National Central University
College of Earth Sciences

Applied Geology Seminar

Unraveling elastic and inelastic storage of aquifer systems by integrating fast independent component analysis and a variable pre-consolidation head decomposition method

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CONTENT

I. BACKGROUND

Land subsidence is a gradual settling or sudden sinking of the Earth’s surface due to the surface or subsurface movement of the earth’s material.

Cause:
- natural processes (soil compaction, withdrawal of underground fluids)
- human activities (extraction of underground resources or overpumping of groundwater)

Maximum area affected: China, USA

Maximum Magnitudes: Mexico, USA, Japan

Global Land Subsidence, 2019
(sources: United States Geological Survey)

I. BACKGROUND

Why does land subsidence matter?

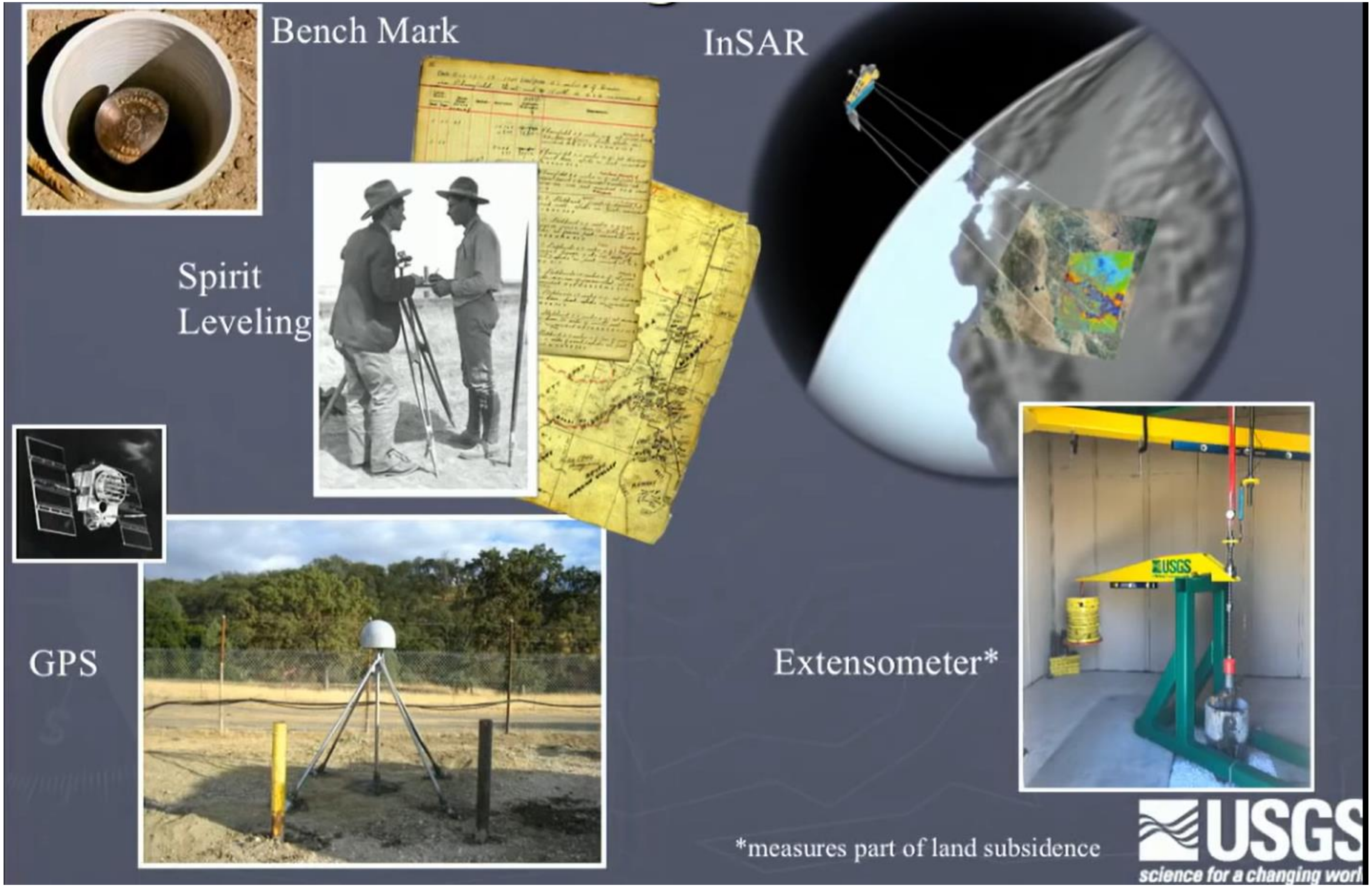
Land subsidence Damages Infrastructure and Natural Resources

- Infrastructure
  - Reduced conveyance capacity and freeboard, panel damage; water surface and liner misalignment; erosion/deposition in unlined channels
  - Roads, rails, bridges, pipelines, wells, etc
- Natural resources
  - Reduced aquifer-system storage capacity
  - Impacts to wetland, riparian, and aquatic ecosystems

I. BACKGROUND

Measuring Land Subsidence

We measure land subsidence using a variety of methods.



I. BACKGROUND

Simulation and Prediction Land Subsidence

Several methods have been developed to simulate and predict land subsidence.

- “Aquifer drainage” models based on Terzaghi theory
- Poroelasticity models based on Biot theory
- Empirical and artificial intelligence methods

The most widely used method is the “aquifer drainage” model developed by Riley (1969) and based on Terzaghi’s (1923) principle.

Many tools are used for the numerical simulation of land subsidence:

- Interbed Storage Package (IBS)
- Subsidence and Aquifer-System Compaction Package (SUB)

