Adaptive, Resilient Urban Underground Space (UUS)-Subsidence and Economic Impact Spatial Planning Model (USEM): The Extent Development Impact via Cause-Effect and Spatiotemporal Analyses Circa 1960-2020-2050 in Shanghai Megacity

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Abstract: As a rapidly growing coastal megacity, Shanghai is continuously threatened with land subsidence issues since 1920s. Land subsidence was controlled in 1960s, however in 1990s, unconscious and dangerous urban underground space (UUS) exploration and tunneling development are causing further land subsidence. It is imperative to study previous relations towards future adaptive and resilient scenario modelling and planning. There are multiple cause-effect factors determined in the urban built environment of Shanghai megacity. This paper presents the current evidence based on the relations of the multifactor of the spectrum. Methods consist of understanding the cause-effect relations and spatiotemporal from the crucial period of 1960-2020. Data are collected secondarily from multiple open sourced databases. The results determine Shanghai are highly influenced by the UUS development induced-subsidence, tunneling leakage and weak spatial modelling. Spatiotemporal pattern has shown a mixed positive-negative impact: population, land subsidence is growing in parallel distribution (positive) with tunneling leakage, construction of tunneling, metro system, UUS development, building price, reconstruction area, GDP growth, land price, arable land decrease and further tunnel settlement in Urban City Centre, Pudong New Area, Minhang, Baoshan and Songjiang districts. These results are useful for further adaptive and resilient scenario modelling and spatial planning.

Keywords: Land subsidence; urban underground space; cause-effect; spatiotemporal; economic impact; spatial planning model; Shanghai

1. Introduction

Climate change contributes to natural hazards and extreme weather: accelerated sea level rise, storm surge, land subsidence and tectonic movement [1-4]. This complicates further especially in low laying, coastal urban areas with rapid and unconscious socio-economic development via urbanisation, agglomeration, population growth which increase demand for space and resources (e.g. excessive groundwater extraction, minerals, oil, gas, coal mining), surface development load, water demand and carbon emissions [4-6]. Taking land subsidence as a silent killer and underrated issue in coastal megacity, the cause-effects are diverse from the excessive groundwater extraction, mining, natural

subsidence: tectonic movements to urbanisation induced subsidence such as population growth; surface development load and currently, dangerous or unconscious UUS development [7]. The impacts are direct and indirect on all aspects of sustainability spectrum which can include Economic, Environment and Social [8, 9] (refer Figure 1). With all due respect, economic impact is the most visible, monetary and quantifiable by the local decision makers or authorities to justify how feasible, sustainable and cost-saving a certain impact and perhaps, future planning or modelling to realise a feasible, sustainable and cost saving projects in line with the challenging effect of land subsidence.
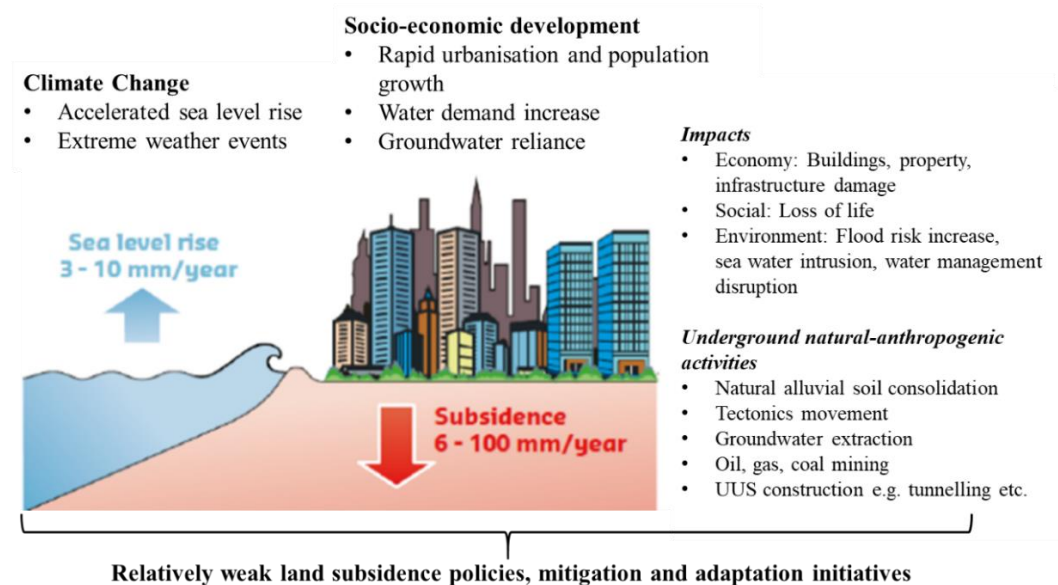
Figure 1. Natural-anthropogenic causes and impacts of land subsidence at major coastal megacities worldwide. Adapted and modified from [8-11].

For Shanghai, as a coastal megacity, is facing serious challenges based on previous records, current and possible future of time [10,12]. Functioning as a major economic megacity, socio-economic development and dangerous urban underground space (UUS) exploration have put further stress to the megacity [13,14]. With continuous land subsidence rate of 6-100mm per year and increasing flood risks have significantly create damage to urban economic spectrum e.g. buildings, properties, infrastructures and land. Putting forward the idea of urban spatial planning for the megacity towards future adaptive and resilient state of scenario in spite with the promising function of UUS development is indeed inevitable. The International Geoscience Programme (IGCP) Plan by the United Nations Educational, Scientific and Cultural Organization (UNESCO) [15] is continuously monitoring and funding research projects towards investigating the land subsidence issues especially in coastal megacities like Shanghai. In theory, different urban areas have different loads and anthropogenic activities that presents different land subsidence impact rate [16]. The cause-effect relationships in rapid urban settings are hard to define due many independent factors and undesirable impacts [17].

