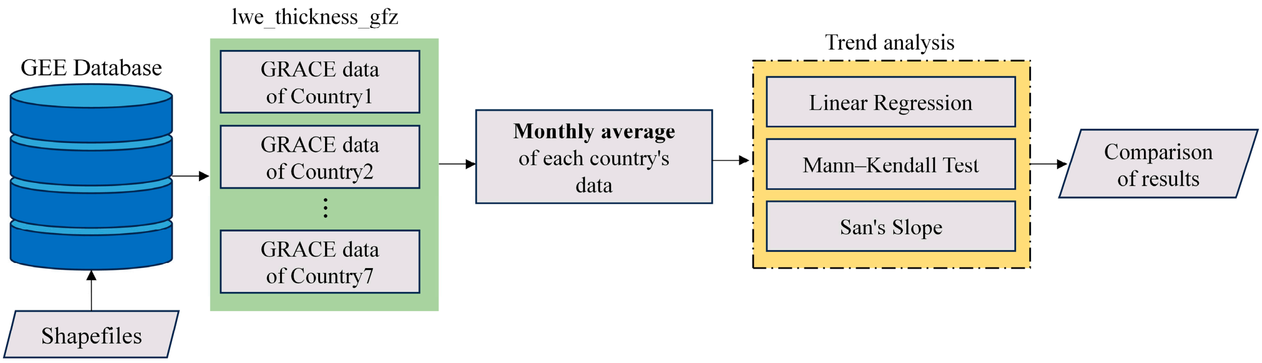


**Figure 2.** The study's flowchart.

Firstly, a country-based boundary map is generated using shapefile data. Then, based on the shapefile, GRACE data (lwe_thickness_gfz) are obtained from the image collection, corresponding to the specified period (from 1 April 2002 to 20 May 2017). In the subsequent stage, a time series chart is created to depict each country's average values of the GRACE data. To gain a deeper insight into the trend of changes, the monthly average values of the GRACE data are analyzed using three trend analysis methods: the linear regression method, the Mann–Kendall test, and San's slope estimator.

Linear regression (LR) is a parametric method used for predictive analysis, assuming normally distributed data. The Mann–Kendall test is a non-parametric test employed to identify monotonic patterns in ecological, atmospheric, or hydrological data, aiming to determine whether the time series data adhere to a specific pattern, such as positive, negative, or no pattern [7]. San's slope test is a statistical method that evaluates the significance of the slope coefficient in a linear regression model [8]. Finally, the findings of the seven countries are compared.

## 4. Experimental Result

### *4.1. Result Analysis*

The graphs below display GRACE data from 2002 to 2017 for the seven mentioned countries. According to Figure 3, the fluctuations in the water storage levels can be analyzed over time. In the following, a trend analysis has been conducted for the obtained data for a more detailed analysis (The blue line shows the trends during the years and the red line shows the linear regression that fitted to the trend.).