I. BAC

Key parameters for Simulation and Prediction Land Subsidence

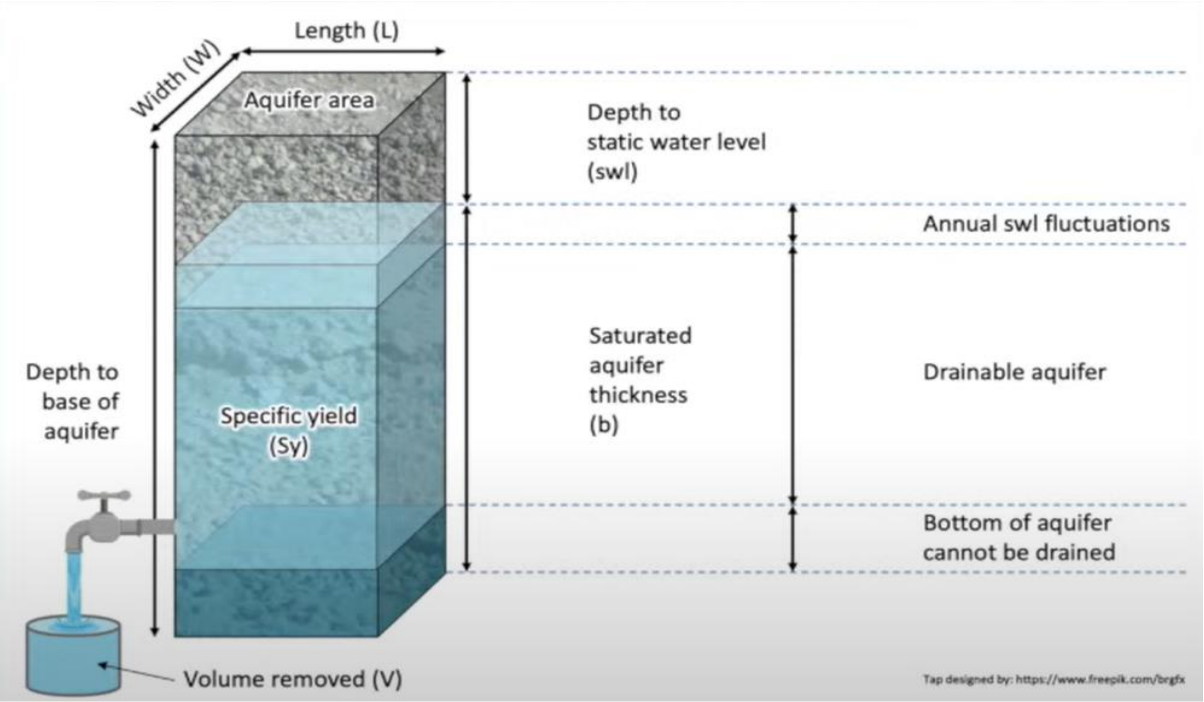
- elastic skeletal storage coefficient (S_{ke})
- inelastic skeletal storage coefficient (S_{kv})
- or elastic (S_{ske}) and inelastic (S_{skv}) skeletal-specific storage

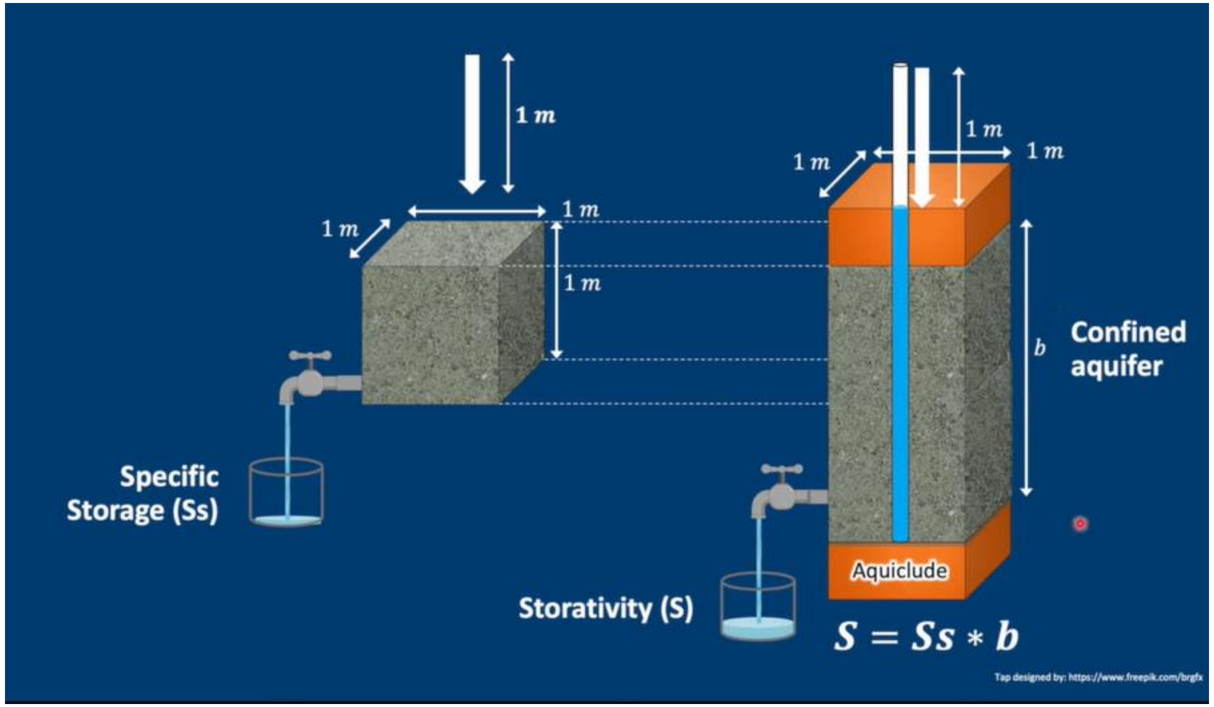
Elastic: can recoverable when aquifer pressure returns to initial values.

Inelastic: can not be recoverable

Storage coefficient is the volume of water an aquifer releases per unit area per unit drop in water level.

Specific storage is the volume released from storage per unit volume of aquifer per unit drop in the head.





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I. BACKGROUND

How to estimate the storage parameters

The conventional methods used to estimate: laboratory experiments or pumping tests.

However, obtaining soil samples from deep layers and pumping tests is difficult.

These parameters have been estimated by long-term processing deformation and hydraulic head records.

Previous hydrogeological studies were mainly focused on characterizing average elastic and inelastic values for complex aquifer systems based on the assumption of yearly and seasonal behavior.

However, elastic deformation may not be seasonal, especially in human-influenced.

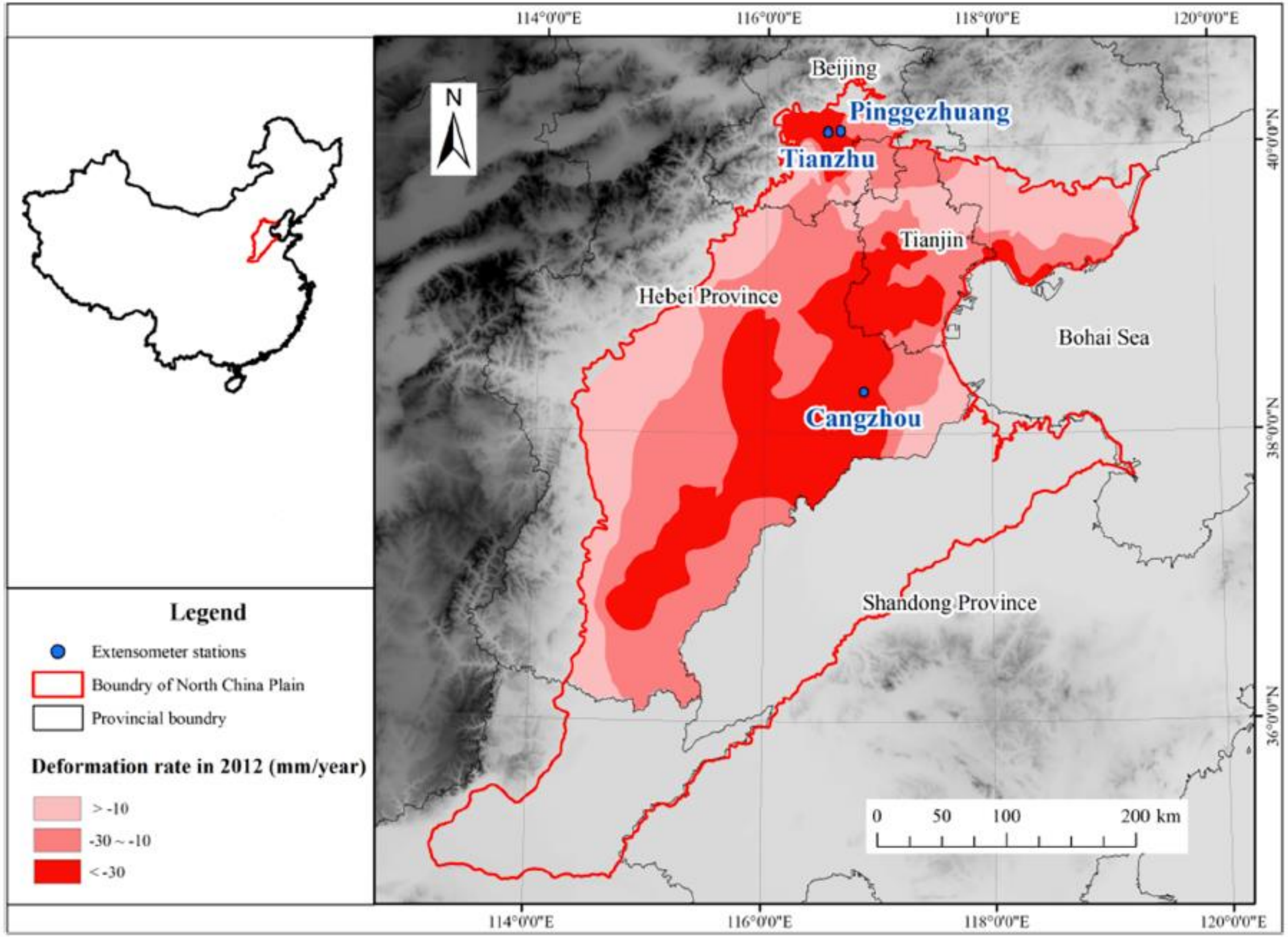
This paper estimates the parameters by separating elastic and inelastic subsidence at various depths and over time from piezometric and extensometer data.

