

Ecological risk Evaluation and Green Infrastructure planning for coping with global climate change, a case study of Shanghai, China

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Abstract. Coping with various ecological risks caused by extreme weather events of global climate change has become an important issue in regional planning, and storm water management for sustainable development. In this paper, taking Shanghai, China as a case study, four potential ecological risks were identified including flood disaster, sea-source disaster, urban heat island effect, and land subsidence. Based on spatial database, the spatial variation of these four ecological risks was evaluated, and the planning area was divided into seven responding regions with different green infrastructure strategy. The methodology developed in this study combining ecological risk evaluation with spatial regionalization planning could contribute to coping with global climate change.

1. Introduction

Global climate change, which caused temperature rise, sea level rise, rainfall imbalance and other phenomena, has become an important topic [1]. And there are increasing extreme weather events caused by these phenomena, for example, frequently extreme rainfall and heatwave [2, 3], with long term and aggravating impacts [4, 5], can lead to enormous economic losses [6], and cause serious impact on human society. However, in developing countries, due to the limited economic power, and scientific and technological level, it would be more vulnerable when facing with extreme climate events [7]. In the process of rapid urbanization in China, green infrastructure, especially lakes, floodplains, arable land, woodland, and wetland, is reducing by large areas. As thus, the regional resilience is deteriorating. According to the data from Ministry of Construction [8], during 2007-2015, More than 360 cities in China suffered from water logging, one-sixth of these last for over 12 hours, with the depth of flood over 0.5 m. For coping with global climate change in urban development, compared with blindly focusing on infrastructure construction and post-disaster recovery, it will be more efficient to practice antecedent planning, [7].

There are mitigation and adaptation measures for coping with global climate change [9]. Mitigation measures depends on land use adjustment and carbon capturing to reduce the emission of greenhouse gas, which is a fundamental way but take a long time to come into effect. Adaptation measures, aiming at certain disaster prevention, is a targeted way. Green infrastructure, a regional life-support system, is



a spatial network forming by green and blue space of urban, rural, and natural area [10]. It depends on spatial pattern optimization, and ecological engineering integrated with mitigation and adaptation measures, to improve ecosystem resilience and management at multi-scale for coping with global climate change.

To deal with extreme weather events of global climate change, European Union has launched green infrastructure planning since 2010 [11]. The major cities in the UK have carried out spatial planning focusing on green infrastructure to prevent various potential disasters. Among these, the coastal cities attached great importance to extreme rainfall, typhoon, high temperature, and urban heat island effects related to global climate change [12]. In China, the impact of global climate change on ecological and hydrological processes, such as surface water quality [13] and wetland hydrology [14], is also getting an increasing attention from scholars and government sectors. It has become an important part of regional planning to strengthen disaster control, and water resources management. Since the State Council promulgated the “*Opinions on Promoting Sponge City Construction*” in 2015 [15], China has launched 30 pilot sponge city projects (a common use term in China, internationally known as low impact development of rainwater systems), aiming at consuming or utilizing 70% of the rainfall locally, and minimizing the impact of urban development on the ecological environment through green infrastructure.

Although there have been plenty of researches and practices on ecological risk responding in urban planning [16,17], the fundamental mitigation of climate change and its impact has always been ignored. Josef Jabareen (2013), developed a conceptual framework for coping with climate change and environmental risk [18], but an operational spatial analysis and planning methodology for big cities in developing countries is still not reported. Hence, there is a strong desire to identify and evaluate ecological risks from the perspective of global climate change to promote regionalization planning of green infrastructure. And measures system with both mitigation and adaptation ones is the key to deal with ecological risks caused by global climate change. The objective of this research is to develop a methodology combining ecological risk evaluation and spatial regionalization planning, to provide an approach for the current sponge city construction in China, and to promote sustainable development under the background of global climate change. Taking Shanghai, China as a case study, based on main impacts of global climate change, we identified and evaluated the major ecological risks of Shanghai, and then developed spatial strategic planning for green infrastructure.

2. Materials and methods

2.1. Study area

Shanghai, is located in the Middle-Lower Yangtze River Plain, east part of China, with flat terrain. With Yangtze River to the north, East China Sea to the east, and Hangzhou Bay to the south, it is not only the boundary between the sea and land, but also the border of salt and fresh water. As the biggest economic center in China, Shanghai is proceeding to be one of international centers for economic, finance, trade and shipping. However, under the background of global climate change, due to simultaneous rainfall and heat, centralized storm surges, and unorderly spreading of built-up area, potential ecological risks could threaten its sustainable development. Green infrastructure planning can contribute to coping with various ecological risks, and increasing the potential of city development.

