Detect groundwater storage in an island watershed by GRACE gravimetry

Chung-Chieh Huang[1], Hong-Ru Lin[2], Jyun-Lin Chen[3], Shao-Yang Huang[3], Jet-Chau Wen[3,4], Jen-Feng P. Yeh[5] and Ben Jarihani[6]

[1]Graduate School of Safety Health and Environmental Engineering, National Yunlin University of Science and Technology, 123, Section 3, University Road, Douliou, Yunlin 64002, Taiwan (R.O.C.)
[2]Graduate School of Engineering Science and Technology, National Yunlin University of Science and Technology, 123, Section 3, University Road, Douliou, Yunlin 64002, Taiwan, (R.O.C.)
[3]Research Center for Soil & Water Resources and Natural Disaster Prevention (SWAN), National Yunlin University of Science and Technology, 123, Section 3, University Road, Douliou, Yunlin 64002, Taiwan (R.O.C.)
[4]Department and Graduate School of Safety Health and Environmental Engineering, National Yunlin University of Science and Technology, 123, Section 3, University Road, Douliou, Yunlin 64002, Taiwan (R.O.C.)
[5]Monash University Malaysia, Jalan Lagoon Selatan, Bandar Sunway, 47500 Subang Jaya, Selangor, Malaysia
[6]University of Central Asia, Mountain Societies Research Institute, SAS Tajikistan

EGU General Assembly 2020

Study Motivation

The groundwater storage (GWS) variations can be observed by gravity recovery and climate experiment (GRACE) in many studies, especially in large-scale GWS variations (over 50,000 km^2, California Central Valley [Famiglietti et al., 2011; Scanlon et al., 2012], Bengal Basin [Shamsudduha et al., 2012]). However, few researchers focus on scales which are smaller than 5,000 km^2.

Study Purpose

This study is to investigate the potential of GRACE gravimetry for estimating the GWS variations in Zhuoshui River alluvial fan (~2,560 km^2) of central Taiwan.

Flowchart

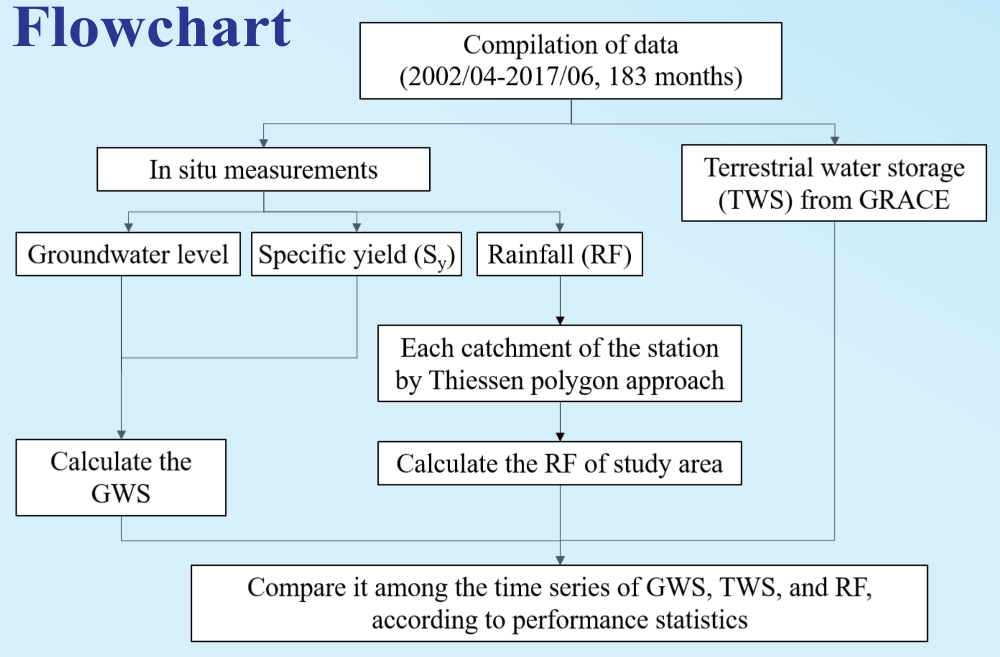

Figure 1. Flowchart.