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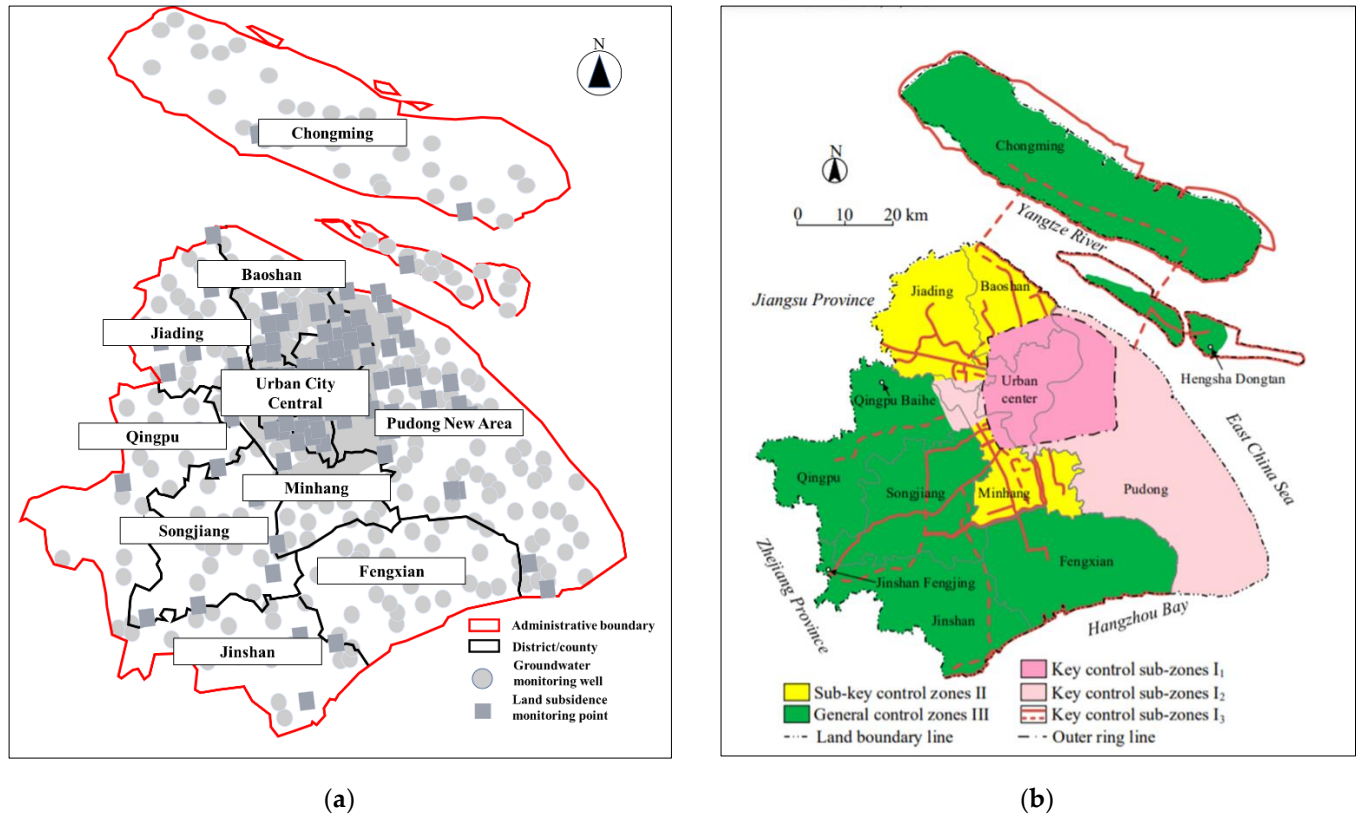
Figure 2. Shanghai megacity's current land subsidence monitoring stations, control zones and district maps: (**a**) Groundwater monitoring well and land subsidence monitoring points distribution map; (**b**) Comprehensive division map of land subsidence control zones in Shanghai. Adapted and modified from [12, 18-19].

UUS exploration in a compact Shanghai megacity, offers three-dimensional (3D) development with promising role of *big, deep, long, fast* and *dense* [20]. As a rapidly growing coastal megacity, Shanghai is continuously threatened with land subsidence issues since 1920s [12, 21]. Starting in 1960s, land subsidence was controlled through groundwater banning in the urban area, however in 1990s, unconscious and dangerous urban underground space (UUS) exploration and tunneling development are causing further land subsidence [22-24] (refer Figure 3). The UUS exploration, land subsidence, economic impact and spatial modelling is a complex multidisciplinary field of research. There is still limited research on the integrated modelling of future potential socio-economic impact damages by UUS exploration from land subsidence in coastal megacities. Hence, this paper presents the understanding of development extent and impact of UUS-subsidence to economic via cause-effect analysis and spatiotemporal. As different urban areas may possess different causes, load and activities that represent different impact, it is imperative to study the ever-complex multidisciplinary spectrum [25]. The investigation of the past and current situation can potentially provide basis for future scenario modelling.

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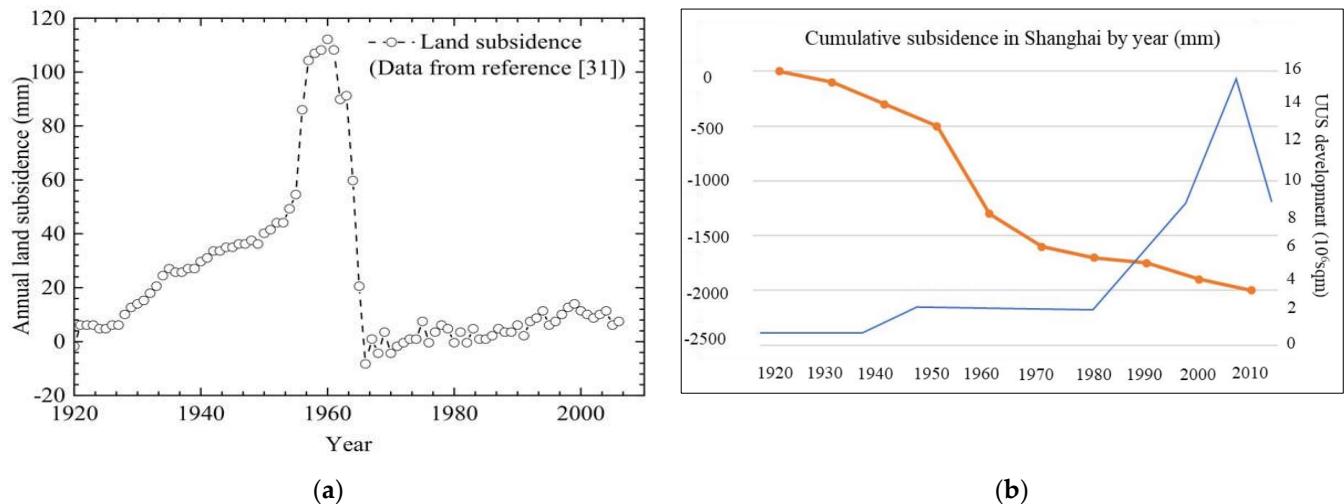
Figure 3. The uncertain phase of land subsidence in Shanghai megacity: (**a**) 1920-1960 accelerated phase, 1960-1990 controlled stage and 1990-2000 onwards continuous further land subsidence increase due to rapid urbanisation [26]; (**b**) Shanghai's cumulative subsidence by year to UUS development from 1920-2010 which depicts rapid positive correlation especially starting in 1990 [27].

2. Materials and Methods

The methods used in this research consist of understanding the relations of multi-factors through cause-effect and spatiotemporal analysis for the study period of 1960-2020. The reason of selecting 1960 as base year is because that was when the control of land subsidence through groundwater banning was successfully implemented. Most of the data for cause-effect multi-factors are secondarily gathered and synthesised from various open sourced databases e.g. scientific journal articles and reports. Factors are selected based on various existing UUS-subsidence-economic impact (USEM) framework: subsidence-economic impact framework [28-29], digital land price model (DLPM) [30], property values [31], UUS evaluation database [31], infrastructure vulnerabilities [22, 33] as well as modification and adaptation from the Shanghai Masterplan 2017-2035 (SM 2035) and Sustainable Development Goals (SDGs) 2030. The multi-factors for cause-effect analysis are derived and integrated into the USEM framework [31,33,34-37,38]. The framework basically involves (refer Figure 4):

> **USEM** *framework* = **Step 1**: Causing hazards x Exposure x Economic Impact Factors x **Step 2**: Space x Time x Vulnerability/Capacity x **Step 3:** Disaster Risks Scenario Spatial Simulation/Modelling x **Step 4:** Comparative

Figure 4. Simplified basics of USEM framework [8, 10, 13-14, 27].

2.1. Multi-Regression Analysis of USEM's Cause-Effect Multi-factors

The cause-effect analysis is used to study the relation of the multifactor which comprise of causing factors (selected based on the previous literatures on local condition of Shanghai megacity) in relation specifically, with the economic impact factors (e.g. land, building, properties, UUS development and infrastructures). It can be considered as a complex method [39]. The cause-effect multi-factors are preliminary determined by constructing 'Ishikawa cause-effect diagram' [40] to provide a clear framework of the cause-effect situations.