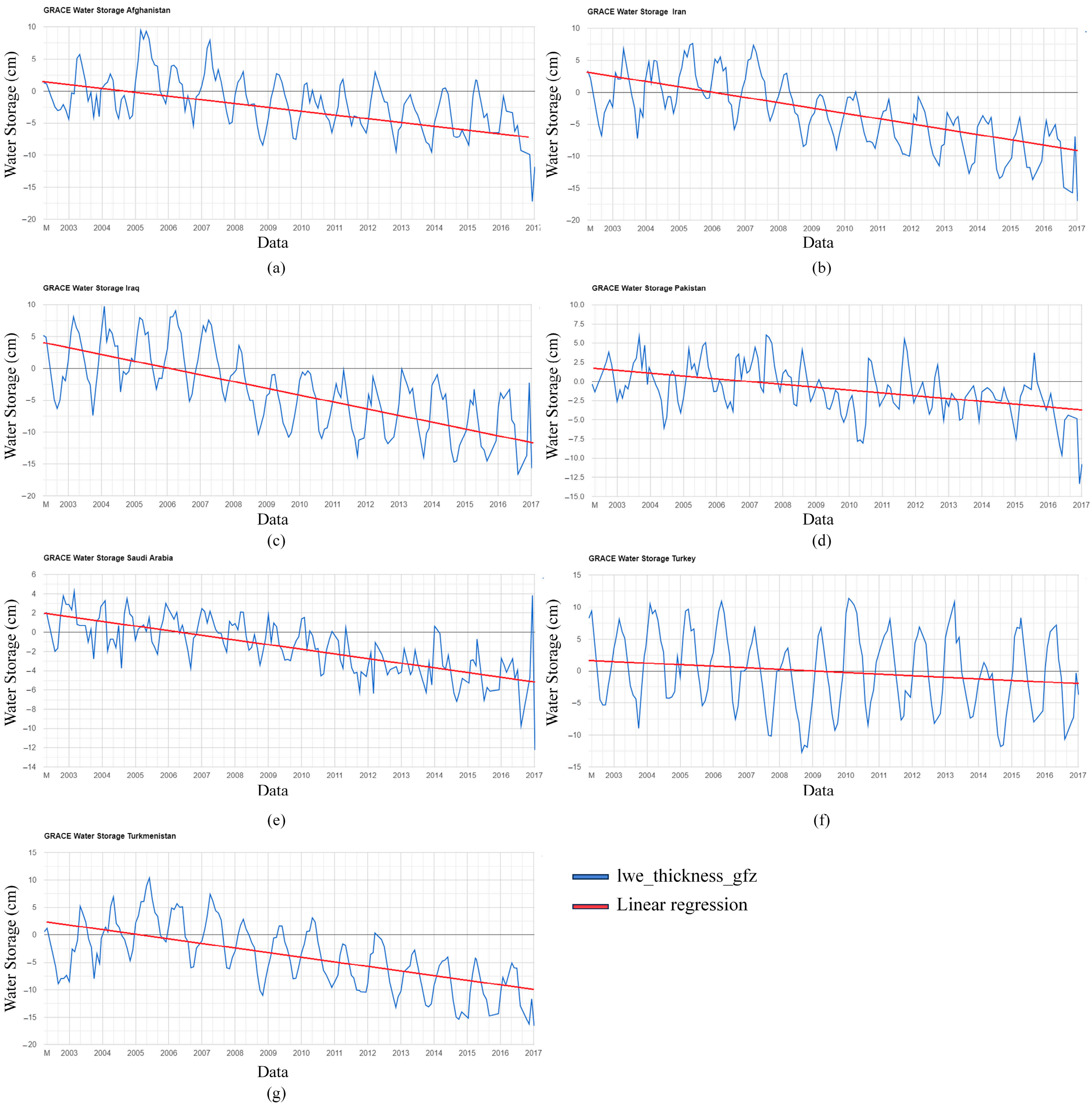


**Figure 3.** The average changes in water storage levels (in cm) have been analyzed for seven countries: (**a**) Afghanistan, (**b**) Iran, (**c**) Iraq, (**d**) Pakistan, (**e**) Saudi Arabia, (**f**) Turkey, and (**g**) Turkmenistan.

In the above figures, the trend analysis carried out using LR can be observed as red lines. The outcomes of this trend analysis are presented in Table 1. The regression line serves as a valuable tool for identifying long-term trends. A negative slope of the regression line suggests a negative trend, indicating a decrease in LWE thickness. Additionally, the Mann–Kendall test, employing the Z statistic, determines the significance of a trend in the data. A statistical trend is indicated if the absolute value of this statistic exceeds 1.96. San's slope test is also a non-parametric test employed to detect GRACE data trends.

**Table 1.** The LR slope, Mann–Kendall statistic values, and Sen's slope for water storage fluctuations.

| Country | LR slope | Mann–Kendall Test | | San's Slope Value |
|---|---|---|---|---|
| | | Trend | Z-Value | |
| Afghanistan | −0.0452 | Decreasing | −6.1199 | −0.04287 |
| Iran | −0.0809 | Decreasing | −9.5618 | −0.08365 |
| Iraq | **−0.0898** | Decreasing | −8.8648 | **−0.09135** |
| Pakistan | −0.0331 | Decreasing | −5.8711 | −0.03129 |
| Saudi Arabia | −0.0427 | Decreasing | −9.6274 | −0.04419 |
| Turkey | **−0.0209** | **No trend** | **−1.8796** | **−0.02107** |
| Turkmenistan | −0.0774 | Decreasing | −7.9905 | −0.08252 |

The regression analysis shows that water reserves have decreased in all mentioned countries. Of course, in the meantime, the reduction rate is different in all these countries. This rate was slowest in Turkey and fastest in Iraq. Except for Turkey, the Mann–Kendall test also confirms the declining trend in water reserves for almost all countries. Additionally, San's slope test results indicate a consistent downward trend in groundwater thickness across all countries, the same as the regression analysis. Among the seven neighboring countries, Iraq exhibits the highest rate of water level reduction.

### *4.2. Discussion*

Turkey has experienced relatively high rainfall and the construction of numerous dams, which have contributed to minimizing changes in the country's water reserves. In contrast, Iraq's water reserves have experienced a significant decrease due to several factors. These factors include the construction of dams by its neighboring countries and an extended period of drought accompanied by reduced rainfall [5].

