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Integrated study of GRACE-based groundwater storage variability across Ethiopia for sustainable economic development

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INTRODUCTION & AIM

Groundwater is water from precipitation that percolates into the soil and moves downward to fill cracks and openings in the rocks and sands. It makes up about 30% of the global freshwater. The total groundwater value in the upper 2km of the continental crust is approximately 22.6 million km3, of which is 0.1-5.0 million km3 is less than 50 years old (Gleeson et al. 2016). Globally, about 50% of drinking water is obtained from groundwater withdrawal. Globally, 38% of land uses groundwater for irrigation (Fleckenstein et al. 2010; Gleeson et al. 2016). Traditionally, water wells were used for monitoring groundwater levels. There are no direct measurements of groundwater from remote sensing observations. But, the recent advances in remote sensing have provided data sets and tools that can be used to evaluate sustainable yield in aquifers (Seo and Lee 2016), and it is necessary to analyze groundwater storage change for a long-term period. The increasing water demand in Ethiopia due to a growing population and overexploitation of surface water add extra pressure on groundwater. Therefore, it is essential to keep a check on levels of groundwater for its long-term sustenance for monitoring sustainable water resources. From the review of past studies, it is clear that no attempts have been made to study the spatio-temporal variability of groundwater at the country level using GRACE and GLDAS datasets. The main aim of the paper is to estimate groundwater storage with spatiotemporal variation by using the Gravity Recovery and Climate Experiment satellite mission with the Global Assimilation System. The evaluated historical variability analysis of GRACE-derived groundwater storage will help to understand future groundwater conditions.

METHOD

Description of study area

Ethiopia is a country located in the Horn of Africa, a rugged country split by the Great Rift Valley with archaeological finds dating back more than 3 million years, which is a place of ancient civilization. The country lies completely within the tropical latitudes and is relatively compact with similar north-south and east-west dimensions. It is the second-most populated country in Africa, next to Nigeria.

Methodology

The water inflow and outflow of the system can be described using the water balance equation.

$$P - ET - R = \Delta TWS \quad (1)$$

$$\Delta TWS = \Delta GW + \Delta SM + \Delta SW + \Delta SWE \quad (2)$$

$$\Delta GW = \Delta TWS - \Delta SW - \Delta SM - \Delta SWE \quad (3)$$

P is precipitation, ET is evapotranspiration, q is stream flow of river, ΔTWS is change in terrestrial water storage from GRACE, ΔGWS is change in groundwater storage, ΔSM is change in soil moisture, ΔSW is change in surface water. To evaluate GW from GRACE TWS, soil moisture, surface runoff and snow-water equivalent was used from Global Land Data Assimilation(GLDAS).