2.1.1 Ishikawa Cause-Effect Diagram

Based on preliminary and thorough continuous literature reviews, the main causing factors and economic impact factors for land subsidence in Shanghai megacity have been

structurally determined using 'Ishikawa fish bone method' for easy interpretation into the USEM framework. With integration from SDG 2030 and SM 2035, the concrete cause-effect factors and indicators are determined and integrated into the USEM framework (refer Figure 5).
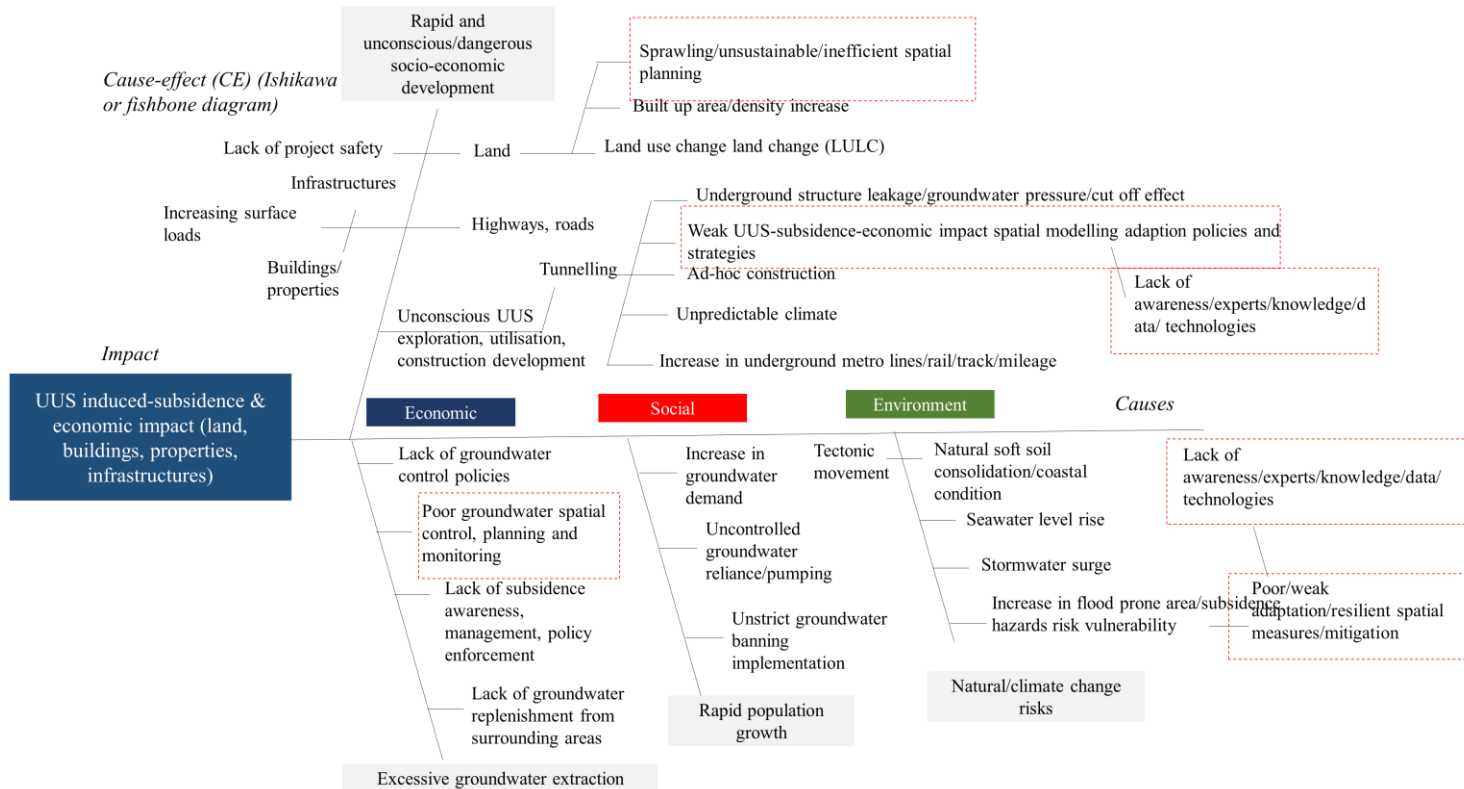
Figure 5. The main causing factors and economic impact factors for land subsidence in Shanghai megacity have been structurally determined using 'Ishikawa fish bone method'.

After careful selection and in line with the Sustainable Development Goal 2030 (SDGs 2030) and Shanghai Masterplan 2017-2035 (SM 2035), there are 38 determined causing factors and 28 economic impact factors. The multi-factors are as well derived from previous and existing literature framework on land subsidence and economic impact. Data are then, secondarily syntehsised from online databases, scientific journals and statistical reports for year 1960, 1990 and 2020. Datasets are input in Excel sheets and each factor has varied type of measurement unit from mathematical (e.g. km per year) and scoring (e.g. Full (F) = 100%, Intermediate (I) = 60% or Low (L) = 40%) by year. The causing and economic impact factors are then analysed via multiple regression to analyse the relationship between a single dependent variable (y) and several independent variables (x). The objective of multiple regression analysis is to use the independent variables whose values are known to predict the value of the single dependent value via the common following equation:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 \ldots + \beta_i X_i \tag{1}$$

Y is dependent variable; β_0 is intercept, β_i is slope for X_i and X is independent variable. To provide simplicity, only the main causing factors and their factors are shown, whilst the second tier are not. The main causing factors cover: increasing surface load; UUS development, groundwater extraction and natural disaster probability. Whilst, direct-

indirect economic impact factors include: land, underground, infrastructure, buildings/properties, socio-economic activities and further land subsidence. As mentioned, these factors are identified, adapted, modified, simplified and integrated to the USEM framework from various existing framework, SDG 2030 and SM 2035 to provide relevancy, comprehensiveness, and inclusivity towards adaptivity and resilience. The detailed causing (x) and economic impact factors (y) are enlisted in the following Table 1 and Table 2.

Table 1. Causing factors.

Main Causing Factor	Factors	Unit
1.0 Increasing surface load	1.1 Building floor area	10^6 m²
	1.2 Residential buildings investment/profit value	Bill. yuan/year
	1.3 Special building codes in land subsidence prone areas	Fully (F) (100) /Intermediate (I) (60)/Limited (L) (40)
	1.4 Continuous financial and technical assistance for buildings-subsidence characteristics	F/I/L
	1.5 Total length highways	km/year
	1.6 Total metro system length in operation	km/year
	1.7 Quality, reliable, sustainable and resilient infrastructure layout planning and development for subsidence prevention and control	F/I/L
	1.8 Percentage of land conversion to built-up areas	F/I/L
	1.9 Land subsidence sensitive urban spatial development planning and control characteristic in subsidence prone areas	F/I/L
	1.10 Experts' knowledge, awareness and availability of data and technologies	Yes (100)/no (0)
	1.11 Population density in a medium to very high risk of subsidence prone area	No. of people/km²
2.0 UUS pre-construction-operation-post failures/development	2.1 Underground tunnel leakage	L/m²/day
	2.2 Cumulative UUS development	hectare
	2.3 Construction of foundation pit	m²
	2.4 Pit excavation	m²
	2.6 Construction of tunnel for transportation	km
	2.7 Cut-off effect on groundwater seepage due to underground structures	m
	2.8 Area of tunnel settlement/UUS-induced land subsidence expansion zones	hectare
	2.9 Historical and potential/probability UUS-induced subsidence rate	mm/year
3.0 Groundwater pumping/extraction	3.1 Total groundwater withdrawal/pumping rate/exploitation (historical and potential) within urban/city center/downtown region	10^6 m³/year
	3.2 Groundwater replenishment/artificial recharge for supply resources from surrounding to subsidence prone/urban region	%, million m³
	3.3 Total groundwater withdrawal in suburban/transition region	10^6 m³/year
	3.4 Groundwater replenishment/artificial recharge for supply resources from surrounding to subsidence prone/suburban region	%, million m³
	3.5 Lack of groundwater extraction limit/groundwater replenishment/ prohibition in subsidence/pumping prone areas	F/I/L
	3.6 Weak policies, mitigation, adaptation strategies (need for continuous updates)	Yes (100)/no (0)
	3.7 Lack of subsidence awareness, management, policy enforcement	F/I/L
	3.8 Poor groundwater spatial control, planning and lack or discontinuous monitoring of subsidence characteristics	F/I/L