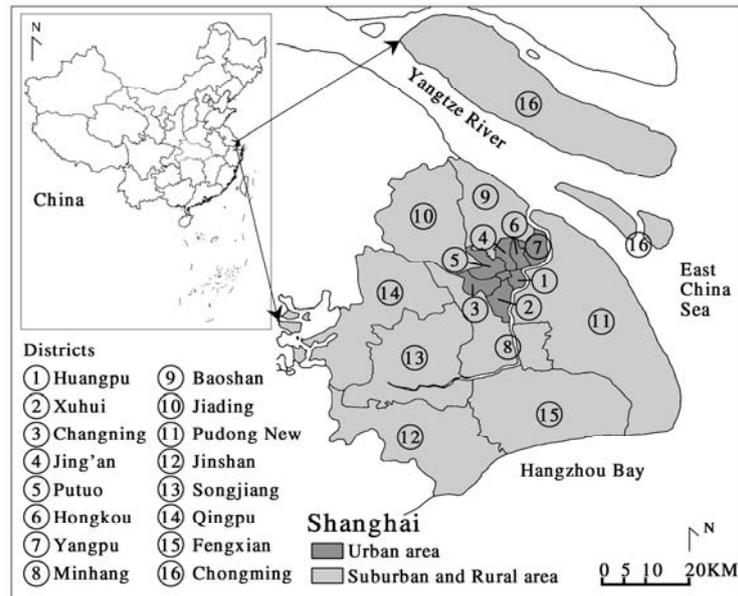


Figure 1. Location of Study Area.

2.2. Identification and Evaluation of Ecological Risks

2.2.1. Flood disaster. With simultaneous rainfall and heat, and centralized storm surges, Shanghai faces a great risk of flood disaster. And the damage could expand in a large area because of the flat terrain, and the lack of valley catchment. Moreover, under the effect of global climate change, rain fall in monsoons in Shanghai is increasing [7, 14]. As a result, flood disaster risk is one of the serious extreme weather events in Shanghai.

In order to avoid the occasional factors in single time rainfall, we adopt Yong Shi's research results [19]. Based on the statistical data, the risk of flood disaster risk was evaluated by rainfall frequency, intensity and affected area.

2.2.2. Sea-source disaster. The sea-source disaster refers to various disasters, such as waves, tsunamis, and seawater intrusions. Global climate change causes temperature rise, which triggered the sea-level rise. The global average sea level witnesses an average annual growth of about 3.1 (2.4 to 3.8) mm from 1993 to 2003 [20]. Sea level of Shanghai have rose by 115mm from 1978 to 2007, far higher than other coastal areas in East China [21]. And seawater intrusion accelerates coastal salinization [22], followed by ecosystem degradation. As a coastal city, Shanghai faces a great threat of soil salinization and erosion [23] caused by sea level rise, even worse, land subsidence will exacerbate the impact of disasters [24].

Although damage scale of waves and tsunamis invasion is usually uncertain [25], through plenty of exist research results, we determined high-risk region within 600 m from the coastline, and the sub-high-risk region of 600-1500 m from the coastline.

2.2.3. Urban heat island effect. In the context of the greenhouse effect and global warming, as Shanghai is one of the several metropolises in China, built-up area is highly concentrated, the urban heat island phenomenon in Shanghai has expanded and strengthened rapidly since 1980s [26], with an annual occurrence rate of 87.8% [27]. With the global climate change, the continuously increasing average temperature [28] and the frequent heat waves [7] will make Shanghai face a more severe heat island effect. During 1961-2013, the high temperature heat waves in central urban area of Shanghai increased 0.8 times every 10 years on average [29]. At the same time, heat island effect promotes climate warming in turn. In the last 50 years, China's urban heat island effect contributes about 30% to

climate warming [30,31]. Thus, the vicious circle of heat island effect and climate change is one of the major problems in the development of metropolises like Shanghai.

The evaluation of urban heat island effect is generally conducted by remote sensing calculation and surface temperature correction method [32]. In this study, research results of Rui Chen [33] was integrated. To mitigate the heat island effect, potential ventilation corridor should be identified. The heat island effect is closely related to the land use type [32]. Vegetation and water areas are effective in controlling heat island effect [34,35]. However, because of the high level of city development in Shanghai, the potential to enlarge urban green space at large area is relatively low. Hence the potential ventilation corridor was identified based on the main rivers and wind direction in Shanghai.

2.2.4. Land subsidence. Although land subsidence is not caused by global climate change, it will exacerbate the impact of related extreme weather events. In Shanghai, due to overdrawn groundwater and highly concentrated built-up areas, land subsidence has lead to the elevation of main urban area lower than the average high tide level of the Huangpu Park Coastal Observation Station in Shanghai for many years. It aggravates the damage of floods, reduces the urban drainage capacity, brings various secondary disasters [36], and directly hinders the sustainable development of the city.

Evaluation of land subsidence generally depends on the detection of relevant data. Here we integrated the research results of Han-Mei Wang [24] to assess the risk and vulnerability of land subsidence. The risk of land subsidence is evaluated according to its occurrence rate and impact extent. The vulnerability is evaluated according to the probability and degree of the damage of suffering area.

2.3. Integration and Analysis of Spatial Data

Spatial database of the above four ecological risks in Shanghai was established, based on ArcGIS 10.2, and integrated with existing research results. Through spatial superposition analysis and spatial dominance technology, spatial variation of overall ecological risks is evaluated. And then green infrastructure strategy plan was developed based on the evaluation results, and responding mitigation and adaptation measures were suggested.