II. INTRODUCTION

Study Area: in North China Plain
(Beijing, Tianjin, Hebei, Henan, and Shandong provinces)

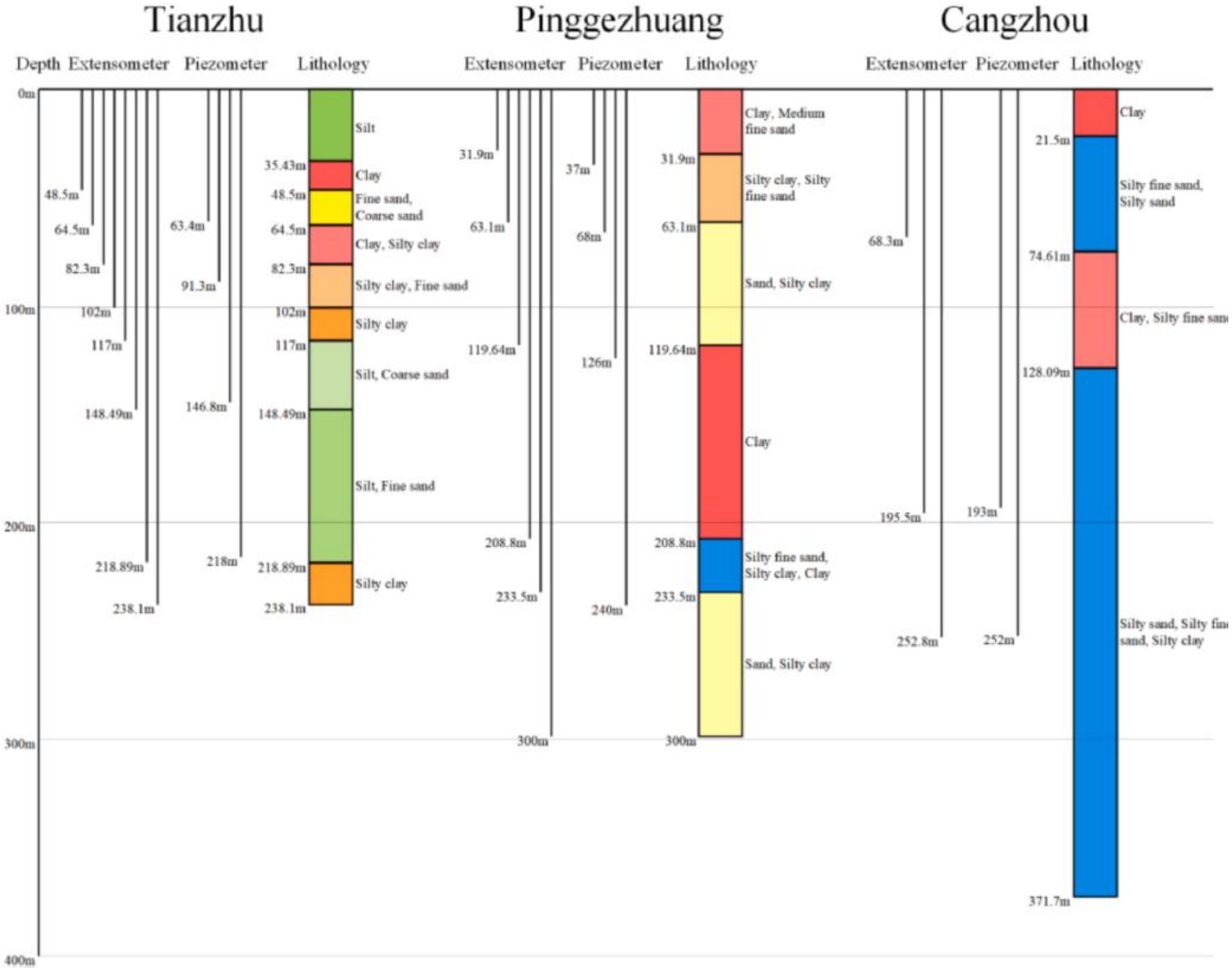
Piezometric and extensometer data from 3 stations:

- Tianzhu
- Pinggezhuang
- Cangzhou



Stations location, Deformation rate in study area

II. INTRODUCTION



Extensometers, piezometers, lithology in the study area

III. METHODOLOGY

Step 1. Provide a theoretical basis for separating elastic and inelastic deformation

Hydraulic head change → elastic and/or inelastic deformation (Terzaghi).

Elastic deformation: Hydraulic head > Hydraulic minimum historical head

Inelastic deformation: Hydraulic head < Hydraulic minimum historical head

The actual value of the hydraulic minimum historical head is updated as the hydraulic head exceeds the historical minimum.