	3.9 Lack or discontinues monitoring of subsidence characteristics	F/I/L
	3.10 Unstrict groundwater banning implementation	F/I/L
	3.11 Historical and potential cumulative/average subsidence/compression due to pumping rate urban and suburban overall cumulative	mm/year
4.0 Natural disaster probability	4.1 Tectonic movement speed/activities/rate/active fault	mm/year
	4.2 Storm surge	m/km
	4.3 Natural soft soil consolidation/compression/coastal condition/alluvial soil	mm/year
	4.4 Seawater level rise	mm/year
	4.5 Subsidence-adaptive and resilient urban development and spatial planning	F/I/L
	4.6 Continuous monitoring of subsidence characteristics	F/I/L
	4.7 Storm surge induced/flood events/inundation probability/ prone area/zone/designation/subsidence hazards risk expansion vulnerability	>500mm:km²
	4.8 Experts' awareness/knowledge/data/ technologies on disaster adaptive urban spatial planning	F/I/L

Table 2. Economic impact factors.

Main Economic Impact Factor	Factors	Unit
1.0 Land	1.1 Average benchmarked land price	$/m²
	1.2 Loss of land resources/arable/cultivated land/area/elevation	>500mm:km²
	1.3 Decrease/changes/(+-) in land and property values/price	%. $/RMB
	1.4 Land area developed	m²
2.0 Underground	2.1 Underground structure damage/deformation	$/m²/mm/year
	2.2 Tunnel /metro settlement	mm
	2.3 Breaking of underground pipelines and utilities	$/m²
3.0 Infrastructures	3.1 Cracking/deformation of permanent constructions, bridges and roads/metros	$/m²
	3.2 Malfunction of sewerage and drainage system	$/m²
	3.3 Deterioration of infrastructure	$/m²
	3.4 Increase in maintenance cost of infrastructure	$/m²
	3.5 Reconstruction area ratio (housing)	Billion yuan/year, million m²
4.0 Buildings/properties	4.1 Building structure damage (replacement/maintenance cost) of old/new/historical buildings	Billion yuan/year.
	4.2 Average building/property/real estate values/prices – residential, commercial, industrial, etc.	(Selling prices) $/m²
	4.3 Abandoned buildings and facilities - due to tilting/damages/sinking/subsidence	No. of buildings/properties/facilities
	4.4 Demand in building and reconstruction sector (+) (value of completed buildings residential)	Yuan/m²/year
	4.5 Percentage of newly-built buildings will reach the standards for green building. E.g. 'Gold' LEED certified, carbon neutrality ZEB by 2060 China	%/No
	4.6 Proportions for rent among newly built residential buildings.	%
5.0 Socio-economic activities	5.1 Disruption to economic activities and governance	F/I/L
	5.2 Production effect for companies	Gross Domestic Product (GDP)/RMB per year

	5.3 Business interruption (BI) for infrastructure/utility services due to increased operation and mechanical (O&M) works and increased failure risk (-) (onshore disruption)	BI = T x Q x V
	5.4 Government revenue	$/district/year
	5.5 Industry's share of unemployment rate	%
	5.6 Number of deaths and the number of people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations	Number of populations in urban area/ No. (mills)
	5.7 Climate change-adaptation related policies measures in developed-developing countries cooperation spectrum (effectiveness)	F/I/L
6.0 Further land subsidence	6.1 Subsidence hazards intensity rate (historical and potential/probability)	mm/cm/year
	6.2 Increased inundated flood hazards and coastal flooding expansion areas and infrastructures	>500mm:km²
	6.3 Quality of environment condition	F/I/L

2.2. Spatiotemporal Analysis with ArcGIS Pro

It is acknowledged to produce reliable and goods results out of Geographic Information System (GIS) analysis require extensive set of data. Hence, it is almost limited to impossible to be able to visual spatiotemporally each determined causing and economic impact factors. Hence, after multiple regression analysis was conducted, only those factors with high *R* values (depicts high regression relationships) from 0.90 and above are selected to be spatiotemporally visualise in ArcGIS. The tool used in this analysis is ArcGIS Pro. With limited data availability and highly depending on secondary open sourced data bases, scientific journals and reports, however, a series of spatiotemporal maps for each selected high regression factors are visualised successfully for year 1960-2020. Selected highly regression causing and economic impact factors are:

2.2.1. High Regression Causing Factors with 0.90 and above *R* values

- **1.0 Increasing surface load:**
  Population density (no./km²/year);
  Total construction of tunnel/rapid transit/metro in operation (km/year);
- **2.0 UUS development:**
  Underground tunnel leakage (L/m²/day/year);
  Cumulative UUS development (hectare);
- 3**.0 Groundwater extraction:**
  Cumulative land subsidence (mm/year/hectare)

2.2.2. High Regression Economic Impact Factors with 0.90 and above *R* values

- **1.0 Land:**
  Average land price (yuan/m²/year);
  Loss of arable land (mill.km²/year);
- **2.0 Underground:**
  Tunnel/metro settlement (mm/year);
- **3.0 Infrastructure:**
  Reconstruction area ratio ($/m²/year);
- **4.0 Buildings/properties:**
  Average building price ($/m²/year);
- **5.0 Socio-economic activities:**
  GDP growth/revenue by district of governance ($/district/year)

After determining which cause-effect factors are highly regressed, specific spatiotemporal analysis are conducted using ArcGIS Pro platform and edited with Microsoft PowerPoint graphics by gathering most geospatial data components (e.g. vector, raster, imagery, features, and base maps linked to spreadsheets and tables) and assumptions based on the considerations of existing available raster and vector data on UUS development, land subsidence, previous and current land use and spatial planning, interdependence of land use and human activity changes in coastal areas, economic impact and socio-economic factors for year 1960-2020, to strengthen the spatiotemporal visual relationships. The purposes of learning the spatiotemporal relationship is to determine disaster risks and scenario spatial simulation or modelling by identifying possible countermeasures, planning options, land use changes and consequence mitigation strategies. It involves:

> **Step 3:** Disaster Risks Scenario Spatial Modelling =
> **Step 1:** Causing hazards x Exposure x Economic Impact Factors $\otimes$
> **Step 2:** Space x Time x Vulnerability/Capacity
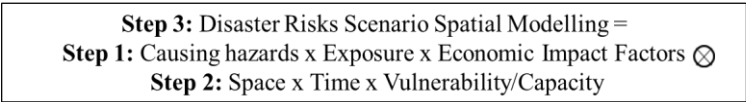
Figure 6. Step 1 and Step 2 are conducted to produce Step 3 based on the USEM framework. Where $\otimes$ represents the overlay analysis in GIS platform.

