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Economic Loss Assessment of Land Subsidence: A Case Study of Shenzhen City

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Abstract: As a highly urbanized megacity, Shenzhen has soft soil layers distributed in its western coastal areas. Driven by factors such as groundwater extraction and urban engineering construction, it faces the risk of land subsidence. This paper constructs a Computable General Equilibrium (CGE) model for Shenzhen to assess the economic impact of land subsidence in soft soil areas. Simulation results show that subsidence will lead to a decrease of approximately 0.85% in Shenzhen's real GDP, presenting a dual impact path: it will severely weaken the export competitiveness of sectors such as mining and manufacturing, while causing significant value-added losses to asset-intensive sectors such as construction and transportation. The study finds that post-disaster restoration demand will stimulate short-term growth in labor input and total investment, forming a "disaster stimulus" effect. However, corporate income and total savings still suffer substantial declines (reaching -4.12% and -3.24% respectively), and the associated losses far exceed direct losses. The research indicates that disaster prevention and mitigation policies need to adopt differentiated strategies based on sectoral heterogeneity to enhance urban economic resilience.

Keywords: CGE model; Land subsidence; Soft soil area; Economic loss assessment; Shenzhen city

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1. Introduction

Shenzhen is located on the eastern bank of the Pearl River Delta. Its western coastal zone is widely distributed with marine and marine-continental interactive sedimentary soft soil, which has typical engineering geological characteristics of high water content, high compressibility, low permeability, and low strength [1,2]. The soft soil distribution in the city is mainly concentrated in the western coastal areas. Land subsidence directly threatens infrastructure such as building foundations, subway tunnels, municipal pipelines, and road systems, and triggers extensive indirect economic losses through impacts on production factors and industrial chains [3–5].

Currently, economic impact assessments of geological disasters mostly focus on direct loss statistics or use input-output models to analyze industrial linkage effects, failing to fully capture price mechanisms, factor substitution behaviors, and multi-market general equilibrium effects [6,7]. The Computable General Equilibrium (CGE) model, by simulating the supply-demand relationships of multiple markets and the optimization decisions of economic agents, can systematically assess the comprehensive impact of disasters on the economic system [8,9].

2. Literature review

Main methods for assessing economic losses from disasters include econometric models, Input-Output (IO) models, and Computable General Equilibrium (CGE) models. Econometric models rely on historical data and are difficult to capture the particularity of disaster impacts [10]; although IO models can depict industrial linkages, their linear assumptions and rigid structures may overestimate indirect losses. By introducing price mechanisms and the optimization decisions of economic agents, the CGE model can simulate the dynamic adjustment and equilibrium process of the economic system under disaster impacts, and has become an important tool for disaster economic assessment.

In domestic research, Zhang et al. (1999) [11] applied the CGE model to the analysis of economic impacts of natural disasters; Xie et al. (2012) [12] used the CGE model to assess the economic impact of traffic paralysis caused by snow and ice disasters in Hunan Province. Internationally, Rose et al. (2005) [13] introduced the concept of “resilience” through an improved CGE model to assess the indirect economic losses from water supply system disruptions after earthquakes. Tan (2017) [14] constructed a CGE model for Guangdong Province to systematically assess the economic losses of Typhoon Haima. In terms of model parameter calibration, He et al. (2006) [15] addressed the production function and energy substitution elasticity in the Chinese CGE model.

In summary, research on the economic assessment of land subsidence, a slow-onset disaster, remains largely unexplored. Existing studies mainly focus on monitoring technologies, genetic mechanisms, and engineering prevention, lacking a comprehensive assessment from an economic system perspective. Constructing a CGE model for Shenzhen, taking the capital stock loss and productivity decline caused by land subsidence as exogenous shocks, can fill the research gap in this field and provide new methodological support for geological disaster risk management in megacities.