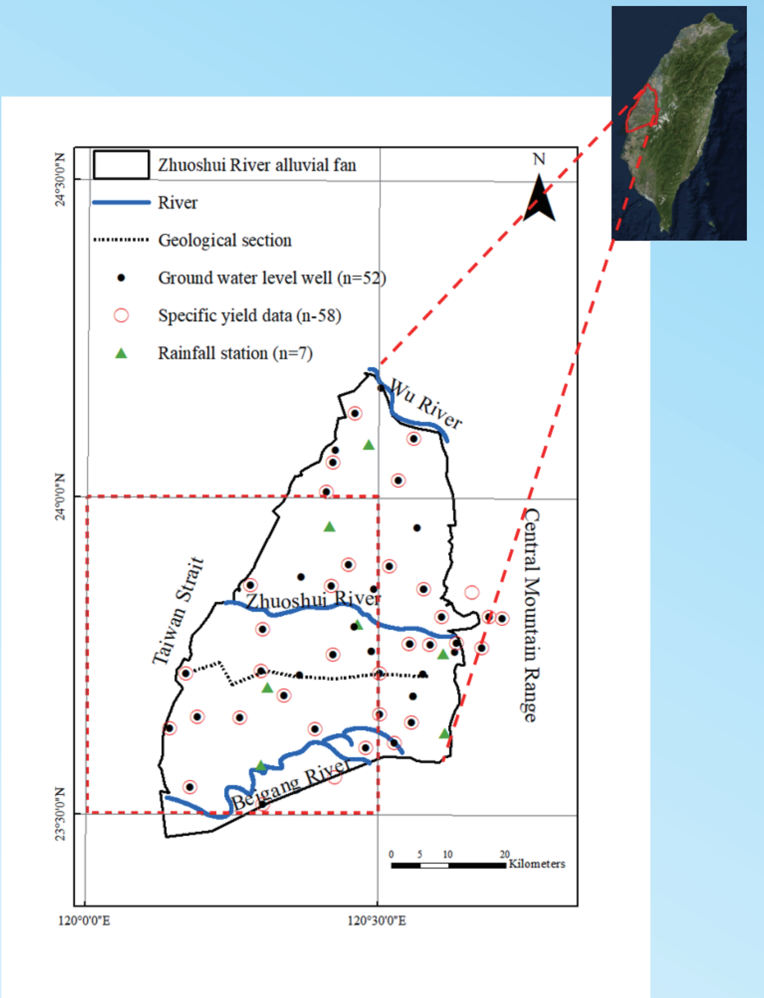

Figure 2. The Zhuoshui River alluvial fan (~2,560 km2). Locations of 52 wells (black circles) and 7 rainfall stations (green triangles).

Materials and Methods

Study Area

The Zhuoshui River alluvial fan (~2,560 km^2) is located at mid-west part of Taiwan. It is bounded by Wu River at the north, Beigang River at the south, and Taiwan Strait at the west.The red dashed square is the grid of GRACE (0.5° × 0.5°).The elevation of the fan is about 100 m at the apex and 0 m at the tail.

In situ measurements

The data of in situ measurements are from the Taiwan Water Resources Agency And the monthly records of 52 wells and 7 rainfall stations were from April 2002 to June 2017 (a total of 183 months).

Geological section

The Central Geological Survey (1999) constructed hydrogeological profiles for the alluvial fan based on the core samples from drilled wells. An unconfined and three confined aquifers, namely, layer 1 to layer 4, were approximately identified from shallow to 300 meters depth. The main research area in this experiment is the first confined aquifers, because this layer is closely related to human activities.