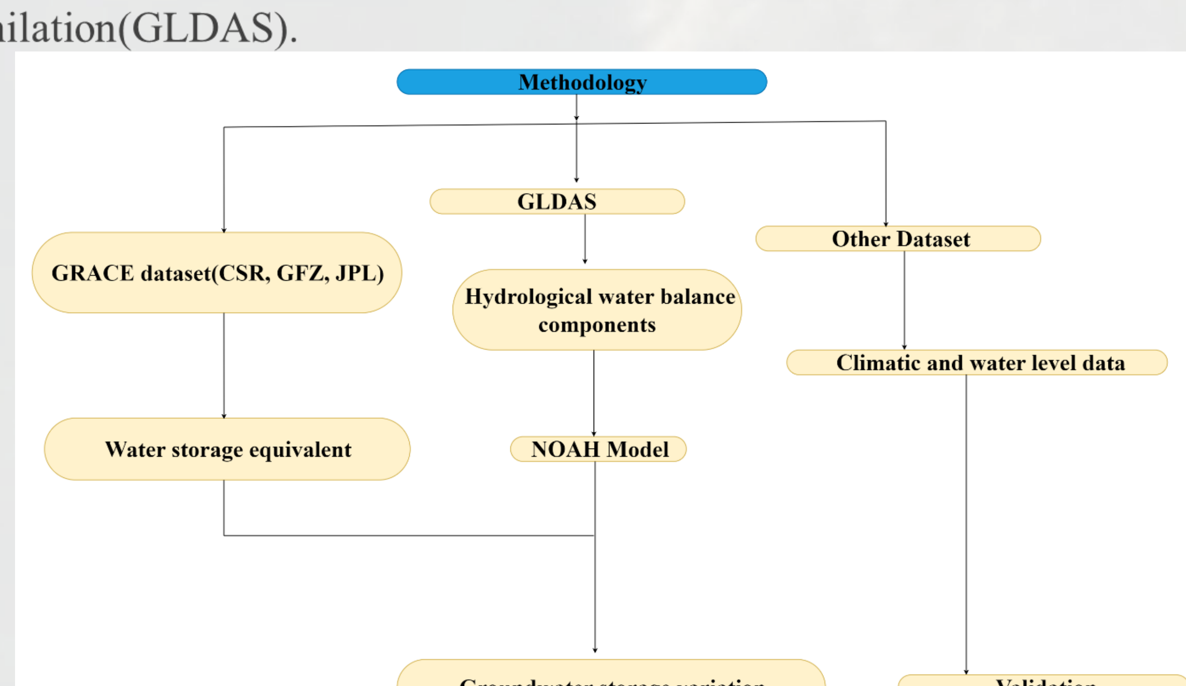

Figure 1 Flow chart for groundwater estimation

RESULTS & DISCUSSION

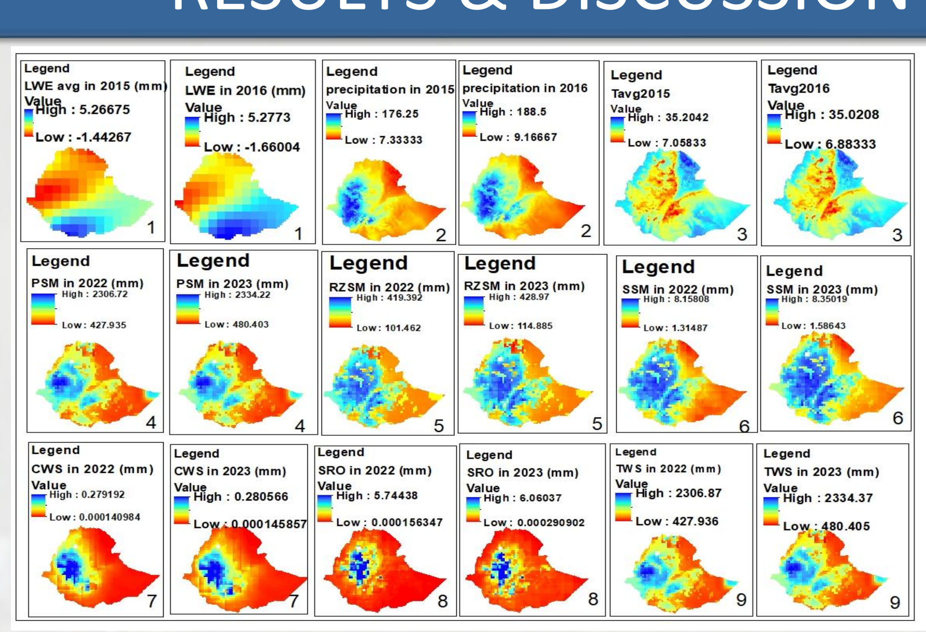

Figure 2. Spatial variation of water balance components: 1.LWE from GRACE, 2. Precipitation, 3. Average temperature, 4. Profile soil moisture, 5. Root zone soil moisture, 6. Surface soil moisture, 7. Canopy water storage, 8. Surface runoff and 9. Terrestrial water storage

RESULTS & DISCUSSION

Figure 2 shows interannual spatiotemporal variations of GRACE-based water equivalent thickness and GLDAS water storage components. The findings of the current study provided a significant variation in GRACE based terrestrial water storage(LWE), surface runoff, surface soil moisture storage, profile water storage, root zone water storage, canopy water storage and terrestrial water storage from GLDAS.