3. Results

The results determine that the cause-effect of UUS-subsidence-economic impact factors in Shanghai megacity in 1960-2020, has been and are still being influenced due to high regression values of causing factors: weak spatial modelling and experts' knowledge, population, cumulative UUS development, subsidence and tunneling leakage. Meanwhile, the low regression includes seawater level rise, tunneling construction and metro length. Kindly note that these results are based on Business as Usual (BaU) while scenarios such as Countermeasures (CM) with full adaptive measures and Worst Case (WC) scenario are yet to be analysed.

3.2. High R squared value 0.92-1.00

Based on the multi-regression analysis, it is found that the following factors: weak USEM spatial modelling, experts' knowledge, population density, cumulative UUS development, land subsidence, and underground tunneling leakage have high R squared values with values between 0.90-1.00 on the economic impact factors: average building prices, reconstruction area ratio, average land price, number of newly built green buildings, tunnel settlement, arable land and government revenue by districts. The causing factors: population density, UUS-subsidence and tunneling leakage have high impact on the economic factors: on averaged land price, no. of green buildings built and tunneling settlement with 0.97,0.94 and 0.92 R squared values, respectively (refer Figure 7). This indicates the multi-regression relationships are distributed mostly on main causing factors: 1.0 Increasing surface load; 2.0 UUS development and 3.0 Groundwater extraction, with even main economic impact factors: 1.0 Land, 2.0 Underground; 3.0 Infrastructure; 4.0 Buildings/properties and 5.0 Socio-economic activities. These multi-regression relationships are crucial towards sustainable, adaptive and resilient built environment in Shanghai megacity, whereby it shows that the USEM awareness has the most regression influenced on the building selling prices. This is followed by lack of spatial planning awareness/knowledge and technologies (0.9789) which have impact further to the increase of reconstruction area ratio (housing) increase due to damages.

(**a**)

(**b**)

(c)

(d)

(e)

(f)

(g)   (h)
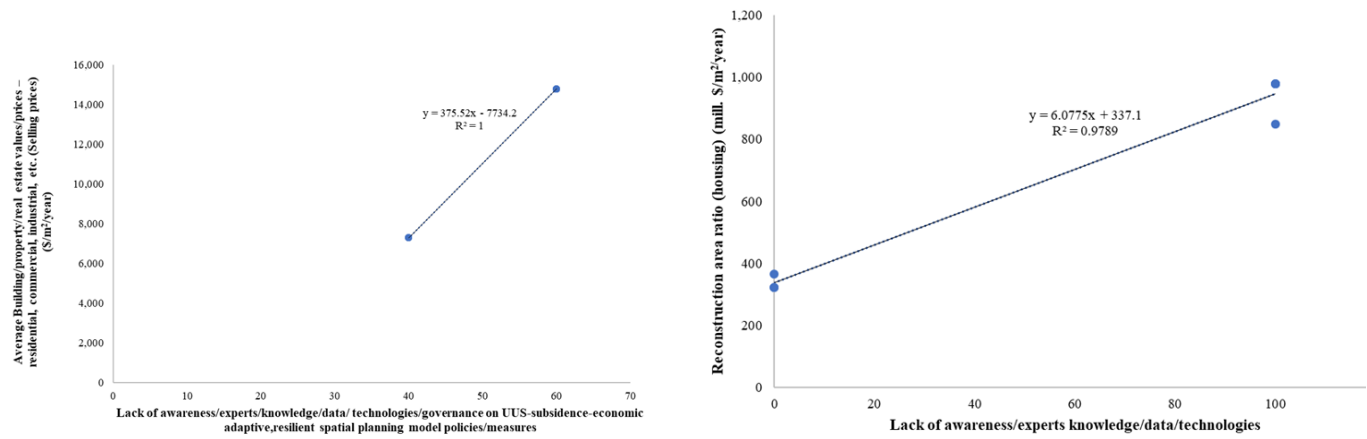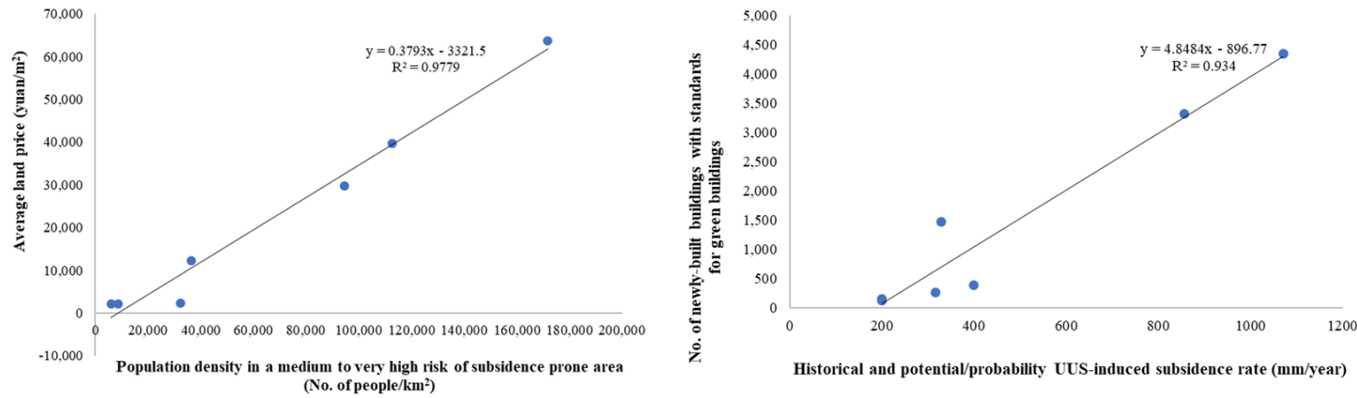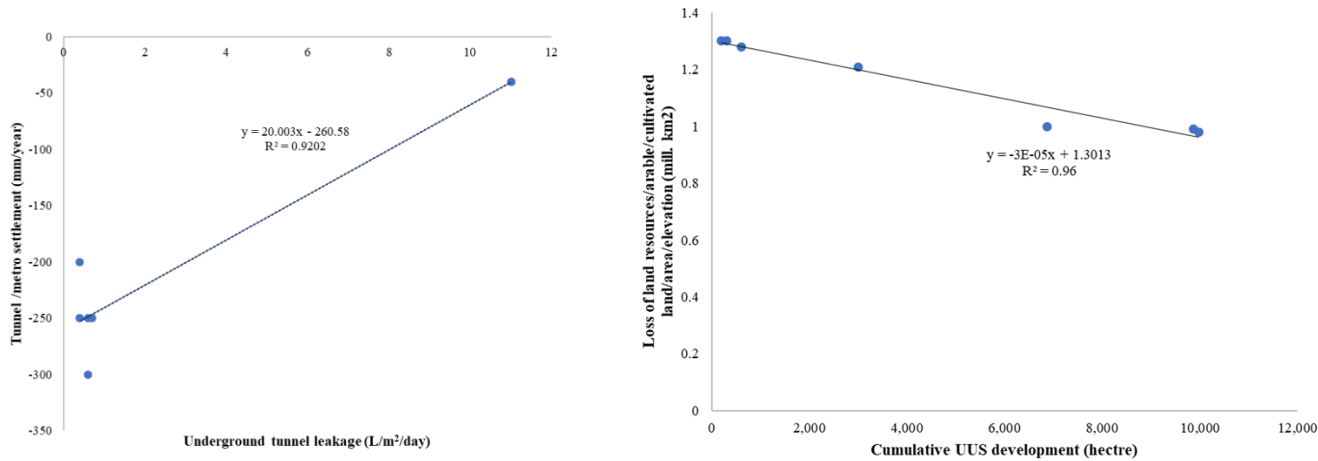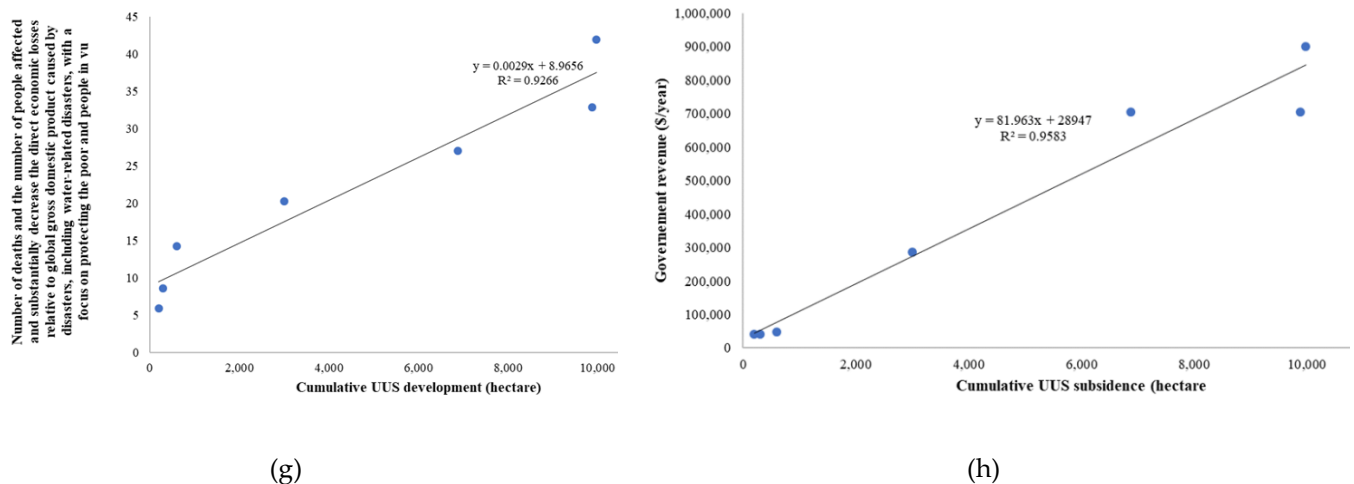
Figure 7. High regression for causing factors to economic impacting factors range from 0.92-1.00 covers: (**a**) expert's aware-ness and knowledge to average building prices; (**b**) expert's awareness and knowledge to reconstruction area ratio; (**c**) population to land price; (**d**) UUS-induced subsidence to number of green buildings; (**e**) underground tunnel leakage to tunnel settlement; (**f**) cumulative UUS development to loss of arable land; (**g**) cumulative UUS development to number of death and (**h**) cumulative UUS subsidence to government revenue.