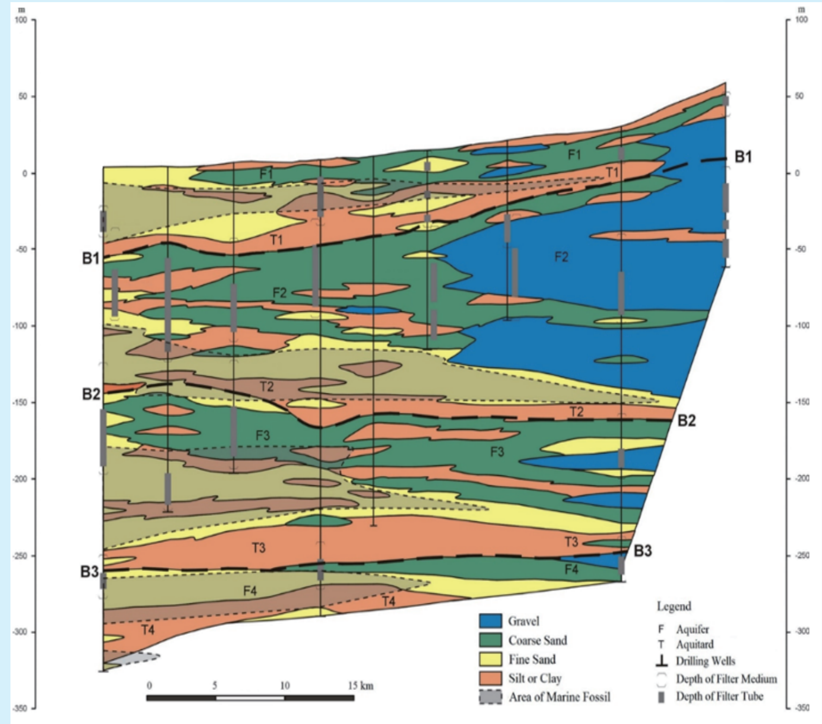

Figure 3. Geological section profiles of the Zhuoshui River alluvial fan

Meteorological characteristics

During the observation, the groundwater level and rainfall (Shi-Luo) from April 2002 to June 2017 have significant periodic variations on the annual period.

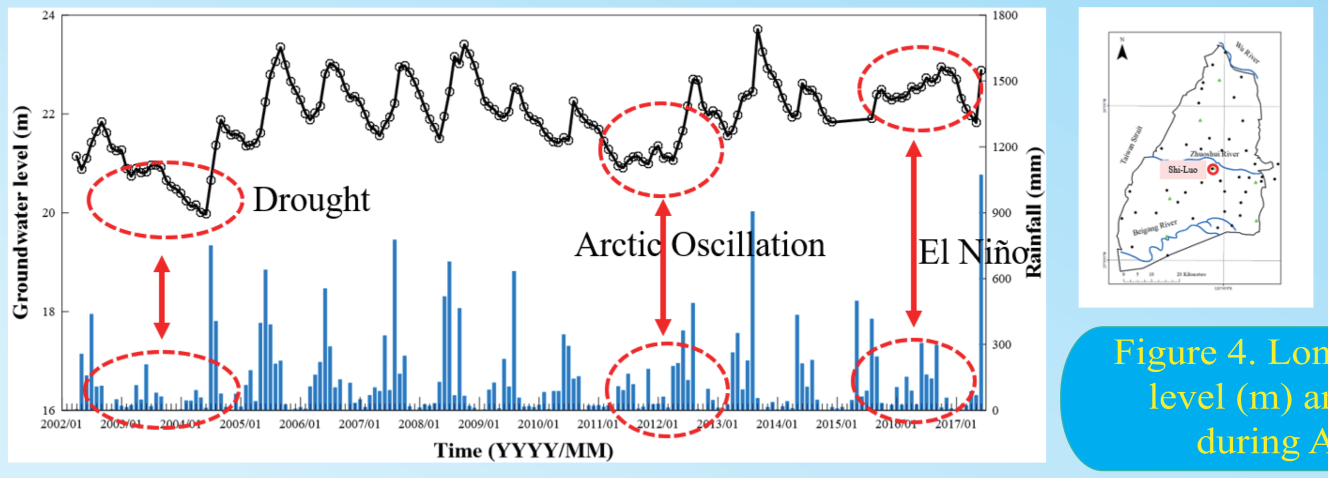

Figure 4. Long term absolute groundwater level (m) andrainfall (mm) at Shi-Luo during April 2002 to June 2017.