III. METHODOLOGY

Step 2. Separating Elastic and Inelastic deformation components

Function:

$$\mathrm{x}(t) = A^{*}\mathrm{s}(t)$$

where $\mathrm{x}(t) = [\mathrm{x}_1(t), \mathrm{x}_2(t), \cdots, \mathrm{x}_m(t)]^T$: Observed signal matrix composed of m observation signals

$\mathrm{s}(t) = [\mathrm{s}_1(t), \mathrm{s}_2(t), \cdots, \mathrm{s}_n(t)]^T$: Source signal matrix composed of n independent source signals

A :matrix of m × n dimensions

t : time

III. METHODOLOGY

Step 3. Estimation storage parameters

$$\boxed{\begin{aligned} S_{ke} &= \frac{\Delta b_e}{\Delta h_e} \\[2em] S_{kv} &= \frac{\Delta b_v}{\Delta h_v} \end{aligned}}$$

S_{ke}: elastic skeletal storage coefficient

S_{kv}: inelastic skeletal storage coefficient

Δb_e: elastic deformations

Δh_e: hydraulic head (elastic)

Δb_v: inelastic deformation

Δh_v: hydraulic head (inelastic)

$$\boxed{\begin{aligned} S_{ske} &= \frac{S_{ke}}{b_0} \\[2em] S_{skv} &= \frac{S_{kv}}{b_0} \end{aligned}}$$

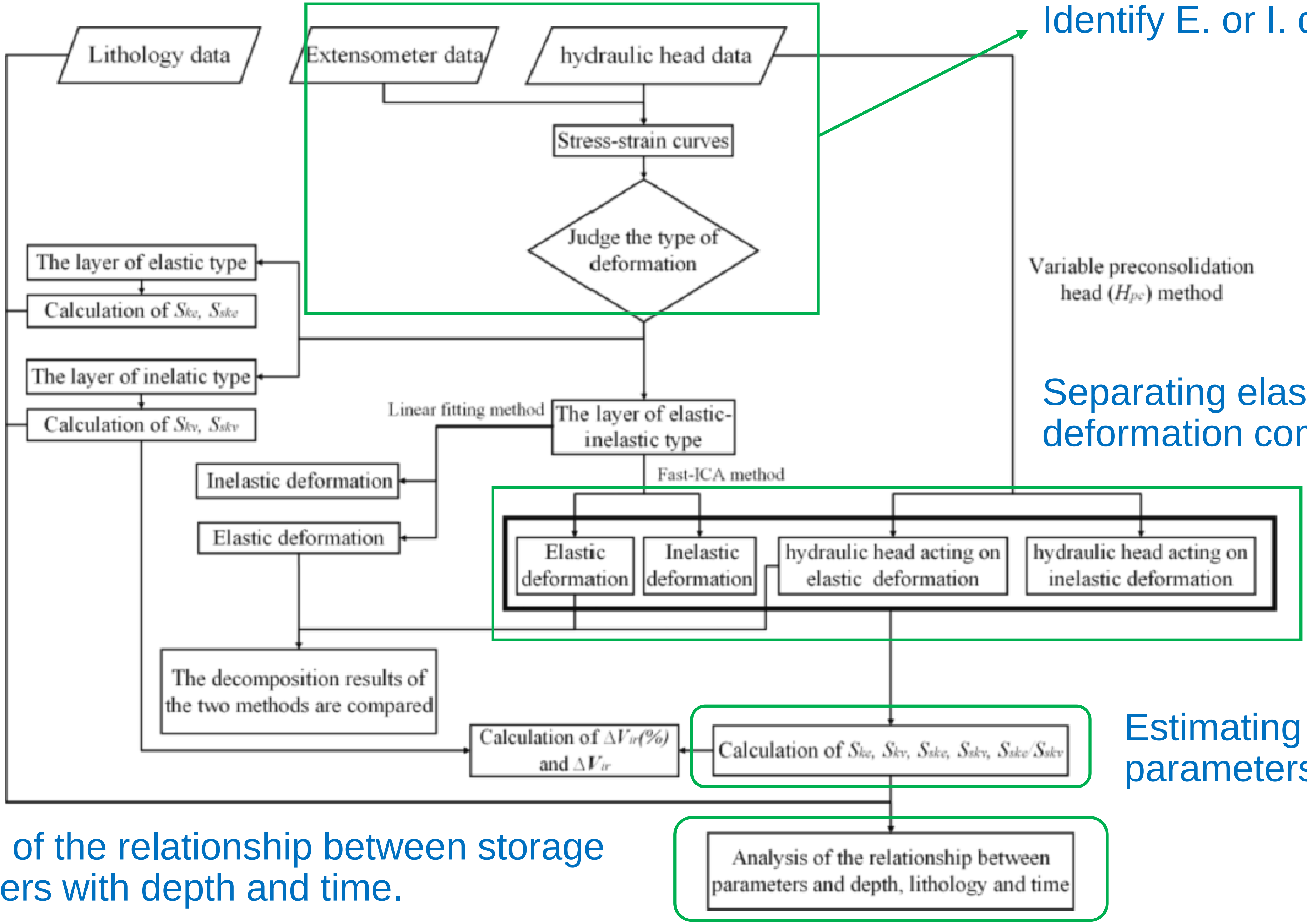
S_{ske}: elastic skeletal-specific storage

S_{skv}: inelastic skeletal-specific storage

b_0: aquifer thickness

Procedural Flowchart

III. METHODOLOGY



Identify E. or I. deformation

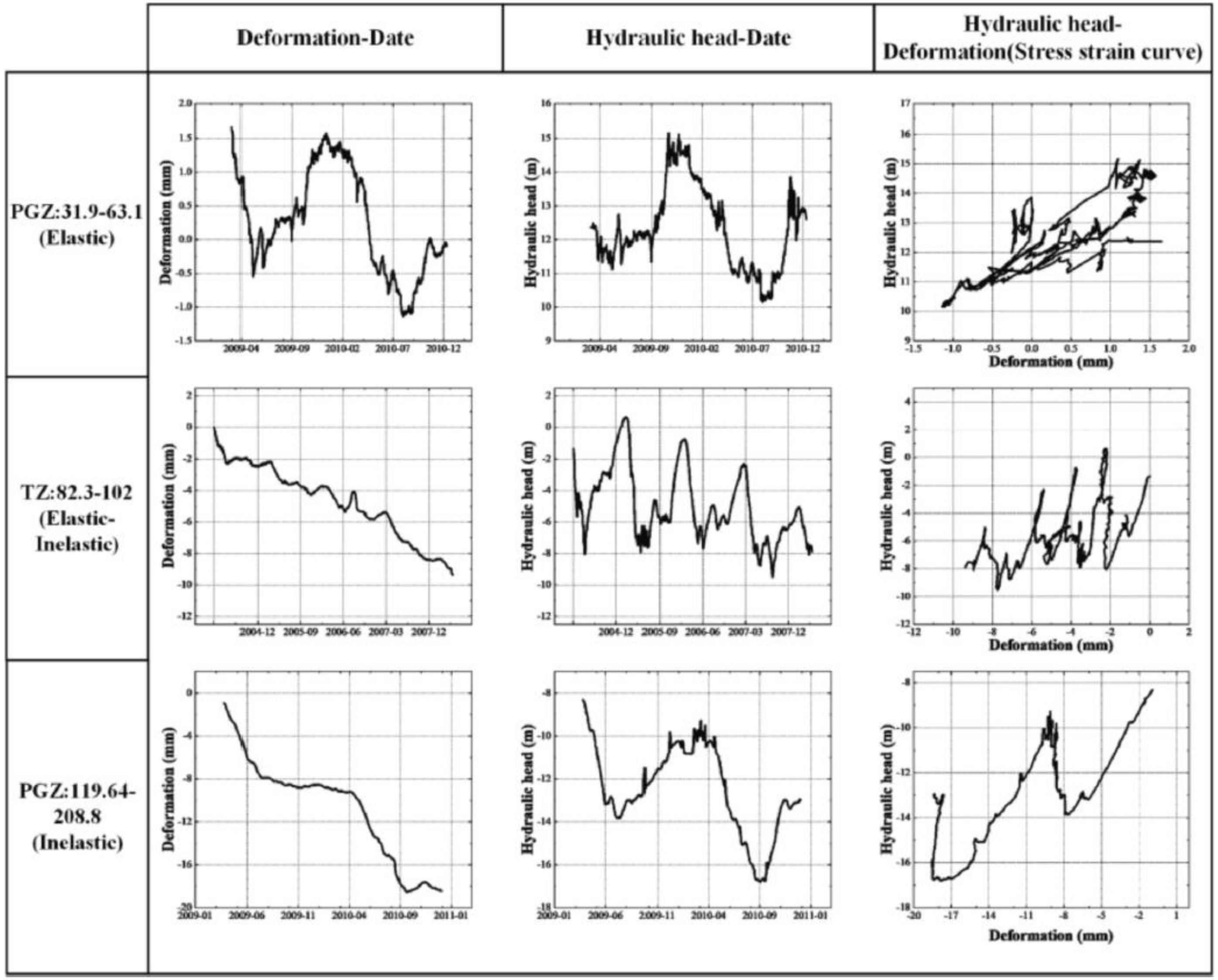
Separating elastic/inelastic deformation components

