ESTIMATION OF GROUNDWATER LEVEL IN THE HUNSHANDAKE SANDY LAND, CHINA BASED ON KBDI AND *IN SITU* MEASUREMENTS

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ABSTRACT: Groundwater is a vital resource for agriculture, industry and domestic water use, especially in arid and semi-arid regions. Hunshandake Sandy Land in Inner Mongolia Autonomous Region, China, is abundant in groundwater resource. Whereas, this region belongs to the area where availability of water resource is declining, mainly caused by increasing water exploitation by agriculture and industry. Demonstrated by groundwater depletion and deterioration of lakes, the shortage of water resource is expected to continue not only because of increasing exploitation of groundwater resource but also changing climate. To protect this fragile ecosystem and the livelihood of local people, it is crucial to evaluate the state of groundwater resource in this region. Keetch-Byram Drought Index (KBDI), which is calculated using rainfall and temperature, is a value reflecting the dryness of the upper soil layers. KBDI is balanced with rainfall and evapotranspiration. As groundwater recharge is dominated by infiltration of rainfall, and groundwater discharge is dominated by evaporation from aquifers, in this study, we estimated the groundwater level by using satellite-based KBDI and *in situ* well measurements in the Hunshandake Sandy Land. Our study shows the decrease in groundwater level had a significant negative correlation with increasing KBDI, demonstrating the significance of integrating satellite observations and *in situ* measurements for interpreting regional groundwater changes.

1. INTRODUCTION

Groundwater is an important component of the hydrological system that maintains the natural productivity of grassland, but also ensures the life quality of local people. The Hunshandake Sandy Land, although located in the eastern part of China’s desert belt, is abundant in groundwater resource (Yang,2015). Whereas, this region belongs to Xilingol league of Inner Mongolia, where groundwater resource storage is declining at a rate of 26 million m^3 per year (Fig.1), which mainly caused by water exploitation for agriculture and industry (Batunacun,2018). Over exploitation of groundwater has caused various environmental problems, such as grassland degradation and lake shrinkage (Batunacun,2019).

Demonstrated by increasing groundwater level (Fig.2), the shortage of water resource is expected to continue not only because of increasing exploitation of groundwater resource but also drier and warmer climate. However, detailed information and descriptive data of groundwater level is usually limited, especially in sparsely populated areas such as the Hunshandake Sandy Land, in which limited number of stations monitor the groundwater level.

Keetch-Byram Drought Index (KBDI), whose inputs are mean annual rainfall, the maximum temperature for the day, the previous 24 hours’ rainfall and the previous day’s drought index value, is a value reflecting the daily water balance. As groundwater recharge is mainly from infiltration of rainfall into the aquifer, and groundwater discharge is dominated by evaporation from aquifer, some study investigated the correlation between KBDI and groundwater level and found good time series of KBDI-modelled groundwater level with that of *in situ* measurements at forested peatland (Takeuchi,2016).

The objective of this study is to estimate the groundwater level from satellite-based KBDI, which is calculated from Global Satellite Mapping of Rainfall (GSMaP) product for rainfall and Japanese Meteorological Satellite (MTSAT) product for land surface temperature.

2. METHODS

2.1 Study Area

The study area is located in the Inner Mongolia Grassland Ecosystem Research Station in Baiyinxile pasture station, Xilinhot, Xilingol League of Inner Mongolia, China. The geographical coordinate of the study area is N43° 37′, E116° 42′, which is located on the north of the Xilin River and south of the Hunshandake Sandy Land. The study area has a temperate semi-arid climate, with a mean annual rainfall of 330mm, which mainly occurs during the growing season from May to September.

