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Impact of solar activity on ~200-year cyclic variations in groundwater recharge rates in the Badain Jaran Desert, Inner Mongolia, Northwest China

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ABSTRACT

Understanding groundwater recharge variations is crucial for assessing the impact of climatic and solar influences on water resources. We attempt here to quantify the cyclic solar forcing on groundwater recharge rate (GRR) through the analysis of ~ 700 years of GRR data from the dry lands of the Badain Jaran Desert in Northwest China and Total Solar Irradiance (TSI) data using principal component analysis and statistical methods. Our results confirm a significant role of solar activity in groundwater recharge variations. Singular spectrum analysis of GRR and TSI time series reconstructed from the first three principal modes, revealed common spectral peaks, indicating a significant influence of solar activity on GRR. We observed that a small portion of solar variation (~ 0.021%) of TSI appeared in the second and third eigenmodes of TSI, is found to be responsible for the ~200-year cyclic variability. Approximately 33.66% of the GRR variability is attributed to long-term solar activity trends, while 11.81% is associated with the ~200-year Suess solar cycle. Additionally, residual spectral analysis suggests potential influences of shorter solar cycles (63±10 years, 33±3 years, 24±2 years, and 18±2 years) and non-linear solar phenomena. Thus, this study provides critical insights into the coupling between solar activity and groundwater recharge, emphasizing the importance of long-term and cyclic solar influences, in modeling future groundwater scenarios under changing climatic conditions.

Keywords: Groundwater recharge rate, Spectrum analysis, Total Solar Irradiance, Eigenmode, Badain Jaran Desert.

INTRODUCTION

Understanding changes in groundwater recharge is crucial for society, as it requires analyzing the sensitivity of recharge processes to both internal and external factors that influence groundwater availability. These changes are predominantly driven by climatic variations, with temperature, precipitation, and evapotranspiration being among the key factors. Numerous studies have explored the potential links between climate change and water resources (Goderniaux et al., 2009; Green et al., 2011; Newcomer et al., 2014; Rossman et al., 2014; Zhang et al., 2014; Shamir et al., 2015). A detailed statistical or mathematical analysis to identify trends and cyclic patterns in long-term groundwater fluctuation rates, as well as their potential links to influencing processes, is crucial for improving the modeling of groundwater recharge. Since groundwater recharge is increasingly recognized as a proxy for climate change, such an analysis would provide valuable insights into climate and environmental changes. Researchers have compared groundwater recharge rate (GRR) data with various climatic indicators, including tree rings, unsaturated zone profiles, and sunspot numbers, to explore these relationships (Gates et al., 2008; Tiwari and Rajesh, 2014).

Tiwari and Rajesh (2014) have shown evidence of a ~200-year solar suess cycle and its impact on the long-term groundwater recharge rates by analyzing proxy reconstructed GRR (Gates et al., 2008) and Sunspot Number (Solanki et al, 2004) data. They have suggested that ~48% of the recharge is controlled by this ~200-year solar cycle. However, in the above study, a quantified relationship between solar energy (TSI) and GRR was not established. According to them, during the reversal phase of sunspot, the increased TSI through facular excess emission (Frohlich, 2000, 2009) enhances the evaporation of surface water and thereby reduces the infiltration. Such an increase in TSI will also cause a change in the timing and intensity of precipitation, which might affect the groundwater recharge. However, the TSI data was not used in their study to quantify the percentage of TSI variation that drives the groundwater recharge rate variation at ~200-year periodicity. Therefore, in the present study, we use advanced statistical and spectral methods to identify the significant correlations between GRR and TSI, to estimate the percentage of TSI variation responsible for ~200-year cyclic variation in GRR.

METHODS AND DATA SOURCES

Singular Spectrum Analysis (SSA)

The time series X(t) of length N is embedded into the trajectory matrix $T_{l\times k}$ using an appropriate window length 'l' guided by weighted correlation (here k=N-l+1). In the next step, we apply singular value decomposition to decompose the trajectory matrix into eigenvectors and eigenvalues as shown in Equation 1.

$$T = \sum_{i=1}^{d} \sqrt{\lambda_i} U_i V_i^T \qquad (1)$$

Where λ_i is the i^{th} Eigen value corresponding to the i^{th} eigenvector U_i of TT^T. The triple ($\sqrt{\lambda_i}$, U_i, V_i) is called the i^{th} Eigen triple and d is the number of Eigen triples with nonzero Eigenvalues. We identify the significant individual and paired Eigen triplets from proper analysis of Eigen spectrum