Estimating storage parameters

Analysis of the relationship between storage parameters with depth and time.

IV. RESULTS

Land subsidence had characterized by three behaviors: elastic, elastic-inelastic, and inelastic



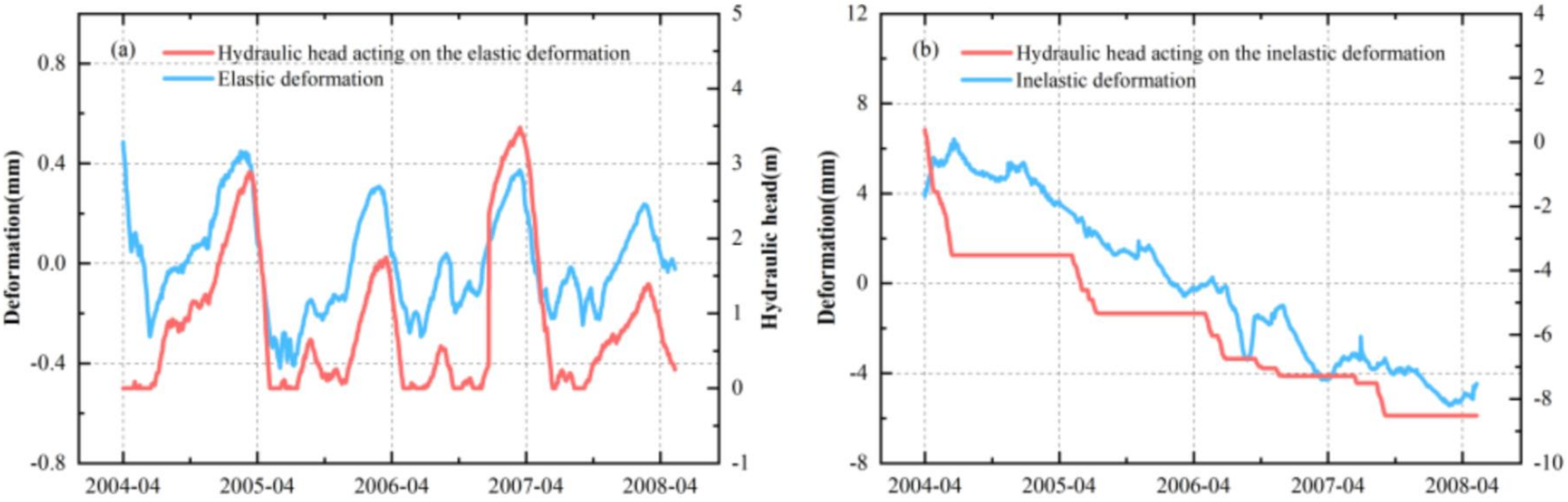
The residual deformation is low, revealing almost elastic behavior

Several hysteresis loops and large residual deformation indicate occurs elastic-inelastic

The residual deformation is large, but there is no hysteresis loop, indicating that mainly inelastic deformation occurs

IV. RESULTS

The correlations between deformation and hydraulic head acting on deformation.