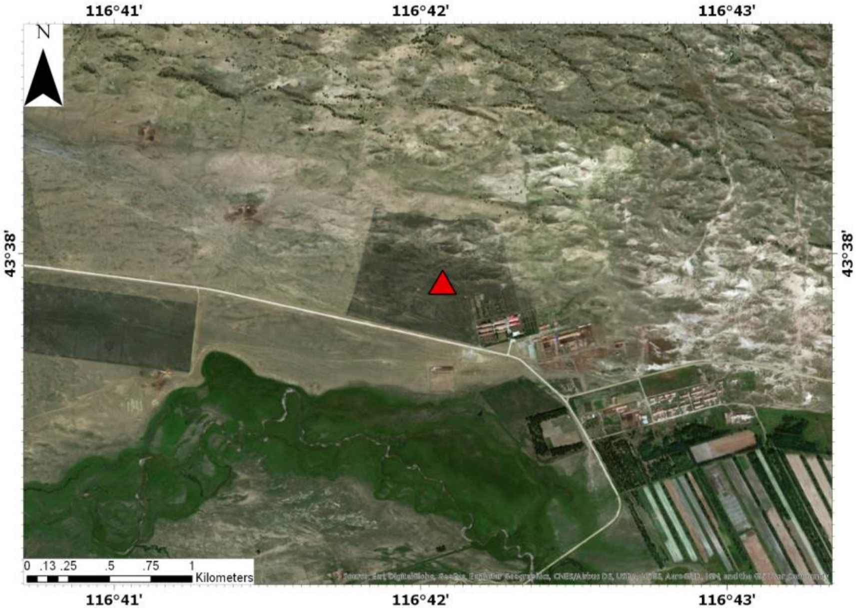

Figure 3. Location of the Groundwater Monitoring Well

2.2 Data Collection and Analysis

Satellite-based daily KBDI (with a 4 km resolution, provided by Institute of Industrial Science, The University of Tokyo, Japan) was downloaded from the Google Earth Engine platform for the year of 2013. Groundwater monitoring well data was obtained from grassland ecosystem groundwater level records provided by Inner Mongolia Grassland Ecosystem Research Station. Rainfall data was obtained from National Centers for Environmental Information for the Xilinhot station. Groundwater resource data was obtained from Inner Mongolia Water Resource Bulletin for the period of 1998-2017.

The linear relationship between Satellite-based daily KBDI and *in situ* groundwater level measurements were constructed using the regression analysis method from 21 Jun to 1 Nov for the year of 2013. As KBDI is obtained daily, while groundwater level data is obtained every 5 days, we took the average of 5 days' KBDI previous the groundwater level measured day as the KBDI of the measured day.

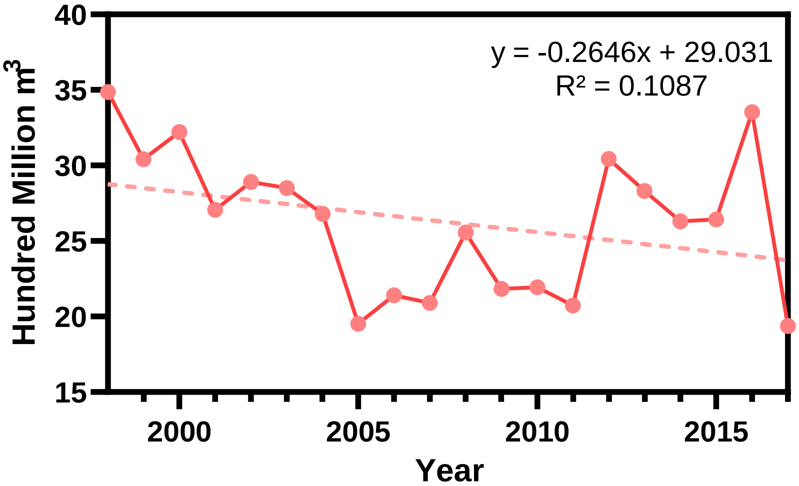

Figure 1. Time Series of Groundwater Resource Storage in Xilingol League

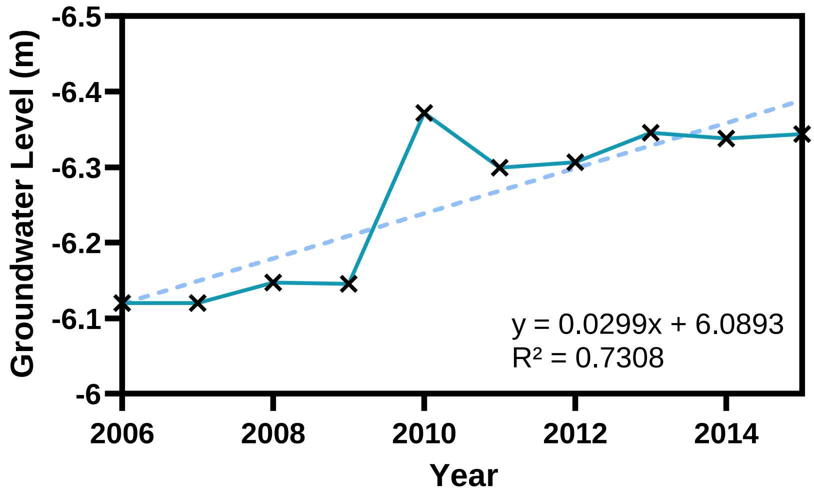

Figure 2. Time Series of Groundwater Level from 2006 to 2015 in the Study Area

2.3 Keetch-Byram Drought Index

Keetch and Byram (1968) designed a drought index to determine forest fire potential (Keetch,1968), whose value indicates the amount of rainfall that is required to relieve the soil from drought to saturation. KBDI is expressed at a scale from 0 to 800. An index of 0 represents there is no moisture deficiency in soil, and an index of 800 represents the most severe drought. The index increases without rain and decreases when rainfall is enough to offset the drying effect of the maximum daily temperature. Generally, KBDI is calculated from *in situ* measurements of temperature and rainfall derived from weather stations. In this study, we took advantage of the satellite-based KBDI, which is calculated as follow:

$$KBDI{=}{\times}100r+\frac{0.968\ (800-\ KBDI0)\ \exp\ (0.486T)}{1.00+10.88\ \exp(-0.441R)} \quad (1)$$

where r is daily rainfall (mm/day), T is maximum daily temperature (degrees in Celsius) and R is annual rainfall (mm/year).

3. RESULTS

From 21 Jun to 1 Nov for the year of 2013, KBDI exhibits increasing trend, while groundwater level exhibits decreasing trend. Groundwater level decreased with a rate of 5.7 mm every 5 days (Fig. 3). The decrease in groundwater level had a statistically significant negative correlation with increasing KBDI ($p < 0.05$).

$$\text{Groundwater Level}= -0.00040*KBDI-6.275 \quad (2)$$

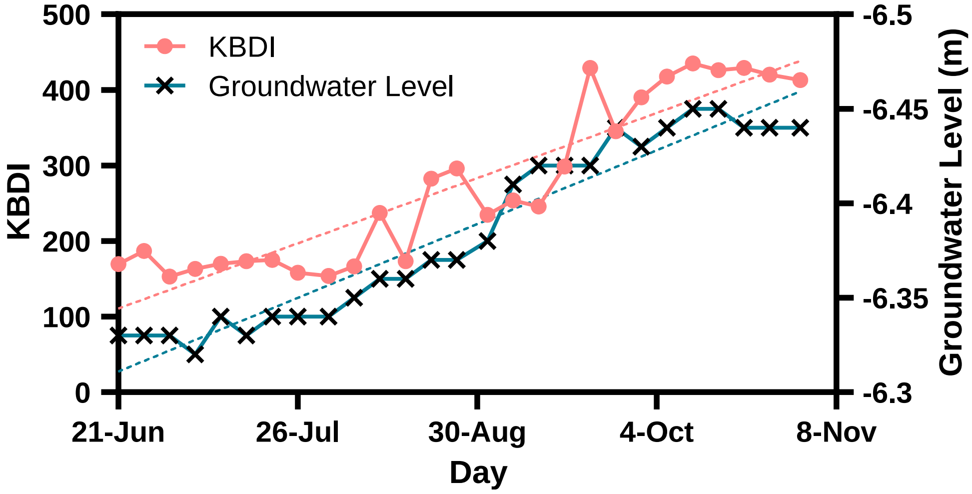

Figure 3. Time Series of Groundwater Level and KBDI

Figure 4 shows the time series of KBDI and rainfall from 15 Jun to 1 Nov for the year of 2013. Rainfall was mainly concentrated from late Jun to Aug for this year, which led to the decrease in KBDI for the period. KBDI increased again after the concentrated rainfall.

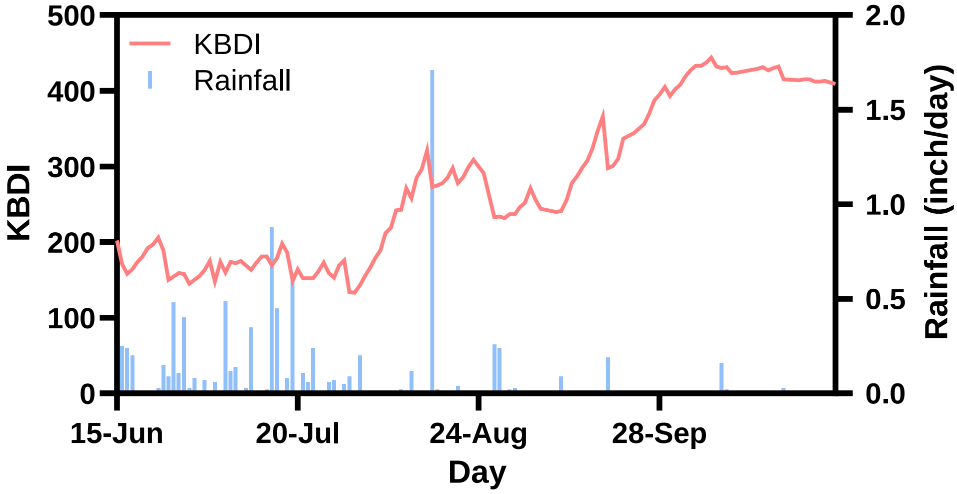

Figure 4. Time Series of Rainfall and KBDI

Figure 5 and Figure 6 show the trend of KBDI and groundwater level for two periods, 16 Jun to 1 Aug (more rainfall) and 1 Aug to 1 Nov (less rainfall). Both of them tended to be stable when there was more rainfall. KBDI tended to increase, and groundwater level tended to decrease when there was less rainfall.