3. Construction of Shenzhen’s CGE model system

3.1. Model benchmark year and sector division

This study takes 2022 as the model benchmark year. Based on research needs and data availability, the economic system of Shenzhen is divided into 7 sectors: Agriculture; Mining; Manufacturing; Construction; Transportation, Warehousing and Postal Services (hereinafter referred to as “Transportation”); Wholesale, Retail, Accommodation and Catering Services (hereinafter referred to as “Commerce and Catering”); Other Services (including finance, real estate, public administration, etc.).

3.2. Model structure and module design

The Shenzhen CGE model constructed in this paper includes seven core modules: production module, trade module, income module, consumption module, savings-investment module, price module, and system equilibrium module. The model adopts neoclassical closure rules, assuming factor market clearing and full employment of capital and labor.

3.2.1. Production module

A two-level nested Constant Elasticity of Substitution (CES) production function is adopted. The top level is a Leontief combination of value-added and intermediate inputs, and the bottom level value-added is described by a Cobb-Douglas production function of capital and labor.

$$V_i = A_i LD_i^{\alpha i} KDi^{(1-\alpha i)}$$

Where V_i is the value-added of sector i, A_i is the scale parameter of the production function, LD_i and KDi are labor and capital inputs, respectively, and αi is the share parameter of input factors.

3.2.2. Trade module

The Armington assumption is adopted to distinguish domestic products from imported products, and their substitution relationship is described by a CES function. The allocation of domestic output between exports and domestic sales is described by a CET function.

3.2.3. Income and consumption module

Residents' income comes from labor remuneration, capital gains, and transfer payments. After deducting income tax and savings, residents' income is used for consumption of products from various sectors according to fixed shares, and their behavior conforms to the Stone-Geary utility function. Government consumption and investment demand are exogenously given.

3.2.4. System equilibrium

Model equilibrium includes product market equilibrium, factor market equilibrium, investment-savings equilibrium, and balance of payments equilibrium.

4. Data processing and parameter estimation

4.1. Compilation of Social Accounting Matrix (SAM)

The Social Accounting Matrix (SAM) is the data foundation of the CGE model, which comprehensively describes the income and expenditure relationships between various accounts in the economic system in the benchmark year. The 2022 macro SAM table of Shenzhen compiled in this paper (**Table 1**) includes 9 accounts: activities, commodities, labor, capital, households, enterprises, government, savings-investment, and foreign sector. For some data that are difficult to obtain directly, the RAS method is used for balancing to ensure the row-column equilibrium of the matrix.

Table 1. Simplified structure of Shenzhen's macro Social Accounting Matrix

	Activities	Commodities	Labor	Capital	Households	Enterprises	Government	Savings-Investment	Foreign Countries	Total
Activities		Sales of output								Total output
Commodities	Intermediate inputs				Household consumption		Government consumption	Investment	Exports	Total demand
Labor	Labor compensation									Labor income
Capital	Fixed asset depreciation & operating surplus									Capital income
Households			Labor income	Capital income (household part)		Enterprise transfers to households	Government transfers to households			Total household income
Enterprises				Capital income (enterprise part/operating surplus)						Total enterprise income
Government	Net production tax	Import duties			Personal income tax	Enterprise income tax				Total government income
Savings-Investment					Household savings	Enterprise savings	Government savings		Foreign savings	Total savings
Foreign Countries		Imports								Total foreign income
Total	Total cost	Total supply	Labor expenditure	Capital expenditure	Total household expenditure	Total enterprise expenditure	Total government expenditure	Total investment	Total foreign expenditure	

4.2. Model parameter calibration

Parameters of the CGE model mainly include share parameters and elasticity parameters. Among them, share parameters (such as income shares of capital and labor, household consumption shares, etc.) are calibrated through the benchmark year SAM table. Elasticity parameters (such as Armington elasticity, CET transformation elasticity, etc.) are mainly set with reference to existing studies such as Dervis, DeMelo et al. (1982), He et al. (2002), and Zhai et al. (2005).