Calculating groundwater storage (GWS)

Using Kriging method to interpolate a grid 500 m × 500 m, total 10821 of the study area. Then use equation 1 to calculating the GWS.

$$GWS = \bar{S}_y \Delta H \quad (1)$$

GWS : groundwater storage in month (cm)

$\bar{S}_y$: the average of specific yield

$\bar{H}$: anomalies of groundwater level, and are relative to a 2004.01- 2009.12 mean baseline. (cm)

In situ measurements of rainfall

The Thiessen polygon approach (equation 2) is determining average rainfall in this study.

$$RF = \sum_{i}^{n} \frac{a_i r_i}{A} \quad (2)$$

RF : average rainfall of the study area (mm)

n : number of rainfall station

A : study region area (km^2)

a_i : catchment of i station (km^2)

r_i : rainfall of i station (mm)

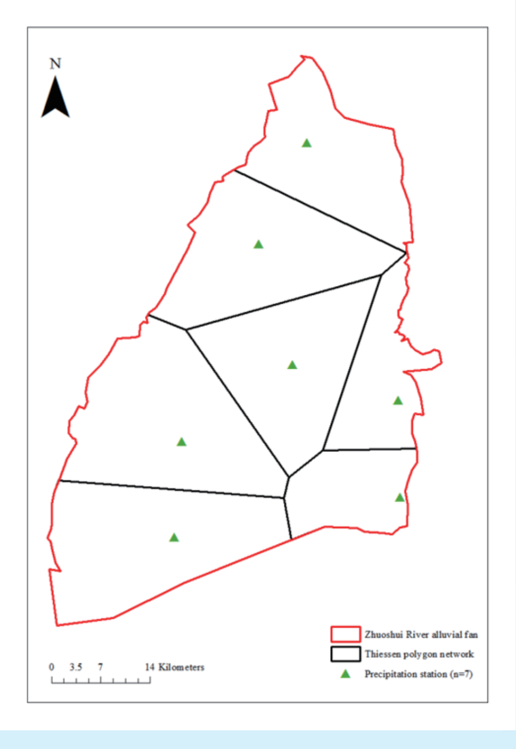

Figure 5. The Thiessen polygon of rainfall station ofZhuoshui River alluvial fan. The black polygon stand for catchment of a rainfall station

Terrestrial Water Storage (TWS) from GRACE

1. The Processing Center, Center for Space Research (CSR) at the University of Texas, Austin, releases GRACE monthly gravity solutions.
2. The solution is terrestrial water storage (TWS) anomaly that is present as equivalent water thickness (cm).

Data Comparison and Error Analysis

To compare different GWS and TWS time series, the mean absolute error (MAE), root mean square error (RMSE), and the correlation coefficient (COR), which are expressed in equations (3), (4), and (5), were adopted for error analysis.

$$MAE = \frac{\sum_{i=1}^{n} |X_i - Y_i|}{n} \quad (3) \qquad RMSE = \sqrt{\frac{\sum_{i=1}^{n} (X_i - Y_i)^2}{n}} \quad (4)$$

$$COR = \frac{\sum_{i=1}^{n} (X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n} (X_i - \bar{X})^2} \sqrt{\sum_{i=1}^{n} (Y_i - \bar{Y})^2}} \quad (5)$$

$X = GWS$ (cm)

$Y = TWS$ (cm)

i = month

Result

Calculate the GWS

Base line:
The elevation of the fan is about 100 m at the apex and 0 m at the tail.