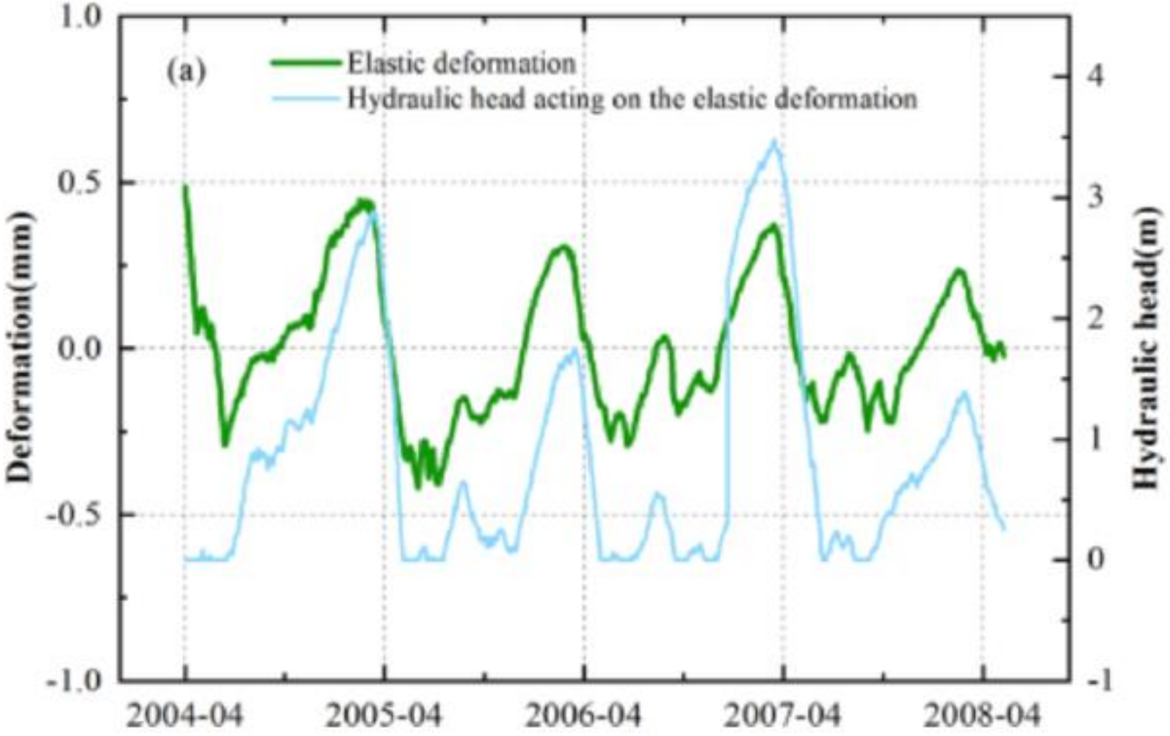


Elastic

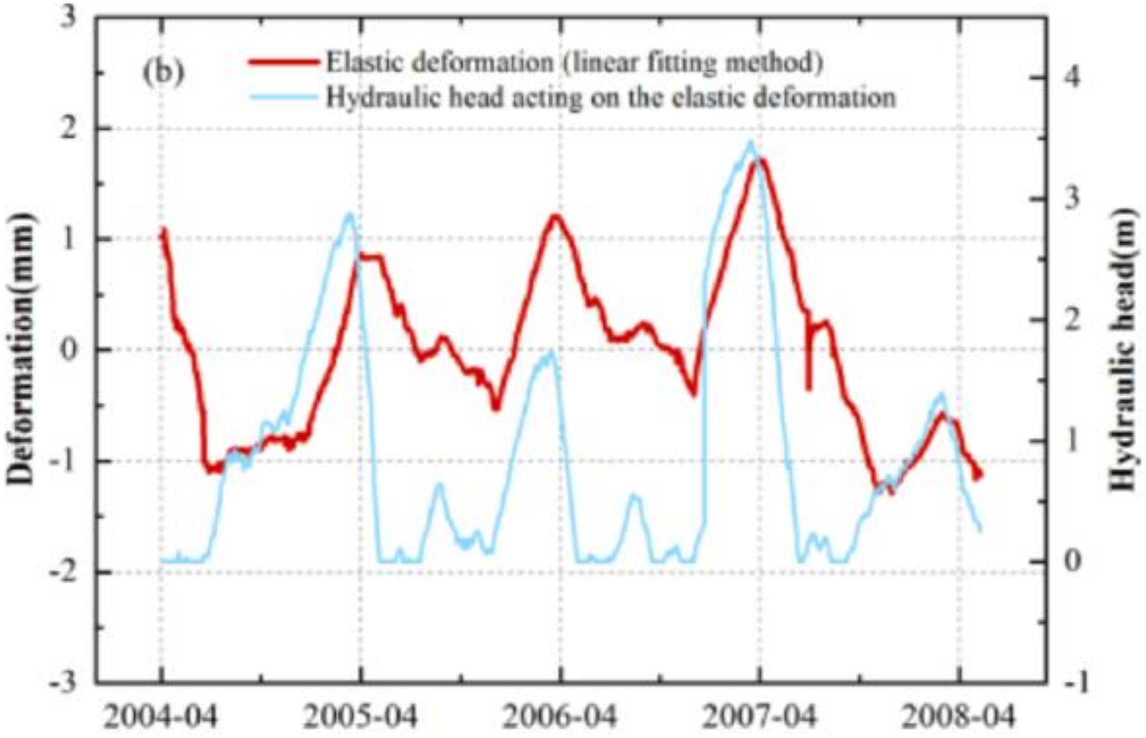
Inelastic

IV. RESULTS

The results estimated by this paper’s method are similar to the traditional linear fitting method.