The labor output elasticity αi in the production function is calculated based on the share of labor remuneration in value-added for each sector.

5. Scenario setting and simulation result analysis

5.1. Direct economic losses and shock setting of land subsidence

This paper sets a benchmark subsidence scenario based on the 2022 status quo. Under this scenario, the direct economic losses caused by land subsidence mainly include:

(1) Repair costs of buildings and infrastructure: Repair and reinforcement costs incurred due to building structural damage, road unevenness, pipeline rupture, etc., caused by subsidence.

(2) Asset value impairment: Decline in real estate value due to unstable foundations.

(3) Production efficiency loss: Output decline caused by infrastructure service disruptions (such as traffic delays).

Based on the loss function and asset stock data, the direct economic losses of each sector are estimated and converted into negative shocks to the capital stock (KDi) and production efficiency parameter (Ai) in the CGE model. The main shock settings are as follows:

(1) Construction and real estate (classified under other services): The capital stock shock is the most significant, set to -1.8% and -1.6% respectively.

(2) Transportation: Due to damage to infrastructure such as roads and railways, its Total Factor Productivity (TFP) is shocked, set to -0.7%.

(3) Manufacturing and mining: The capital stock suffers a slight shock due to the impact on factory buildings and equipment foundations.

5.2. Simulation result analysis

5.2.1. Sectoral economic effects

Substituting the above direct loss shocks into the CGE model, the change rates of economic indicators of each sector after simulation are obtained, as shown in **Table 2**.

Table 2. Sectoral economic effects of land subsidence (Unit: %)

Sector	Labor Input	Capital Input	Value-Added	Domestic Production and Sales	Total Output
Agriculture	-0.21	-0.85	-0.52	-0.48	-0.48
Mining	1.35	-3.21	-1.12	-0.65	-2.85
Manufacturing	1.28	-2.45	-0.95	-0.40	-1.56
Construction	2.86	-5.12	-1.82	-0.29	-2.01
Transportation	0.92	-2.11	-1.36	-0.44	-1.78
Commerce and Catering	1.65	-4.25	-1.64	0.49	-2.35
Other Services	0.75	-1.98	-1.05	-0.10	-1.62

(1) Impact on value-added: The construction sector is the most severely impacted, with value-added decreasing by

1.82%, followed by commerce and catering (-1.64%) and transportation (-1.36%). This is consistent with the characteristics of these sectors being asset-intensive and having high requirements for ground stability.

(2) Impact on factor inputs: Capital inputs of all sectors decline, with construction (-5.12%) and commerce and catering (-4.25%) being the most severe. However, labor inputs generally increase, especially in construction (2.86%) and commerce and catering (1.65%). This indicates that to repair damaged assets and make up for production losses, various sectors increase labor demand in the short term to replace part of the lost capital.

(3) Impact on total output: Total output of all sectors decreases, with mining (-2.85%), commerce and catering (-2.35%), and construction (-2.01%) ranking the top three, reflecting the transmission of subsidence shocks upstream and downstream through the industrial chain.

5.2.2. Macroeconomic effects

At the macroeconomic level, the impact of land subsidence on major economic indicators is shown in **Table 3**.

Table 3. Macroeconomic effects of land subsidence (Unit: %)

Macroeconomic Variable	Change
Real GDP	-0.85
Total Household Income	0.35
Corporate Income	-4.12
Government Income	-2.56
Household Consumption	0.28
Total Investment	0.91
Total Savings	-3.24

(1) Overall economic activity: Real GDP decreases by 0.85%, indicating that land subsidence has a significant negative impact on Shenzhen's overall economy.

(2) Income of economic agents: The corporate sector is the most severely damaged, with income decreasing by 4.12%, mainly due to reduced profits caused by damaged production capital, operational disruptions, and declining exports. Household sector income slightly increases by 0.35% due to increased labor demand, and consumption levels also rise slightly (0.28%). Government sector income decreases by 2.56% due to reduced tax revenue caused by decreased corporate profits and production activities.