3.2. Least R squared value 0.0007-0.0014

Meanwhile for the least regressions, to provide simplicity, the causing factors of tun-nel construction and total metro length are selected. The causing factors have least regres-sion impact to the economic disruption and unemployment rate, respectively perhaps due to good construction mechanism of tunneling development in Shanghai megacity.

(**a**)   (**b**)
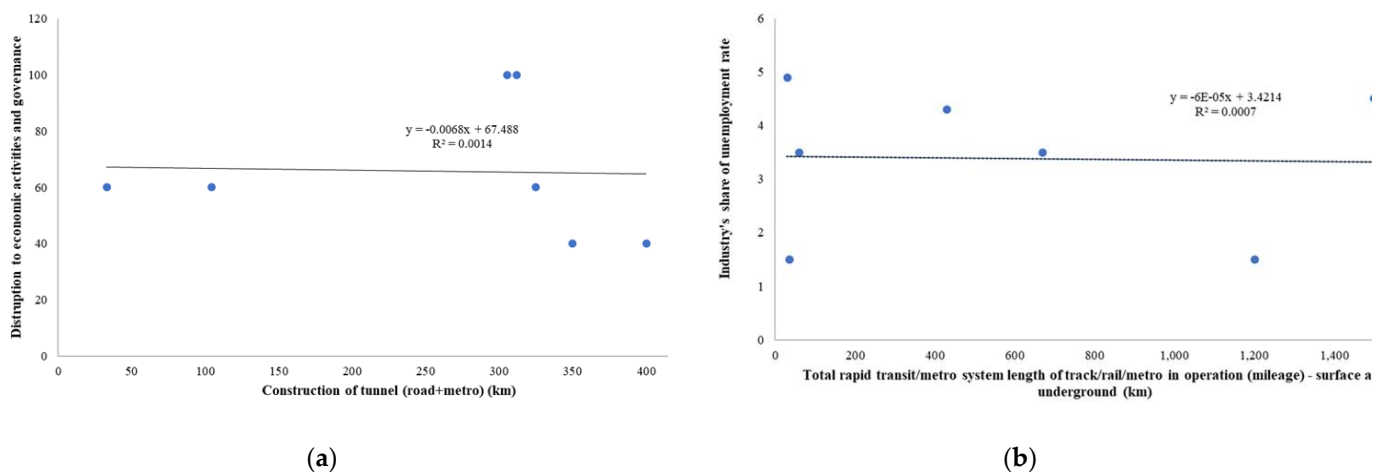
Figure 8. Low regression of causing factors to economic impacting factors range from 0.0007-0.0014: (**a**) tunnel construction to economic and governance disruption; (**b**) total metro length to unemployment rate.

3.3. Spatiotemporal Analysis for High Regression Cause-Effect Factors between 1960-2020

Based on the multi-regression results in 3.2. Only those cause-effect factors with high or significant R squared values are selected to be spatiotemporally visualised in ArcGIS Pro due to data limitation and simplicity. Based on the spatiotemporal analysis, the spatial patterns of the selected high regression causing factors over the period of 1960-2020: pop-ulation density, construction of tunnel or metro, underground tunnel leakage, UUS de-velopment and land subsidence have shown parallel growing pattern with the economic impact factors: land price, arable land, tunnel/metro settlement, reconstruction area ratio, average building price and Gross Domestic Products (GDP) growth or revenue by districts in Shanghai megacity.

