ANALYSIS OF TERRESTRIAL WATER STORAGE CHANGE USING GRACE-BASED OBSERVATIONS OVER EUPHRATES-TIGRIS BASIN

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ABSTRACT

In this study, the change in the terrestrial water budget of Euphrates-Tigris Basin (176.930 km^2) is estimated by using satellite observations of Gravity Recovery and Climate Experiment (GRACE) along with the NOAH hydrological model outputs over the study period from April 2002 to December 2016. The changes in groundwater storage, soil moisture, snow water equivalent, and total canopy water storage are established in Euphrates-Tigris Basin. In addition, this study provides an update for the previous studies assessing the water storage changes of the Euphrates-Tigris basin. The initial results indicate that GRACE-based estimates of groundwater storage agreed well with the droughts occurred in between 2007-2009 and 2014. This study shows the information about the magnitude and the duration of the deficits can be used as supporting information for water resources management in the basin.

KEYWORDS: Euphrates-Tigris Basin, Groundwater Storage, NOAH, GRACE

1. INTRODUCTION

Groundwater reservoirs are regarded as important alternatives for surface water resources. Globally, 43% of the irrigation water is supplied from groundwater (Siebert et al, 2010), while this ratio is around 23% over Turkey. Therefore, it is important to quantify the changes in groundwater storage. In order to monitor and analyze the groundwater storage deficits effectively, a large number of observation wells should be installed and groundwater level observations should be recorded for a long period of time. However, this is not time and cost effective task, especially in basin-scale studies. Hence, recently remote sensing (RS) methods are used to aid groundwater/surface water related regional estimates. Spatio-temporal changes in subsurface storage can be monitored using the measurements of Gravity Recovery and Climate Experiment (GRACE) satellites, which is a joint collaboration between NASA and German Aerospace Center (DLR). Since March 2002, GRACE satellites have been measuring the spatial and temporal variations in the Earth's gravitational field and provide extremely valuable information about the dynamic structure of the Earth. GRACE datasets has been applied in many hydrologic problems such as water storage changes (Long et al., 2013), floods (Chen et al, 2010), the loss of ice mass from ice sheets (Velicogna, 2009), ocean currents and sea level rise (Nicholls and Cazenave, 2010) and the changes in the solid Earth (Han et al., 2006). Most of the GRACE studies conducted in Turkey are focused on modelling the geoid surface and analysis of Earth's gravity field (Avşar et al., 2013; Atayer and Aydin, 2012; Simav et al., 2013). This study focuses on analyzing water storage changes across Euphrates-Tigris Basin (Fig. 1) using GRACE based observations. The Euphrates-Tigris Rivers, which are the second longest rivers of Turkey, originate in the eastern part of Turkey and cross the Middle East. These rivers flow across national boundaries and are the main factor of water related conflict between Turkey, Syria and Iraq. Euphrates (Fırat) - Tigris (Dicle) Basin covers approximately an area of 176.930 km^2.

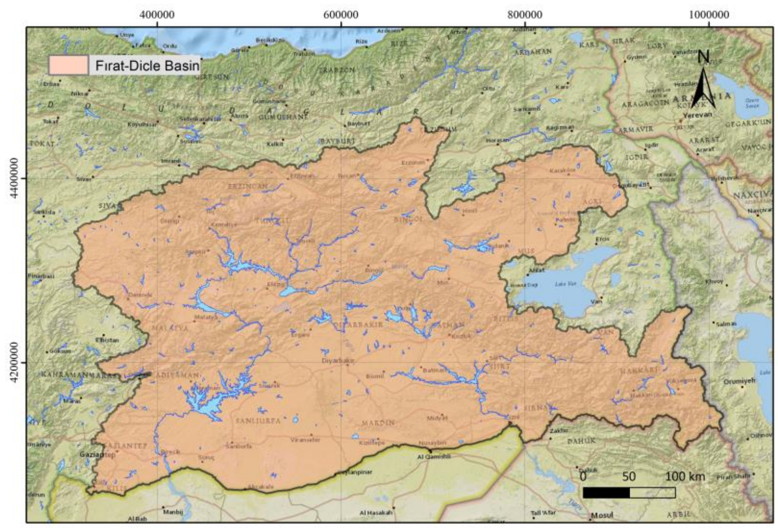

Figure 1. The geographical location of Euphrates-Tigris Basin.

The region has experienced many droughts throughout the history. In recent years, precipitation rates within the basins have drastically decreased below the average and the effect of climate change as well as population growth increase the demand for water. As a result, the demand for water in irrigation, domestic consumption and industry needs have been increasing day by day. These demands are mostly met from groundwater reservoirs which are poorly managed and thus have been under increasing stress. Although groundwater depletion in Middle East including Euphrates-Tigris Basin has been investigated utilizing GRACE observations (Voss et al., 2013; Longuevergne et al., 2013), these studies are not up to date. In the context of this study, for the first time the groundwater change information in Euphrates-Tigris Basin is estimated using GRACE based observations for the period between 2002 and 2016.