(3) Investment and savings: Total investment increases by 0.91%, reflecting the investment demand stimulus brought by post-disaster restoration and reconstruction activities. Total savings decrease by 3.24%, mainly dragged down by the substantial reduction in corporate savings and the decline in government savings.

6. Conclusions and policy recommendations

6.1. Conclusions

By constructing a CGE model for Shenzhen, this paper systematically assesses the comprehensive impact of land subsidence on the economic system, and draws the following main conclusions:

(1) Associated economic losses are significant with diverse transmission paths: The associated economic losses caused by land subsidence (measured by GDP loss) far exceed direct repair costs. The shock is transmitted through two core paths—"capital damage - production obstruction" and "cost increase - competitiveness decline"—exerting differentiated impacts on inward-oriented and outward-oriented sectors.

(2) Sectoral impacts show significant structural differences: Construction, real estate, and transportation are the sectors with the most severe asset losses; while mining and manufacturing suffer particularly sharp export declines and huge total output losses due to impaired international competitiveness. Commerce and catering exhibit unique short-term recovery characteristics due to domestic demand resilience.

(3) The labor market presents a short-term “disaster stimulus” effect: To cope with capital losses and carry out repairs, the economic system increases labor demand in the short term, leading to a rise in the employment rate instead of a decline, and household income and consumption thus increase slightly. This reflects the adaptive adjustment capacity of the economic system under disaster impacts.

(4) Enterprises and government finances face long-term pressure: The substantial decline in corporate income and government savings reveals the potential threats of disasters to the profitability of micro-agents and the sustainability of public finances, and this impact is far more profound and severe than the short-term impact on the household sector.

6.2. Policy recommendations

Based on the above research conclusions, this paper puts forward the following targeted policy recommendations:

(1) Implement differentiated sectoral recovery strategies for outward-oriented sectors (manufacturing, mining), quickly launch a foreign trade enterprise assistance fund, providing export credit guarantees and logistics subsidies to help them recover international market share.

(2) Implement differentiated sectoral recovery strategies for sectors with severe asset damage (construction, transportation). Public investment should be prioritized for them, accelerating the approval and loan processes for infrastructure restoration and fixed asset replacement.

(3) Build a cross-regional and cross-sectoral collaborative disaster prevention system: Establish a “Special Working Group for Subsidence Prevention and Control in Soft Soil Areas” with multi-departmental linkage, including planning, housing and urban-rural development, transportation, water affairs, commerce, and emergency management, to thoroughly solve the problem of fragmented management.

(4) Innovate financial tools to diversify fiscal and corporate risks: Explore the establishment of “urban resilience construction bonds” to provide long-term funds for infrastructure upgrading in soft soil areas. At the same time, encourage insurance companies to develop “business interruption insurance” and “supply chain insurance” for enterprises suffering from production suspension and export disruption due to disasters to prevent the exhaustion of corporate savings.

6.3. Limitations and prospects

This study has the following limitations, which can be further improved in future research: Land subsidence is a dynamic cumulative process, and this paper conducts a static comparative analysis. In the future, a dynamic CGE model can be developed to simulate the intertemporal evolution of subsidence impacts and medium and long-term recovery paths. Sectoral segmentation and spatial dimension: The sectoral division of the model can be further refined. In the future, construction, real estate, infrastructure operation and other sectors can be separated more accurately. At the same time, a spatial CGE model can be introduced to analyze the differences in economic impacts of subsidence in different administrative regions (such as Qianhai and Bao’an Central Area). The estimation of direct economic losses relies on averaged parameters in reports. In the future, it can be optimized by combining higher-precision grid-based asset data and vulnerability curves to make the shock setting more in line with reality.

Disclosure statement

The authors declare no conflict of interest.

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