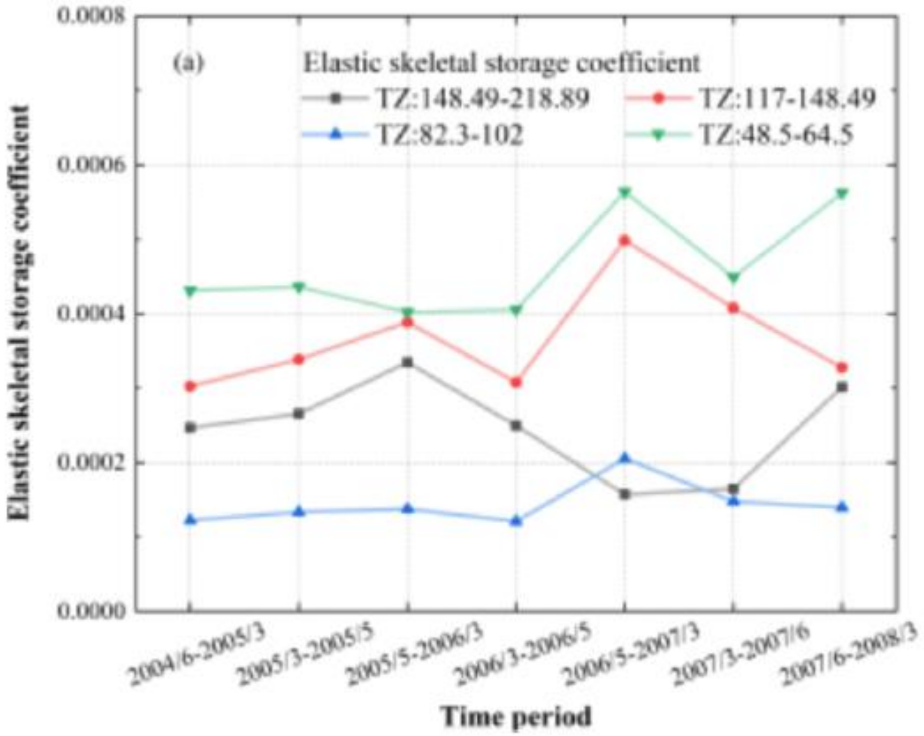
Paper’s method



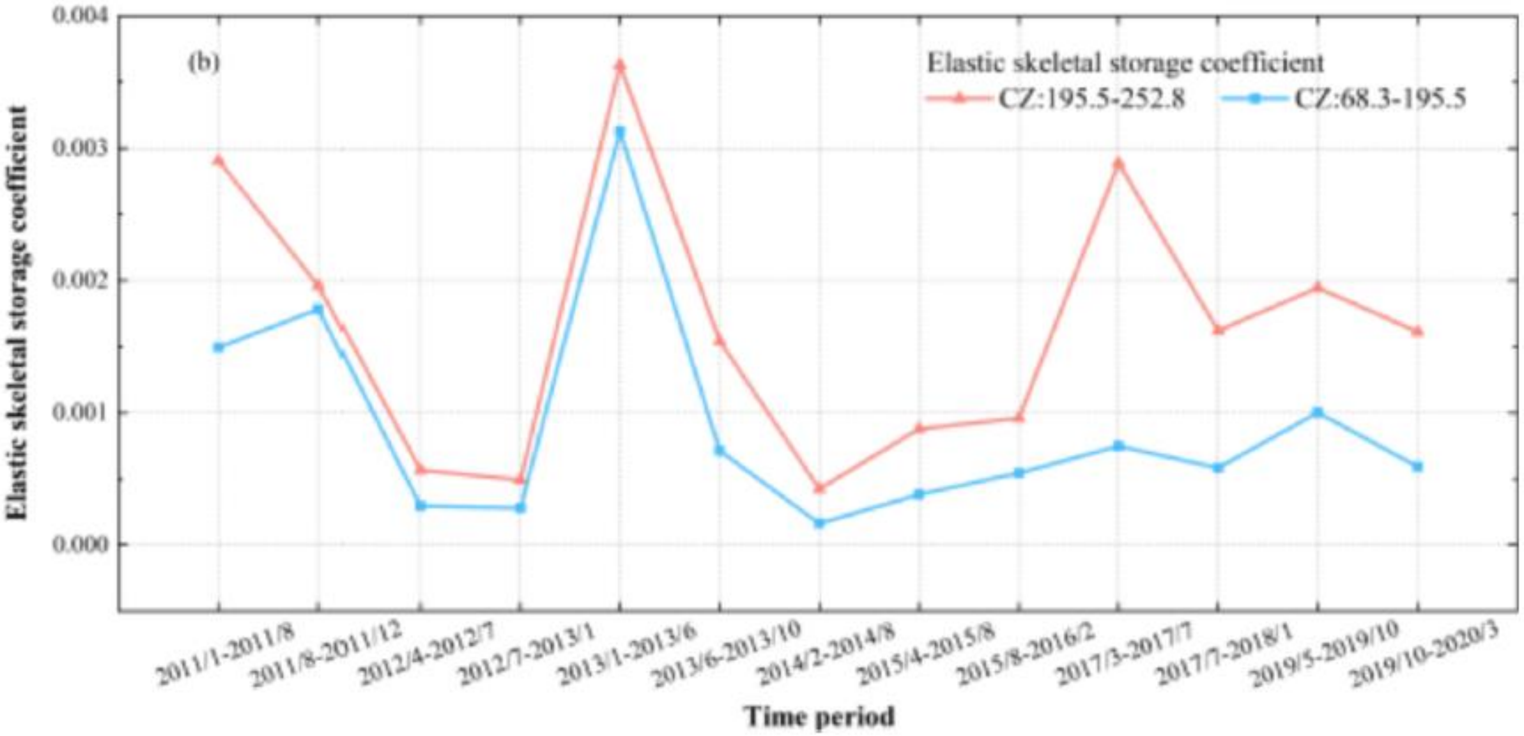
Linear fitting method

IV. RESULTS

Elastic skeletal storage coefficient of each layers varies over time



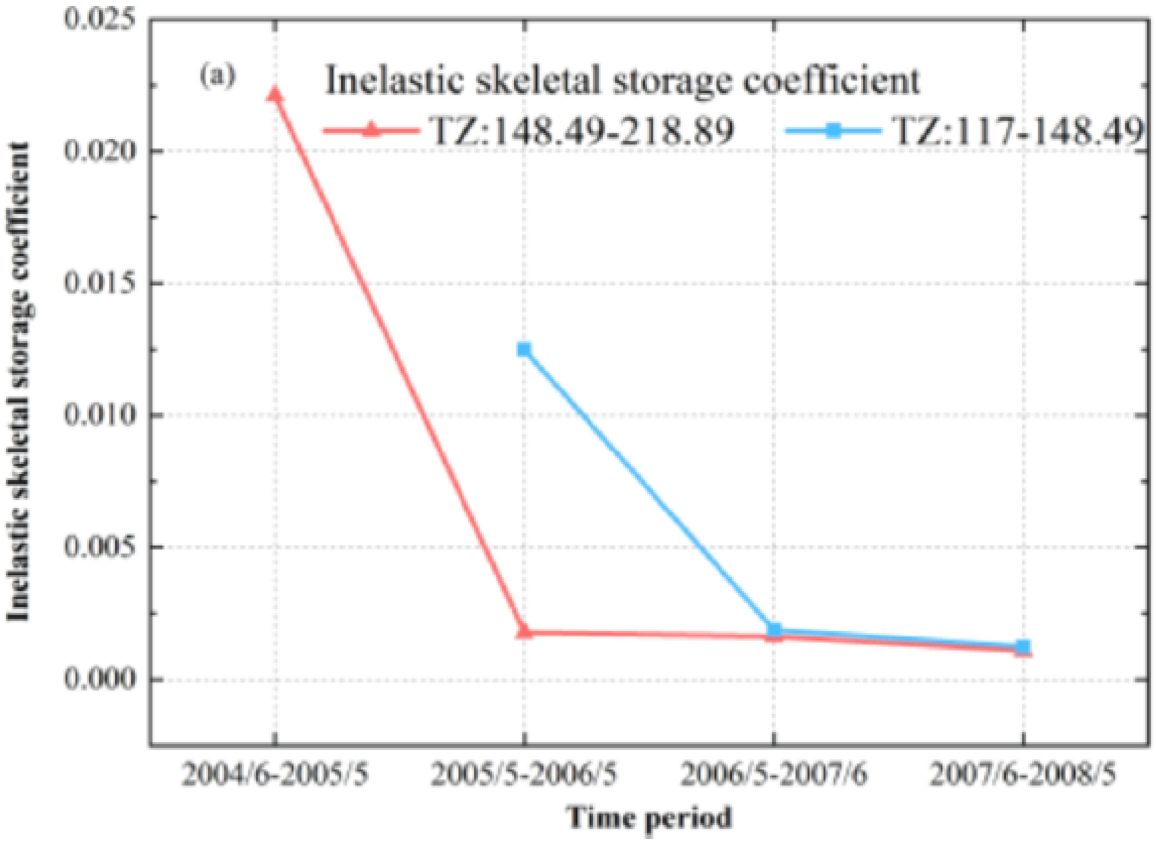
Tianzhu station



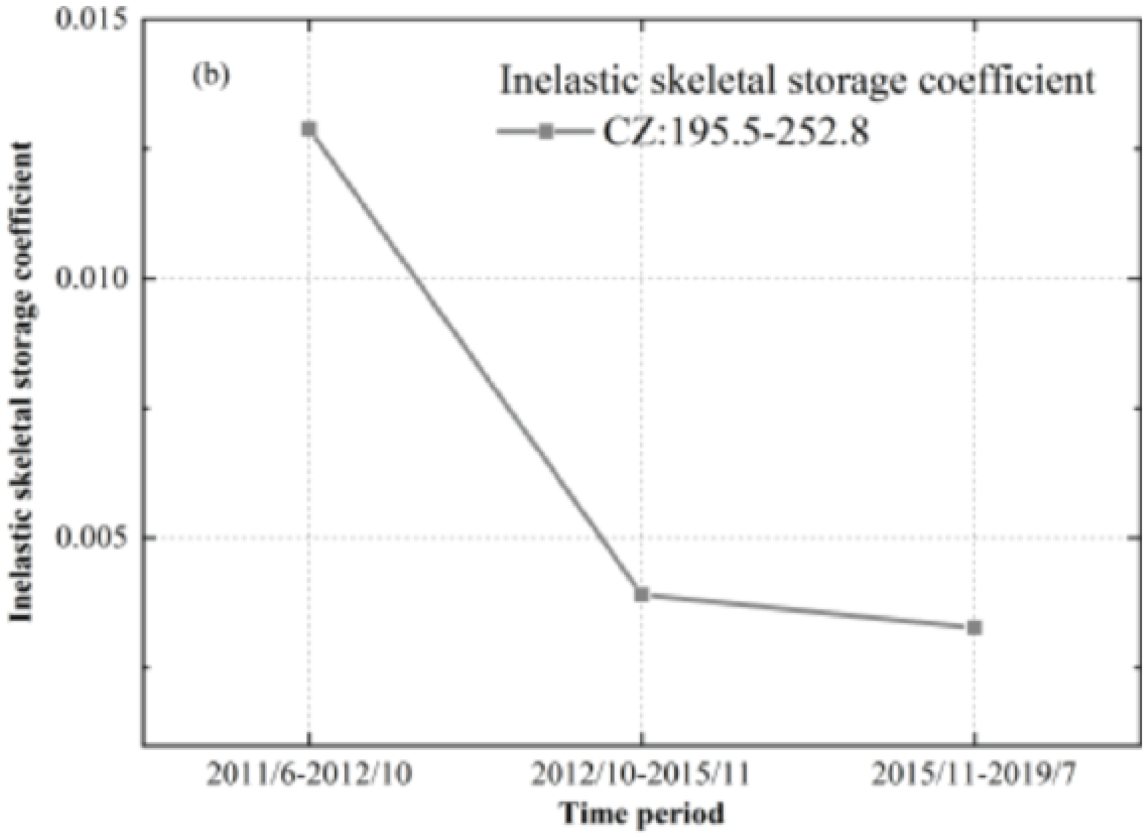
Cangzhou station

IV. RESULTS

The inelastic skeletal storage coefficient of each layer decreases clearly over time.



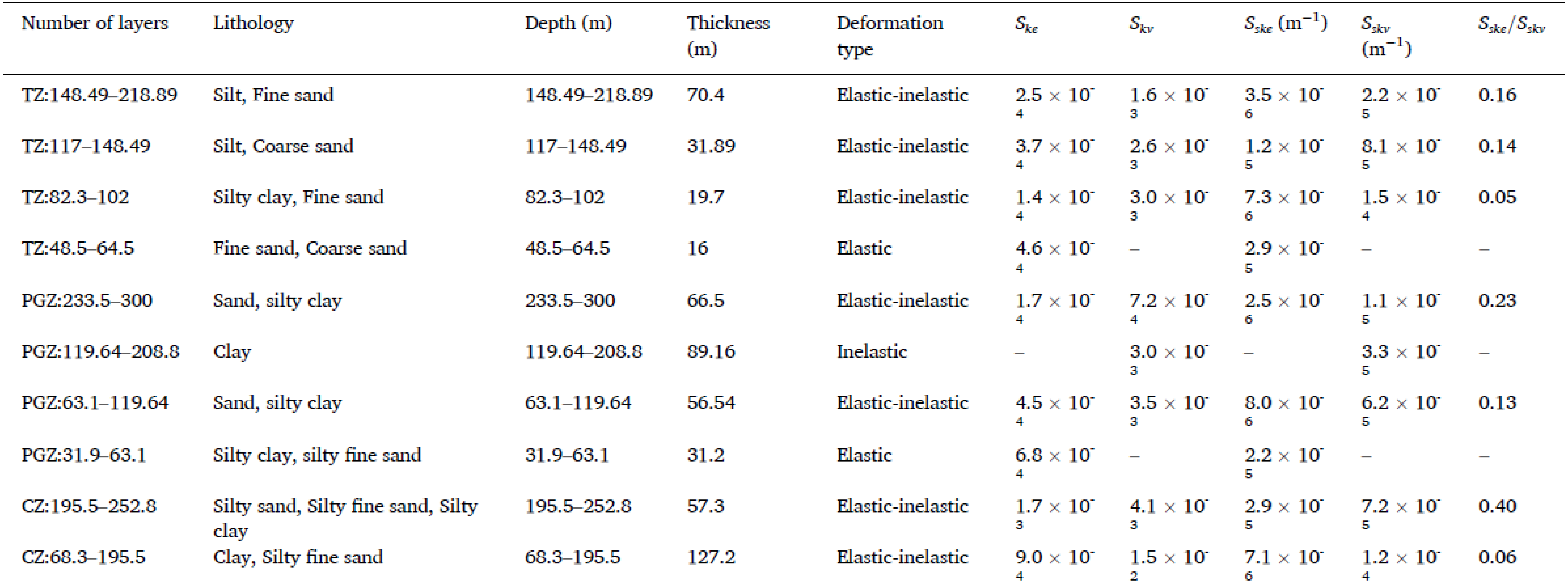
Tianzhu station



Cangzhou station

IV. RESULTS

Storage parameters were estimated for the various depth layers at 3 extensometer stations in the North China Plain.



Number of layers	Lithology	Depth (m)	Thickness (m)	Deformation type	S_{ke}	S_{kv}	S_{ske} (m^{-1})	S_{skv} (m^{-1})	S_{ske}/S_{skv}
TZ:148.49–218.89	Silt, Fine sand	148.49–218.89	70.4	Elastic-inelastic	2.5×10^{-4}	1.6×10^{-3}	3.5×10^{-6}	2.2×10^{-5}	0.16
TZ:117–148.49	Silt, Coarse sand	117–148.49	31.89	Elastic-inelastic	3.7×10^{-4}	2.6×10^{-3}	1.2×10^{-5}	8.1×10^{-5}	0.14
TZ:82.3–102	Silty clay, Fine sand	82.3–102	19.7	Elastic-inelastic	1.4×10^{-4}	3.0×10^{-3}	7.3×10^{-6}	1.5×10^{-4}	0.05
TZ:48.5–64.5	Fine sand, Coarse sand	48.5–64.5	16	Elastic	4.6×10^{-4}	–	2.9×10^{-5}	–	–