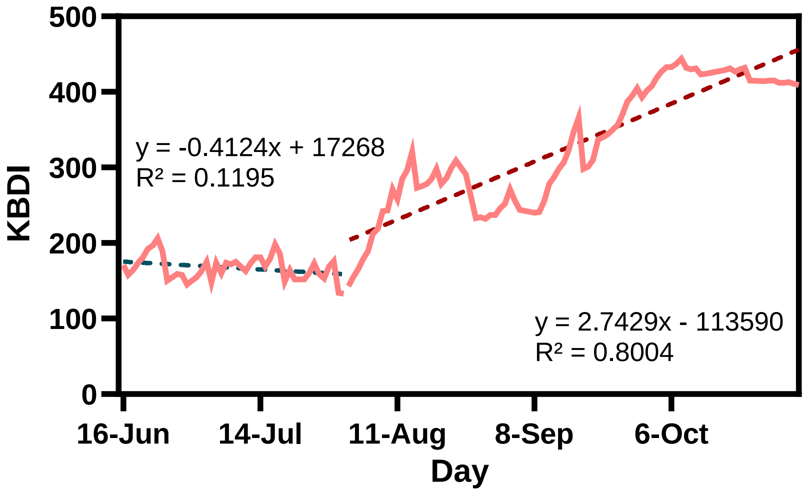

Figure 5. KBDI Trend for 16 Jun to 1 Aug and 1 Aug to 1 Nov

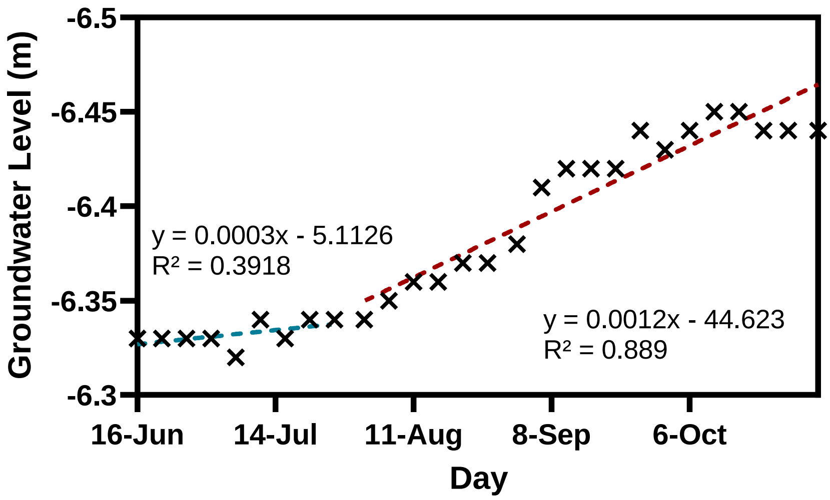

Figure 6. Groundwater Level Trend for 16 Jun to 1 Aug and 1 Aug to 1 Nov

4. DISCUSSION

Groundwater is not only recharged by rainfall infiltration, but also surface water and irrigation water. Groundwater discharge is dominated by evaporation and groundwater exploitation. In this study, we only considered the correlation between groundwater level and KBDI, which is calculated from rainfall and temperature. In this region, groundwater exploitation may have some impact on groundwater level decrease which is not to be neglected (Zhong, 2018). With the background of increasing groundwater exploitation and changing climate, lower KBDI may only make the groundwater level decrease in a slower rate. According to Inner Mongolia Water Resource Bulletin, groundwater storage amount had decreased 212 million m^3 from 2012 to 2013 in Xilingol League. Groundwater has become a vital resource for water supply (Fig. 7). Groundwater exploitation by industry and agriculture is 99 million m^3 and 81 million m^3 in 2013, which is much higher than the amount in 1998, 18 million m^3 and 41 million m^3 respectively (Fig. 8).