3.3.1. Causing Factors Spatiotemporal

Based on Figure 9, the population density, cumulative land subsidence, underground tunneling leakage, cumulative UUS development and total construction of tunnels and metro are growing in parallel distribution between each other in 1960, 1990 and 2020. In 1960, there was no underground tunnel leakage and construction of tunnel metro identified, however UUS development was already constructed for utilities and infrastructures purposed in the Urban City Centre and Pudong New Area. Unfortunately, when the first metro line was constructed and operated in 1990, that was when the underground tunnel leakage starts to be recorded with high concentration in the Urban City Centre and Pudong New Area. These causing factors growing in parallel and worsen by 2020 especially in the Urban City Centre, Pudong New Area, Minhang, Baoshan and Songjiang districts.
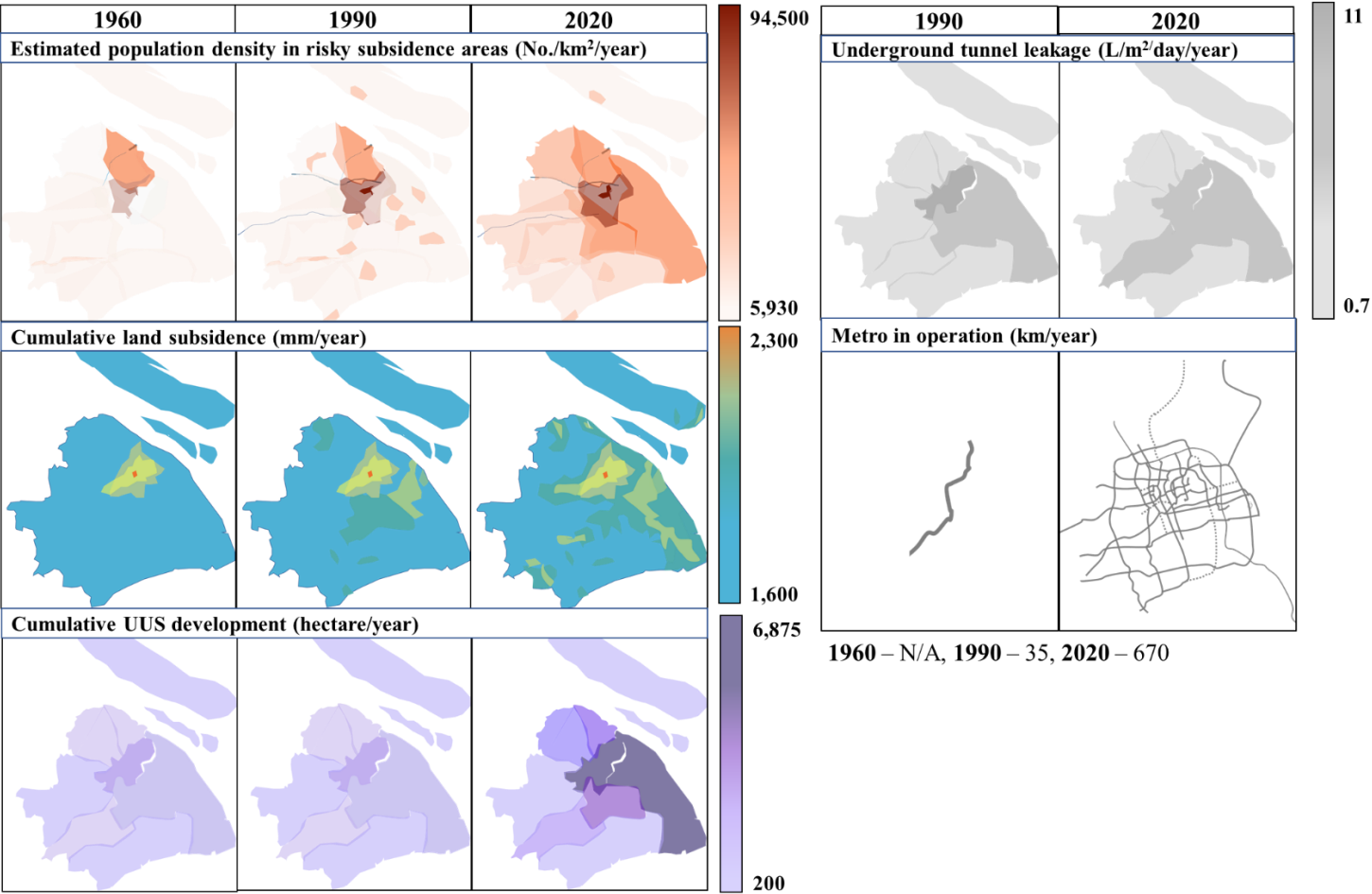
Figure 9. Spatiotemporal maps of high-regression causing factors: population density, cumulative land subsidence, underground tunnel leakage, cumulative UUS development and construction of metro in Shanghai megacity between 1960, 1990 and 2020.

From 1960 to 2020, the population spatial pattern has evolved from merely surrounding Urban City Centre to mostly concentrated at the Baoshan, Minhang and Pudong New Area. The land subsidence is growing mostly parallel with population growth spatial pattern except for Jinshan and Songjiang districts. There seems to be growing subsidence pattern once the tunneling leakage starting in 1990 in parallel with construction of tunnel and metro system. Urban underground space development was not started until 1990 and it was mostly concentrated at Urban City Centre, Minhang and Pudong New Area with additional new area at Songjiang district.

3.3.2 Economic Impact Factors Spatiotemporal

For high-regression economic impact factors, the selected factors include: average land price, arable land, tunnel settlement, reconstruction area, average building price and government revenue (GDP) by districts. Based on Figure 10, the economic impact factors have shown a mixed positive-negative spatiotemporal relation between 1960, 1990 and 2020 to the causing factors. Whereby, building price, reconstruction area, GDP by districts and tunnel/metro settlement have shown parallel (positive) pattern to the causing factors. The results are indeed, revelation, to the state of determining the adverse land subsidence and unconscious rapid development can do to a region. However, for arable land, shows a negative decreasing pattern due to the UUS development. In 1960, there was no tunnel settlement and it has developed in parallel to the causing factor: tunnel leakage in 1990. Most of the economic impact areas are in parallel growth pattern with the causing factor which started in the Urban City Centre, developed to Pudong New Area, Minhang, Baoshan and Songjiang districts. By 2020, the patterns are growing further with the decrease pattern of arable land.
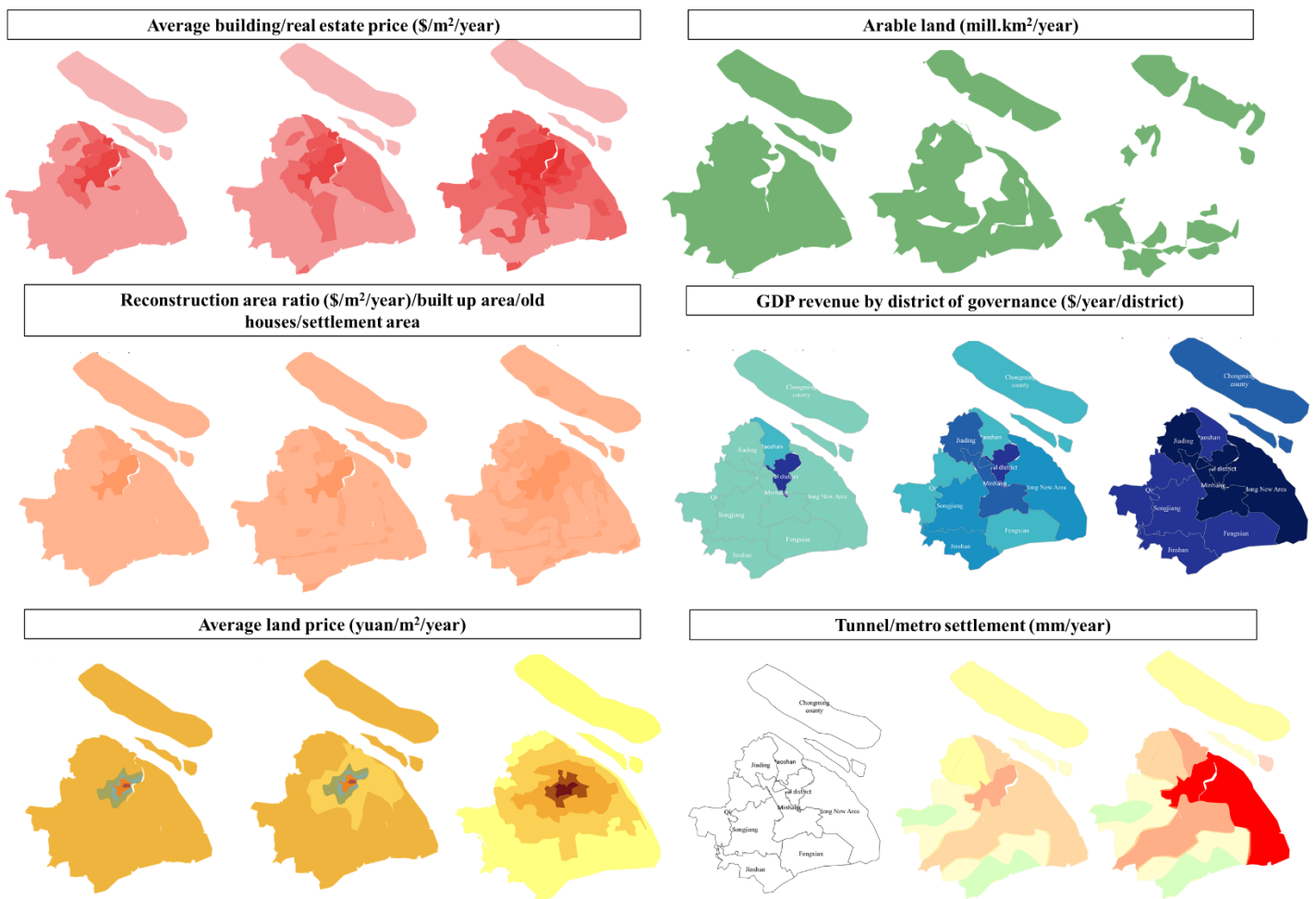
Figure 10. Spatiotemporal maps of high-regression economic impact factors: average building price, reconstruction area, average land price, arable land, GDP by district and tunneling leakage Shanghai megacity between 1960, 1990 and 2020.

