Land subsidence and rebound response to groundwater recovery in the Beijing Plain: A new hydrological perspective

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Abstract: The rapid land subsidence in Beijing Plain, China, has been alleviated since the South-to-North Water Diversion Project. Groundwater level is recovering with more precipitation due to climate change. The land deformation pattern is evolving into a coexistence of subsidence-rebound, which is a new hydrological perspective in the region. Sentinel-1A and InSAR were used to investigate surface deformation in 2016~2022. A new Transfer Function Analysis framework was proposed by integrating deformation, precipitation, groundwater wells, and hydrogeological data to explore the different response mechanisms of subsidence-rebound to groundwater level changes affected by monsoon precipitation. In the typical rebound zone, the maximum land surface rebound under the current groundwater level recovery was estimated.

Keywords: *Land subsidence and rebound, InSAR, Sentinel-1A, Groundwater level recovery, Climate change*

1. INTRODUCTION

In recent years, the South-to-North Water Diversion Project (SNWDP) in China officially transferred water in 2014, bringing new water sources to the Beijing Plain (BJP). Under the joint action of the SNWDP, water management policies, and climate variability, the groundwater level (GWL) is recovering, and land deformation is evolving into a coexistence pattern of subsidence and rebound. However, many previous studies have focused on the continuous subsidence process without bringing this new hydrological perspective. Few have considered coupling the impact of precipitation recharge into the response analysis framework of the aquifer deformation driven by GWL changes, especially the differences in different subsidence and rebound zones in the plain. Hence, an extended analytical framework was proposed to address this gap by integrating multiple datasets and methods. Based on the hydrogeological background, it innovatively reveals the differential response process of land deformation in different subsidence and rebound zones to GWL changes affected by monsoon precipitation in the BJP. Moreover, the maximum rebound at various locations within the rebound zone of the Chaobai River (CB) was estimated using consolidation theory. The study results endeavour to deepen our understanding of the different deformation response mechanism of the BJP under the new hydrological background.

2. METHODOLOGY AND PARTIAL RESULTS

The methodology in this study is shown in Figure 1 (left), Step 1: Interferometric Point Target Analysis (IPTA) is the selected InSAR method to process Sentinel-1A for determining the spatiotemporal distribution and evolution of subsidence and rebound from 2016 to 2022 (Figure 1, a~j), and obtain the annual amplitude and peak time of seasonal deformation based on Seasonal and Trend decomposition using Loess (STL). Step 2: Transfer Function Analysis (TFA) was used to obtain coherence, response intensity, and lag time of the annual response between precipitation and GWL, and between GWL and deformation (Table 1). Combined with different aquifer schematic models, the different effects of precipitation on the aquifers in the plain area through seasonal groundwater recharge will be explained. Step 3: Based on extended deformation time series from IPTA and RadarSAT-2, vectorized groundwater level time series, and consolidation theory, the maximum rebound around the Chaobai River (CB) under the current GWL rise was estimated.

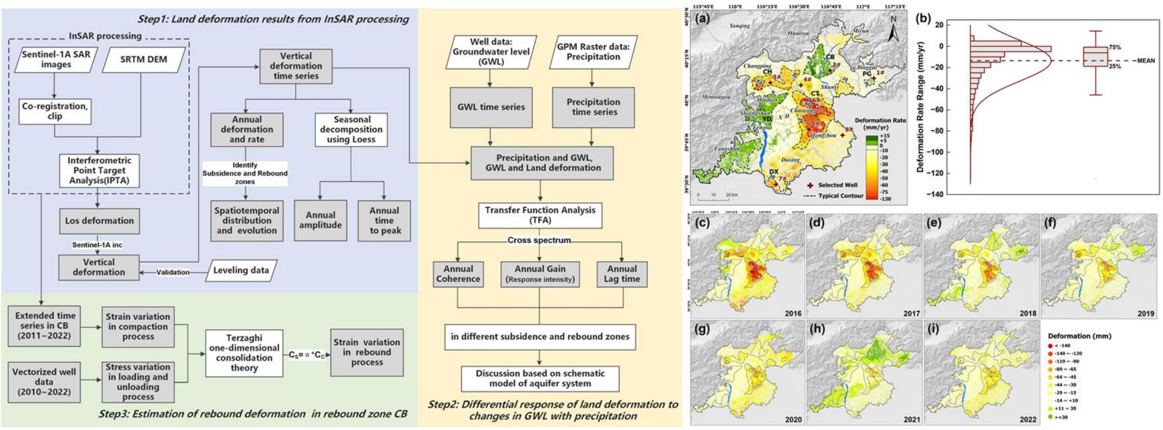

Figure 1 Flowchart of methodology (left), and spatiotemporal distribution of land deformation in BJP (2016–2022) obtained from InSAR and Sentinel-1A (right). a: Average deformation rate. b: Histogram of average deformation rate. c~i: Temporal and spatial evolution of deformation.

Table 1 TFA annual cycle results of wells in three typical zones

Zone	Precipitation and Groundwater level			Groundwater level and Land deformation		
	$Coherence_{pg}$	$Gain_{pg}$	$Time\_lag_{pg}$	$Coherence_{gl}$	$Gain_{gl}$	$Time\_lag_{gl}$
CB	0.68	0.0103×10^{-3}	135 days	0.64	0.349×10^{-3}	33 days
CH	0.89	0.0084×10^{-3}	83 days	0.63	1.988×10^{-3}	54 days
CT	0.77	0.0017×10^{-3}	71 days	0.17	1.618×10^{-3}	118 days

3. CONCLUSIONS

The research provides a new perspective on the coexistence pattern of land subsidence-rebound in the Beijing Plain, and improves understanding of the differential response mechanism of subsidence-rebound to GWL changes affected by precipitation.

Compared to 2011–2015, the area with a subsidence rate of over 60 mm/yr in 2016–2022 has decreased by 37 %. Local areas have experienced a rebound. The area with a rebound rate of over 5 mm/yr is 67.2 km2. The seasonal response between precipitation and GWL exists throughout the plain, while the seasonal response between GWL and deformation is only consistent in the northwest. The aquifer schematic models suggest that the differential deformation response is related to lithology and residual deformation. In the southeast, the aquifer head is still below the adjacent aquitard head, with a larger residual deformation disturbing the seasonal response caused by precipitation. A longer delay between GWL recovery and surface rebound was observed in the aquifer with thicker clay layers, with over 77 % of the compaction being irreversible.

In the future, it is still necessary to pay attention to the restoration process of the aquifer system continuously, providing a basis for the rational allocation of water resources and effective prevention and control of surface differential deformation.

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