Considering the primary focus of the research on Iran, we aim to clarify the factors contributing to the reduction in water reserves in this country. In terms of water resource consumption, Iran ranks second after Iraq. From 1999 to 2018, a period characterized by a dry climate and reduced precipitation patterns, Iran experienced a significant decrease in rainfall. In addition to the drought and reduced precipitation patterns, the depletion of Iran's water reserves is further exacerbated by extensive industrial and agricultural utilization, surpassing the decline observed in neighboring countries. In addition to drought, non-climatic factors, such as irrigation practices, significantly impact water storage in Iran, primarily due to incorrect water management practices. Excessive irrigation, including groundwater abstraction, contributes to the depletion of water resources. Moreover, Iran exceeds its neighboring countries in agricultural and industrial activities, resulting in increased water consumption during periods of drought and subsequent declines in water reserves [9,10].

## 5. Conclusions

Water is crucial for sustaining life and meeting the water needs of various sectors, including agriculture, industries, and households. Therefore, monitoring water changes for effective water resource management is essential. The GEE offers access to a wide range of satellite imagery and geospatial data for various applications. This study used GRACE data to investigate and compare water thickness changes in Iran and six neighboring countries. Based on the findings, water reserves have exhibited a decline in almost all of the countries examined. Among them, Iraq has experienced the most prominent decrease, ranking the highest in change rate, while Turkey has shown the most minor decline, occupying the lowest position. Unlike six neighboring countries, Iran has secured the second position in water reserve depletion, surpassing them due to a combination of factors, including extensive industrial and agricultural usage, alongside prevailing drought conditions and reduced rainfall.

**Author Contributions:** Conceptualization, S.T. and B.A.B.; methodology, S.T. and B.A.B.; software, S.T. and B.A.B.; validation, S.T. and B.A.B.; formal analysis, S.T. and B.A.B.; investigation, S.T. and B.A.B.; resources, S.T. and B.A.B.; data curation, S.T.; writing—original draft preparation, S.T.; writing—review and editing, S.T. and B.A.B.; visualization, S.T.; supervision, M.M. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** The data are accessible at https://earthengine.google.com accessed on 1 April 2002).

**Acknowledgments:** We sincerely thank NASA (National Aeronautics and Space Administration) and the University of California for providing researchers with access to the GRACE data.

**Conflicts of Interest:** The authors declare no conflicts of interest.

## References

1. Joodaki, G.; Wahr, J.; Swenson, S. Estimating the human contribution to groundwater depletion in the Middle East, from GRACE data, land surface models, and well observations. *Water Resour. Res.* **2014**, *50*, 2679–2692. [CrossRef]
2. Funk, C.; Peterson, P.; Landsfeld, M.; Pedreros, D.; Verdin, J.; Shukla, S.; Husak, G.; Rowland, J.; Harrison, L.; Hoell, A.; et al. The climate hazards infrared precipitation with stations—A new environmental record for monitoring extremes. *Sci. Data* **2015**, *2*, 150066. [CrossRef] [PubMed]
3. Yin, W.; Hu, L.; Zhang, M.; Wang, J.; Han, S.-C. Statistical Downscaling of GRACE-Derived Groundwater Storage Using ET Data in the North China Plain. *J. Geophys. Res. Atmos.* **2018**, *123*, 5973–5987. [CrossRef]
4. Rodell, M.; Reager, J.T. Water cycle science enabled by the GRACE and GRACE-FO satellite missions. *Nat. Water* **2023**, *1*, 47–59. [CrossRef]
5. Khaki, M.; Hoteit, I. Monitoring water storage decline over the Middle East. *J. Hydrol.* **2021**, *603*, 127166. [CrossRef]
6. Lezzaik, K.; Milewski, A. A quantitative assessment of groundwater resources in the Middle East and North Africa region. *Hydrogeol. J.* **2018**, *26*, 251–266. [CrossRef]
7. Deoli, V.; Kumar, D. Analysis of Groundwater Fluctuation using GRACE Satellite Data. *Indian J. Ecol.* **2021**, *47*, 299–302.
8. Sen, P.K. Estimates of the Regression Coefficient Based on Kendall's Tau. *J. Am. Stat. Assoc.* **1968**, *63*, 1379–1389. [CrossRef]
9. Forootan, E.; Rietbroek, R.; Kusche, J.; Sharifi, M.A.; Awange, J.L.; Schmidt, M.; Omondi, P.; Famiglietti, J. Separation of large scale water storage patterns over Iran using GRACE, altimetry and hydrological data. *Remote Sens. Environ.* **2014**, *140*, 580–595. [CrossRef]
10. Khaki, M.; Forootan, E.; Kuhn, M.; Awange, J.; van Dijk, A.I.J.M.; Schumacher, M.; Sharifi, M.A. Determining water storage depletion within Iran by assimilating GRACE data into the W3RA hydrological model. *Adv. Water Resour.* **2018**, *114*, 1–18. [CrossRef]