Groundwater storage variation

Figure 3 shows groundwater storage estimated by removing surface water storage, soil moisture, surface runoff and canopy water storage from terrestrial water storage for the study area from 2003 to 2023. The results discussed here illustrate a better understanding of monthly and yearly groundwater storage variations over the study region using GLDAS and GRACE. This study investigated a wide range of variability and magnitude in groundwater storage variations at spatial and temporal levels. The maximum groundwater distribution was observed in 2007 with a maximum value of 1965.8 mm per year per pixel, followed by 2008 with the value of 1958.42 mm per year per pixel and minimum groundwater storage was observed in 2006 with the minimum value of 247.65 mm per year per pixel, followed by 2009 with the minimum value of 247.979 mm per year per pixel. The fluctuations of groundwater storage in the study area were investigated due to natural and anthropogenic activities. The natural changes in groundwater storage variation are likely related to climatic change, hydrological conditions, types of soil deposits, and aquifer properties, whereas the anthropogenic activities include increased agricultural activities, population growth, industrialization, urbanization, dam construction, and improper management, which agrees with similar findings conducted in different area (Salem et al. 2017). The water cycle of the study area and the ability of the climatic circumstances to react quickly to groundwater decline was characterized by the rise in extremely hot temperature events. The result illustrated that groundwater storage variation has a high correlation with soil moisture, terrestrial water storage and has medium correlation with canopy water storage and surface runoff. As presented in Figure 3, the blue color shows high groundwater storage and the red color shows low groundwater storage. The finding shows that high groundwater storage was observed in western parts of the study area, whereas the south-eastern and north-eastern parts show low groundwater storage. The result of the study was essential for policy-makers and stakeholders management sustainable economic development, groundwater management, ecological maintenance and climatic change adoption pathways.

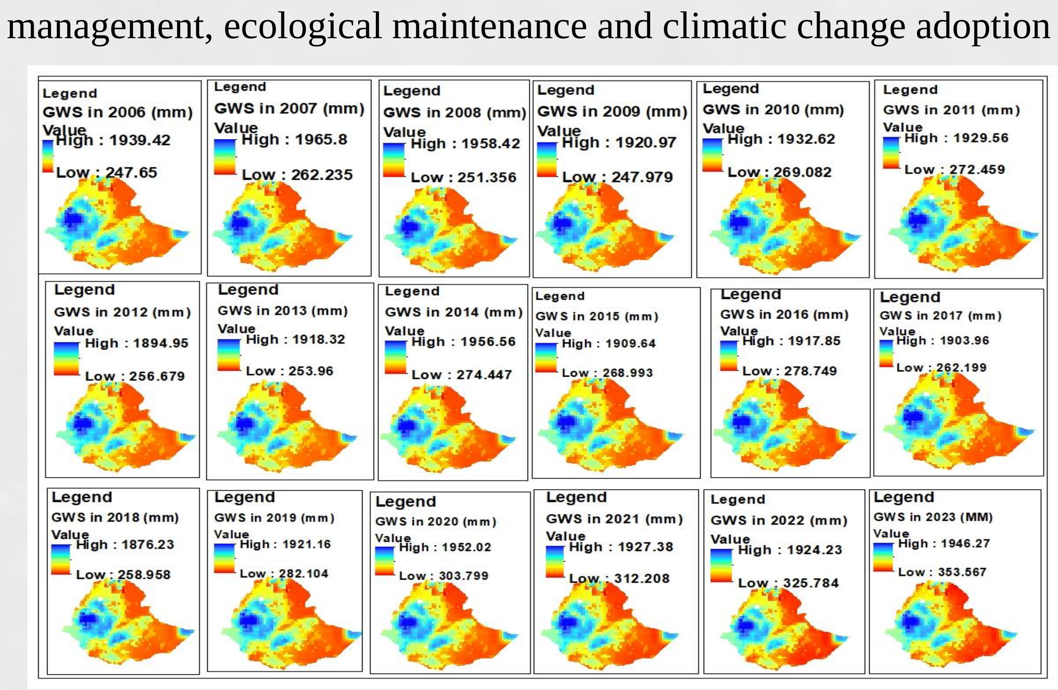

Figure 3 GWS variations for the study area from 2006 to 2023

CONCLUSION

The current study was carried out to assess spatial and temporal distribution of groundwater storage over water-stressed river basins of Ethiopia. The increasing agricultural activities, river flow alteration, dam construction, uneven precipitation, changes in temperature, and increasing domestic and industrial demand have resulted in water resource depletion in the study area. Aquifer monitoring by capturing the rainfall runoff to recharge groundwater is therefore imperative to ensure water security for agriculture, domestic, industrial, and other uses. The research demonstrates that water storage management is critical for water resource optimization and reducing high-risk impacts in the future. This study also identifies that the GRACE and GLDAS hydrological datasets help us to develop a long-term management strategy and identify areas facing severe water scarcity, which was useful for quantitative evaluation and improvement of planning, design, implementation, and groundwater management of groundwater resources.

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