In general, building price has positive spatial temporal relationship with the causing factors in parallel with reconstruction area and GDP growth. For the average land price,

it may seem parallel however, they are mostly influenced based on its location and proximity to the Urban City Centre, of which is the usual determination method for land pricing. Unfortunately, the arable land is decreasing substantially with further tunnel settlement concentrated at Urban City Centre, Pudong New Area, Minhang, Baoshan and Songjiang districts.

4. Discussion

This paper has presented the extent development impact via cause-effect multi-regression and spatiotemporal analysis of the high-regression causing and economic impact factors relations in Shanghai megacity to provide inclusiveness and simplicity in depicting the previous and current situations. The determined causing factors include: population density, total construction of tunnel/rapid transit/metro in operation, underground tunnel leakage, cumulative UUS development and cumulative land subsidence. Meanwhile, for economic impact factors: average land price, loss of arable land, tunnel/metro settlement, reconstruction area ratio, average building price, and GDP by district. The results have determined that the cause-effect relations of the multi-factors in Shanghai has been and still are currently being influenced mainly by the population density, cumulative land subsidence, underground tunneling leakage, cumulative UUS development and construction of metro. Spatiotemporal patterns have majority shown a parallel pattern with mixed positive-negative impact with population, land subsidence is growing in parallel distribution (positive) with tunneling leakage, construction of tunneling, metro system, UUS development, building price, reconstruction area, GDP growth, land price, and tunnel settlement whilst arable lands are decreasing further in Urban City Centre, Pudong New Area, Minhang, Baoshan and Songjiang districts.

The results emphasis on the increasing population, UUS-induced subsidence, underground tunnel leakage and cumulative UUS development and subsidence which in revelation have positive impact mostly on the economic factors such as the average building price and GDP by districts. The increment of the stated economic factors are astonishingly remarkable whilst, on the downside, the parallel and positive increment or growth pattern of the tunneling leakage, reconstruction area, and the decrease of arable land can be seen as negative impact. Hence, the affected areas need to be controlled further in terms of land subsidence monitoring as well as careful UUS exploration and tunneling to avoid further leakage, reconstructions and decrease of arable land. Furthermore, the new discovery such as the expert's awareness and knowledge on the USEM related framework is also substantial. As the factor is limited and could not be transferred spatially, it still upholds the most significant regression towards average building prices and adverse increase of reconstruction areas. Hence, focuses must be continually given to the highly regression factors in the USEM model which have significant impact to many economic factors including housing prices, reconstruction ratios, averaged land price, no. of green buildings built and tunneling settlement. For low regressions: tunnel construction and metro length, it is quite unexpected that the factors have least impact on the economic impact factors: disruptions to economic activities and unemployment rate. This may be perhaps due to UUS exploration which mostly are conducted underground or in sub-surface layer without interfering the surface area.

As current UUS related subsidence, development and exploration are still growing, it can be safe to state that indeed it is currently the leading causing factors to potentially adverse economic impact in Shanghai megacity. With tunneling leakage in underground tunneling projects have high occurrences due to the megacity's coastal region nature and heavy development load [2,11]. Many ad-hoc efforts have been pursued however, the awareness and knowledge for multi-integrated macro-scale spatial planning such as the USEM framework with the emphasis on the multifactor of UUS-subsidence-economic impact resiliency is still lack and needed for implementation to avoid future costlier damages [4,6,11].

5. Conclusions

In conclusion, this research provides clear multi-relation of the cause-effect factors in Shanghai megacity context from 1960,1990 and 2020. Further analysis such as spatiotemporal, scenario modelling and comparative of Shanghai as a developed megacity and developing megacities are still required. The causing-economic impact factors selection and results may depict different situation in other developing megacities in comparison to Shanghai. As initially noted, the results are based on *BaU* scenario from 1960, 1990 and 2020, nevertheless, scenario modelling for *CM* and *WC* scenarios for future years beyond 2020 e.g. 2035 or 2050 are still needed to be analysed in further research conduct. Shanghai has modelled a great and positive economic impact from to the causing factors perhaps due to excellent control mechanism of land subsidence, UUS development and exploration by 2020. However, focuses must be continually given to the weak spatial modelling, experts' knowledge and awareness on USEM, population, cumulative UUS development subsidence, and tunneling leakage in future years to come.

The spatiotemporal analysis from 1960-2020 have shown that population, land subsidence is growing in parallel distribution (positive) with tunneling leakage, construction of tunneling and metro system, UUS development, building price, reconstruction area, GDP growth, land price, arable land decrease and further tunnel settlement especially in Urban City Centre, Pudong New Area, Minhang, Baoshan and Songjiang districts. Different situation/cause-impact factors may occur in developing megacities. These results are useful for further adaptive and resilient scenario spatial planning and modelling based on the USEM framework. It opens for further research step 3 and 4: scenario modelling and comparative analysis between a developed and developing megacities and improving planning via concrete scientific evidence and analysis both statistically and spatially. After investigating the cause-effect, spatiotemporal changes and relationships pattern, future spatial proposals can be re-evaluated especially on land subsidence risks and monitoring as well as providing adaptive and resilient spatial planning via scenario modelling. These results are useful for further adaptive and resilient scenario spatial planning, modelling.

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