Specific yield (S_y):
The Sy is mostly between 0.2 and 0.3, and the S value is high on both sides of the Zhuoshui River, while it is low on the southwest side of the Zhuoshui River alluvial fan.

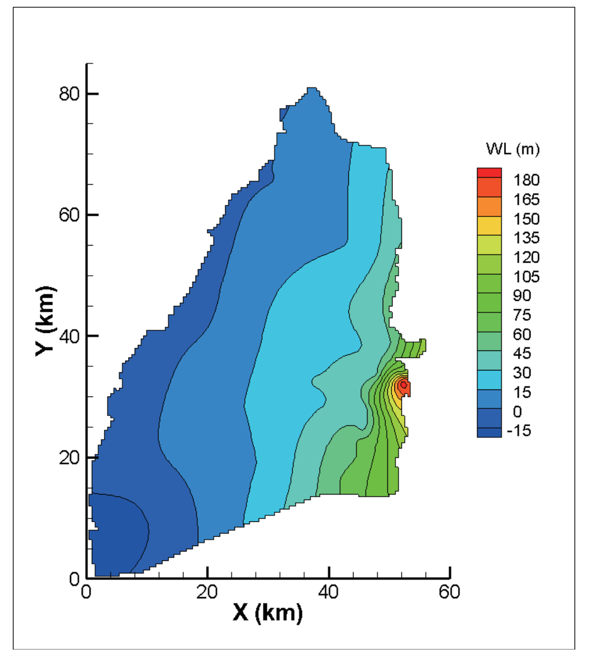

Figure 6. Groundwater level baseline form 2004-2009.

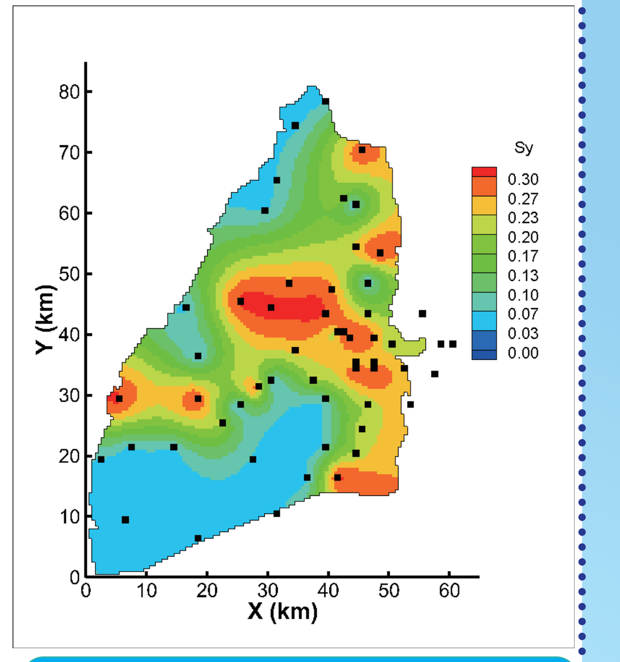

Figure 7. The S_y distribution of the Zhuoshui River alluvial fan.