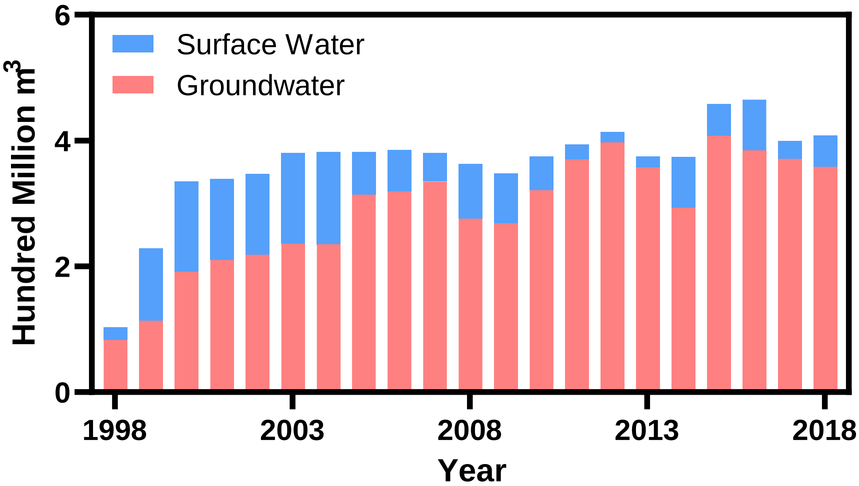

Figure 7. Water Supply Amount in Xilingol League from 1998-2018

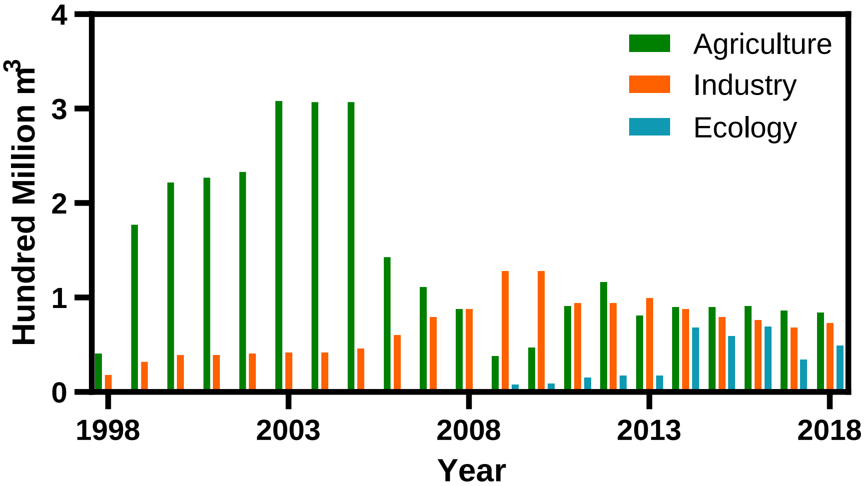

Figure 8. Water Consumption Amount in Xilingol League from 1998-2018

5. CONCLUSION

KBDI, which indicates the balance between rainfall and evapotranspiration, has a significant correlation with groundwater level. Thus, the index can be used to estimate the groundwater level. However, other factors such as groundwater exploitation amount, are necessary to groundwater level estimation, with the background of increasing exploitation of groundwater in this region. What to do next is to investigate the impact of anthropogenic activities to groundwater level changes, such as groundwater exploitation by industry, agriculture and ecology. Long-term climatic change should also be considered.

6. REFERENCES

Batunacun. Nendel, C. et al.2018. Land-use change and land degradation on the mongolian plateau from 1975 to

2015 - a case study from xilingol, china. Land Degradation & Development.

Batunacun, Wieland, R, et al. 2019. Identifying drivers of land degradation in xilingol, china, between 1975 and 2015. Land Use Policy, 83, 543-559.

Inner Mongolia Water Resource Bulletin. Department of Water Resource of Inner Mongolia: Hohhot, China, 1998-2017.

Keetch, J. J., Byram, G. M. 1968. A drought index for forest fire control. USDA Forest Services Research. Paper SE-38, 038.

National Centers for Environmental Information. Daily Summaries Station Details. https://www.ncdc.noaa.gov/

Takeuchi, W. et al. 2015. Near-real time meteorological drought monitoring and early warning system for croplands in Asia. 36th Asian conference on remote sensing (ACRS): Manila, Philippines, Oct. 20.

Yang, X., et al. 2015. Groundwater sapping as the cause of irreversible desertification of Hunshandake Sandy Lands, Inner Mongolia, northern China. Proc Natl Acad Sci USA. Vol.112, pp.702-706.

Zhong, Y. et al. 2018. Groundwater Depletion in the West Liaohe River Basin, China and Its Implications Revealed by GRACE and In Situ Measurements. Remote Sens,10, 493.