PGZ:233.5–300	Sand, silty clay	233.5–300	66.5	Elastic-inelastic	1.7×10^{-4}	7.2×10^{-4}	2.5×10^{-6}	1.1×10^{-5}	0.23
PGZ:119.64–208.8	Clay	119.64–208.8	89.16	Inelastic	–	3.0×10^{-3}	–	3.3×10^{-5}	–
PGZ:63.1–119.64	Sand, silty clay	63.1–119.64	56.54	Elastic-inelastic	4.5×10^{-4}	3.5×10^{-3}	8.0×10^{-6}	6.2×10^{-5}	0.13
PGZ:31.9–63.1	Silty clay, silty fine sand	31.9–63.1	31.2	Elastic	6.8×10^{-4}	–	2.2×10^{-5}	–	–
CZ:195.5–252.8	Silty sand, Silty fine sand, Silty clay	195.5–252.8	57.3	Elastic-inelastic	1.7×10^{-3}	4.1×10^{-3}	2.9×10^{-5}	7.2×10^{-5}	0.40
CZ:68.3–195.5	Clay, Silty fine sand	68.3–195.5	127.2	Elastic-inelastic	9.0×10^{-4}	1.5×10^{-2}	7.1×10^{-6}	1.2×10^{-4}	0.06

V. CONCLUSIONS

- This paper proposes a novel methodology integrating Fast-ICA and a variable hydraulic minimum history head to unravel elastic and inelastic specific storage in confined aquifer systems.

- This method can effectively separate soil deformation's elastic and inelastic components.

- The relations between the storage parameters and depth, lithology, and time are explored.

- Lithology and depth control the values of storage parameters, and at different aquifer systems, they generally decrease with depth.

Thanks for your attention