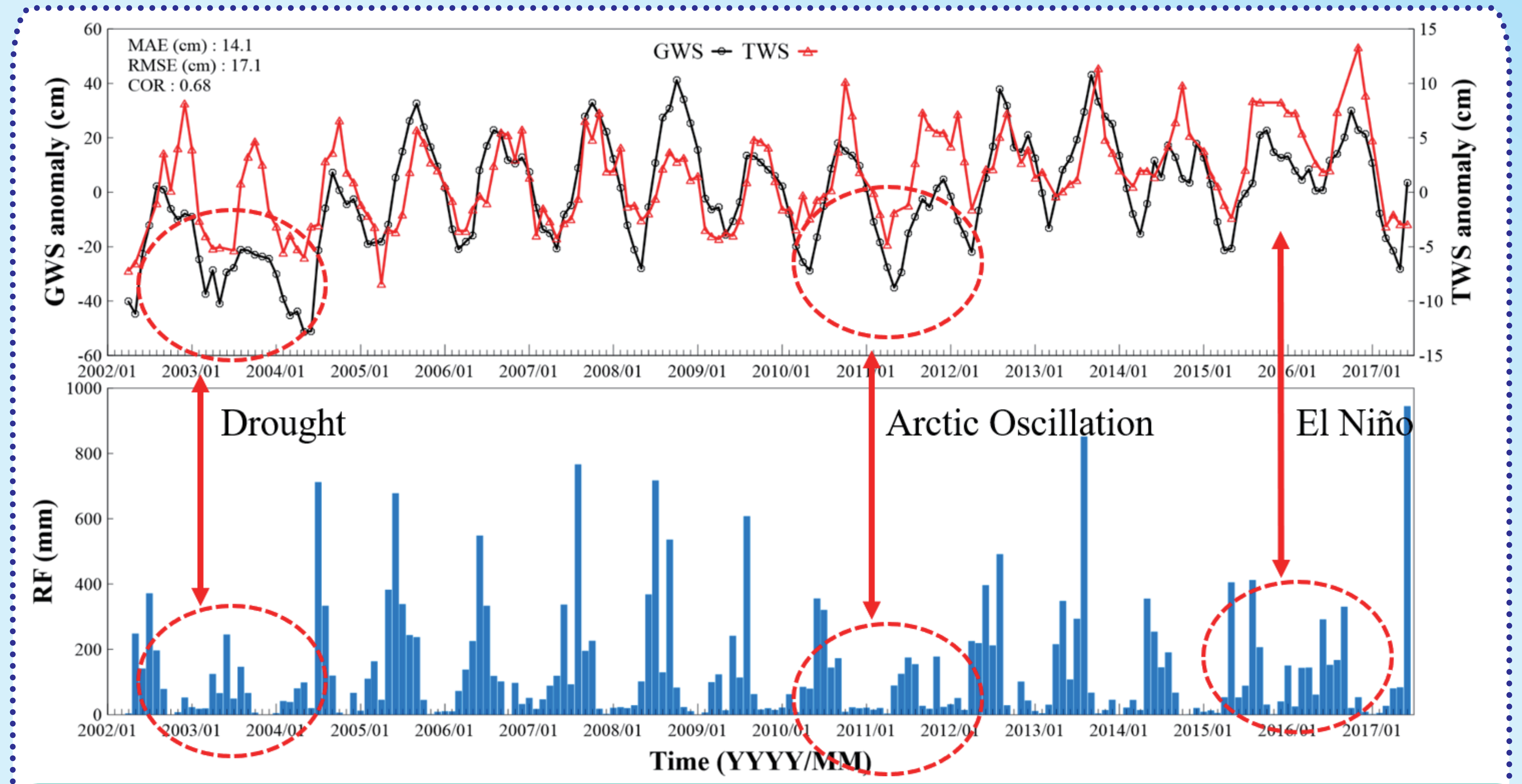

Figure 8 (a) The time series of GWS anomaly and TWS anomaly. The black line with circle symbol is GWS anomaly from in situ. The red line with triangle symbol is TWS anomaly from GRACE.(b) The time series of rainfall of Zhuoshui river alluvial fan.

Conclusion

1. According to the results, the GRACE gravimetry has the potential to observe the GWS variations on the Zhuoshui River alluvial fan according to the peak similarity of TWS from GRACE.
2. The correlation between GWS and TWS is 0.68, which is acceptable. However, the values of MAE and RMSE are unexpectedly high.
3. Moreover, we can observe the relationship between GWS and TWS on rainfall. Therefore, some factors can be used to improve the GRACE in small scale evaluation.

Acknowledgements

The authors would like to acknowledge the research support from MOST 106-2625-M-224-002, MOST 106-2915-I-224-501, MOST 106-2625-M-224-002, MOST 107-2625-M-224-002, and MOST 108-2625-M-224-005, by the Minister of Science and Technology, Taiwan.