2. METHODS

There are two available GRACE solutions released from three different processing centers - Spherical Harmonics (SH) and Mascons (Mass Concentration Blocks). Although the solutions have different advantages, mascon solution is not used because of the native resolution and location of the cells (3º x 3º) exceed the borders of the basins. Therefore for this study, SH products in 1º x 1º gridded resolution from JPL, CSR and GFZ are averaged to reduce the noise in the data (e.g., Sakumura et al., 2014). The temporal variations in the gravity field are mostly attributed to mass changes in the components of water cycle and the exchange between them. These mass deviations are represented in vertical extent in terms of centimeters and it is referred as Liquid Water Equivalent Thickness (EWT). To get terrestrial water storage changes (TWSC), the atmospheric mass variability and the effect of ocean currents are removed during processing. Terrestrial Water Storage (TWS) is the amount of water stored in groundwater, soil moisture, surface water, canopy water, snow and ice. These hydrological parameters - except the groundwater storage - can be estimated from Noah land surface model (Ek et al., 2003). To estimate the variations within groundwater storage, the monthly change in the hydrological components of the land surface models are subtracted from the TWS using the following equation:

$$\Delta GWS = \Delta TWS - \Delta SM - \Delta SWE - \Delta SW - \Delta CW \quad (1)$$

where GWS is groundwater storage, TWS is total water storage, SM is the sum of soil moisture content in all model soil layers, SWE is snow depth water equivalent, SW is surface water and CW is plant canopy surface water storage. The monthly anomaly values of each variable at every grid point are calculated by their deviation from the reference period of GRACE which is the average of all months from January 2004 to December 2009. The NOAH model output are processed between April 2002 and December 2016 period in accordance with the availability of satellite data.

In post-processing step, Gaussian smoothing filter is used to reduce the noise within the data. Because of filtering, some of the signal is lost, thus scaling coefficients are used to substitute the required signals. After filtering and rescaling, the residuals represent measurement and leakage errors which are time independent estimates. The error components correspond to the expected uncertainty. For the region wide error analysis, the error covarience is taken into consideration (Landerer and Swenson, 2012).

3. RESULTS

There is a challenge in applying GRACE products to areas with spatial coverage which is less than the GRACE footprint (100.000 km^2) (Landerer and Swenson, 2012). In this study, basin area (176.930 km^2) is appropriate for the applicability of GRACE data.

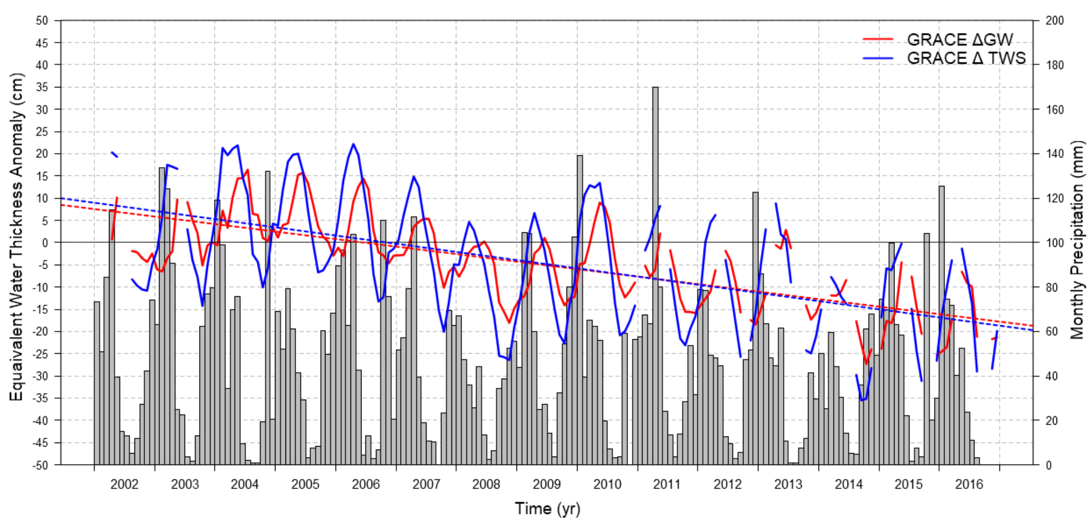

Figure 2. Monthly estimates of GRACE-derived GW and TWS anomaly in Euphrates-Tigris Basin.

Euphrates-Tigris Basin groundwater storage anomaly and observed station-based average precipitation data are plotted for in Figure 2. The initial comparisons show a declining trend in GRACE-TWS and GRACE-based groundwater storage anomaly estimates. The past droughts during the period 2007-2009 and 2014 (unpublished work) can be tracked from GRACE-satellites. Also, there is a lag between TWS and GRACE-based GW. GRACE-observed groundwater change appears 2 months later. This lag can be attributed to infiltration and percolation to groundwater, which is relatively slow process compared to the mass changes in rainfall and snowmelt. The uncertainty estimates in ΔTWS are calculated as ± 3.94 cm. The results are promising that combined GRACE and NOAH LSM groundwater change information is helpful to monitor the large mass changes resulted from excessive groundwater exploitation over Euphrates-Tigris Basin.

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