Aquifer elastic skeletal storage coefficient estimation via PS-InSAR, TICA, and Bayesian inference under precipitation variability

Chenxia Li [a], Jie Yu [a], Lin Zhu [a]

[a] *College of Resources Environment and Tourism, Capital Normal University, Beijing, 100000, China*
Email: yuj2015@cnu.edu.cn

Abstract: The elastic skeletal storage coefficient (Ss) quantifies the capacity of a confined aquifer to undergo elastic deformation of its skeletal structure in response to changes in hydraulic head. It is a key hydrogeological parameter for coupling groundwater level variations with land surface deformation. This study proposes a Bayesian inference–based framework for estimating the elastic skeletal storage coefficient by integrating PS-InSAR, temporal independent component analysis (TICA), and cross-correlation analysis. The approach is applied to the Chaobai River Basin, a region characterized by significant groundwater level fluctuations and substantial land surface deformation.

Keywords: *Sentienl-1A, surface deformation, groundwater level, uncertainty quantification, precipitation variability*

1. INTRODUCTION

Land subsidence and rebound are particularly pronounced in regions where water resources fluctuate, and the elastic skeletal storage coefficient is the critical parameter for quantifying the influence of groundwater level changes on surface deformation (Ghobadi-Far et al. 2023; Dörr et al. 2025). However, the estimation of Ss is subject to significant uncertainties due to limitations in monitoring accuracy and the heterogeneity of subsurface strata (Kuang et al. 2020). This paper presents a Bayesian-inference framework for estimating the elastic skeletal storage coefficient.

2. METHODOLOGY AND RESULTS

The framework first derived time-series surface deformation using PS-InSAR based on 117 Sentinel-1A images acquired from 2018 and 2021 and extracted the elastic deformation component using TICA. Subsequently, using groundwater level data from 36 monitoring wells, cross-correlation was conducted to quantify the time lag between groundwater level variations and the mean elastic component of surface deformation within a 280-meter radius of each well. Building on these, the lag-corrected groundwater level variations, elastic surface deformation, and compressible layer thickness were jointly incorporated as prior information into a Bayesian model. The model employed Markov Chain Monte Carlo (MCMC) sampling to estimate the elastic skeletal storage coefficient (Ss) and quantify its uncertainty. Furthermore, the relationship between precipitation variability and Ss was assessed using the Pearson correlation coefficient.

The results demonstrate that the elastic skeletal storage coefficient in the Chaobai River Basin ranges from 8.2×10^{-6} to 3.5×10^{-4} m^{-1} (Figure 1). The posterior coefficients of variation (CVs) are all below 0.30, representing a 62% reduction compared to the non-informative prior. The estimated Ss values are consistent in magnitude with those obtained from extensometer-based calculations (Li et al. 2022), validating the reliability of the model. The study also finds a positive correlation between annual maximum monthly precipitation and the Ss, with an average correlation coefficient of about 0.64 across the 36 monitoring wells (Figure 2). This may be attributed to the fact that intense precipitation can rapidly recharge the aquifer through rivers or preferential flow paths such as fractures, leading to localized rises in hydraulic head. The resulting short-term reduction in effective stress enhances the elastic rebound of the aquifer skeleton, thereby increasing Ss values.

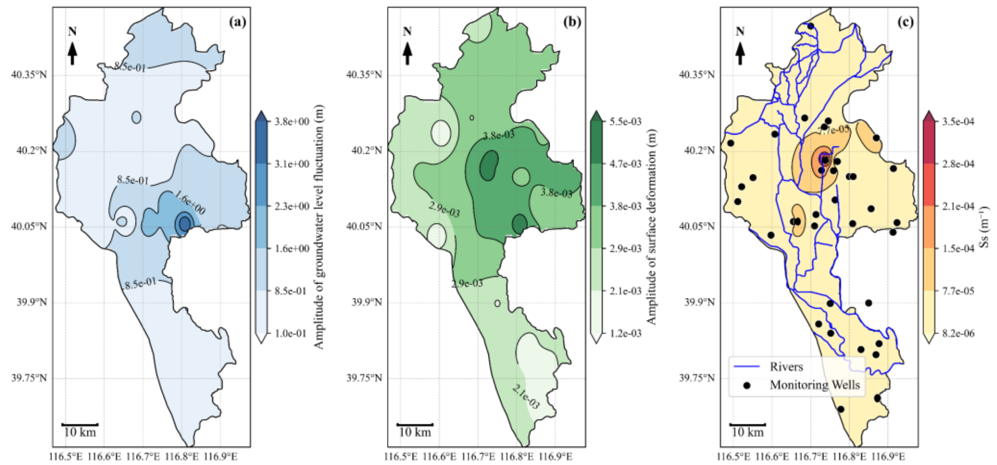

Figure 1 Spatial distributions of groundwater level fluctuation amplitude (a), elastic surface-deformation amplitude(b), and elastic skeletal storage coefficient (c) in the study area

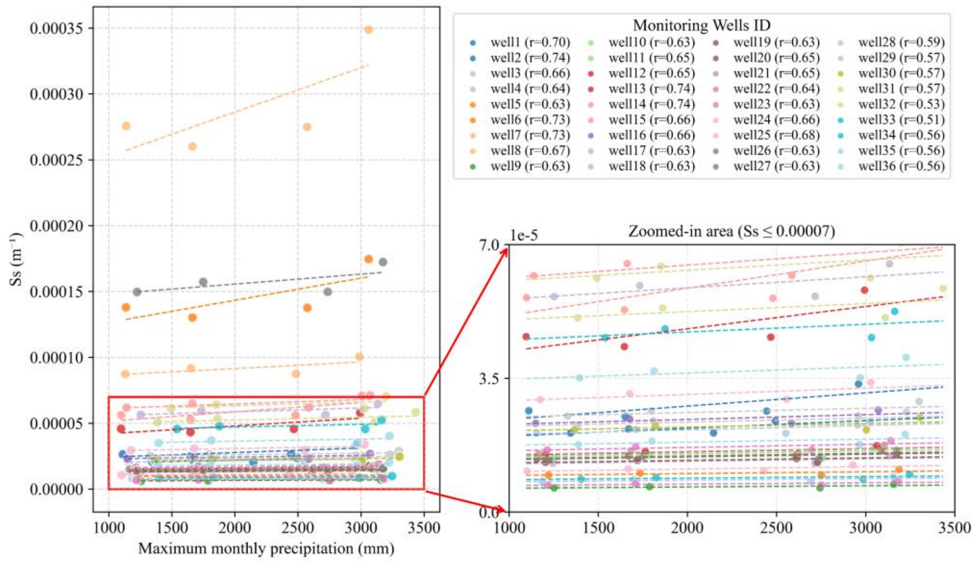

Figure 2 Relationship between estimated elastic skeletal storage coefficient (Ss) and maximum monthly precipitation

3. CONCLUSIONS

This framework of this study enables accurate estimation of the elastic skeletal storage coefficient (Ss) along with rigorous uncertainty quantification. It offers a novel perspective for regional skeletal storage coefficient assessment and for understanding the coupling mechanisms between groundwater level variations and surface deformation.

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