3. Results

3.1. Individual Risk Evaluation

Flood disaster risk (Figure 2. a). Among the districts in Shanghai, Minhang District faces with the lowest flooding risk, while Qingpu District, Songjiang District, Baoshan District, and south part of Pudong New District face with the highest. In the other part of Shanghai, flooding risk is medium.

Sea-source disaster risk (Figure 2. b). As the land subsidence is relatively serious in Pudong New District, the risk of tidal intrusions is aggravated. The high risk area locates in the coastal area south of the Huangpu River Estuary, while the sub-high risk area is distributed across the water and land boundary line between the Yangtze River and the coast.

Urban heat island effect risk (Figure 2. c). Due to the highly concentrated built-up area in the main urban area, high risk of heat island effect is also concentrated here, including Minhang District, Jiading District, south part of Baoshan District, and west part of Pudong New District.

Land subsidence risk (Figure 1. d). High risk of land subsidence is inside and surrounding the main urban area. Eastern coastal areas present a higher risk of land subsidence than the west. And the risk is relatively low at the Yangtze islands.

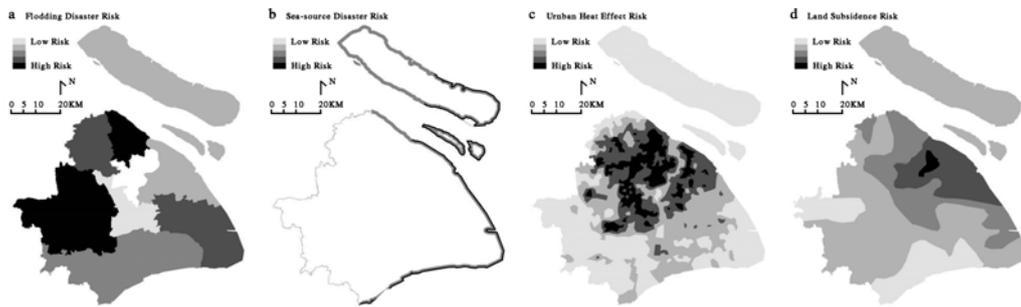


Figure 2. Individual evaluation of climate disaster risk of Shanghai.

3.2. Spatial regionalization planning of Green infrastructure

Based on the individual risk evaluation, through spatial superposition analysis, spatial variation of requirement for coping with global climate change is evaluated, and the planning area is divided into responding regions (Figure 3.). At the same time, for each region, the main ecological risks were presented, and the responding measures (Appendix) of green infrastructure was suggested (Table 1.).

3.2.1. Sea-source disaster region. 1) Sea-source disaster high-risk region is within 600 m from the coastal line. As land subsidence exacerbates the risk of sea-source disaster, these two risks are both key responding objects in this region. It is necessary to enhance the resilience of built-up area, and strengthen vegetation carbon sinks dominated by coastal shelterbelts. 2) Sea-source disaster sub-high-risk region is 600-1500 m from the coastal line. In this region, vegetation carbon sinks should be strengthened, with multifunction of not only controlling soil salinization, but also taken as flood discharge areas to reduce the effect of seawater intrusion.

3.2.2. Intensive built-up region. It is located in Minhang District and the surrounding, where heat island effect and land subsidence is aggravating as a result of dense built-up area. Green infrastructure strategy involves enlarging vegetation carbon sinks especially through vertical greening, setting up flood discharge area, and improving the ventilation function of green space.

3.2.3. Comprehensive region. Located in the main urban area and north part of Pudong New District, it is an important region for urban development. Directly affected by flooding, there is heat island effect and land subsidence, facing with a comprehensive requirement of disaster prevention. Thus in this region, various forms of vegetation carbon storage, ecological restoration of wasteland, multi-scale flood storage system, sustainable storm water management, resilience improvement of built-up area, and maintenance of ventilation corridors are strongly required.

3.2.4. Flood disaster region. 1) Flood disaster high-risk region, located in Qingpu District, Songjiang District, and Baoshan District, is the most important region to control flood disaster in Shanghai. 2) Flood disaster sub-high-risk region, located in Jiading District and south part of Pudong New District, is a less but still important region to control flood disaster. To increase the responding capacity of flood disaster, the current water system should be improved and further multi-scale flood storage system and sustainable storm water management should be established.

3.2.5. Main rivers region. Composed by Huangpu River, Suzhou River, and other main rivers in Shanghai, it is the most important thorough open space in main urban area, playing a significant role as corridors to maintain the ventilation between inside and outside of the urban area. In order to better cope with the urban heat effect, the ventilation function of these main rivers should be improved through riverside buffers and open space.

3.2.6. *Low risk region.* There is relatively low degree of disaster impact in this region. Despite there is no urgent requirement of disaster control, it is meaningful to maintain regional ecological healthy and sustainable development through mitigation measures when coping with global climate change.

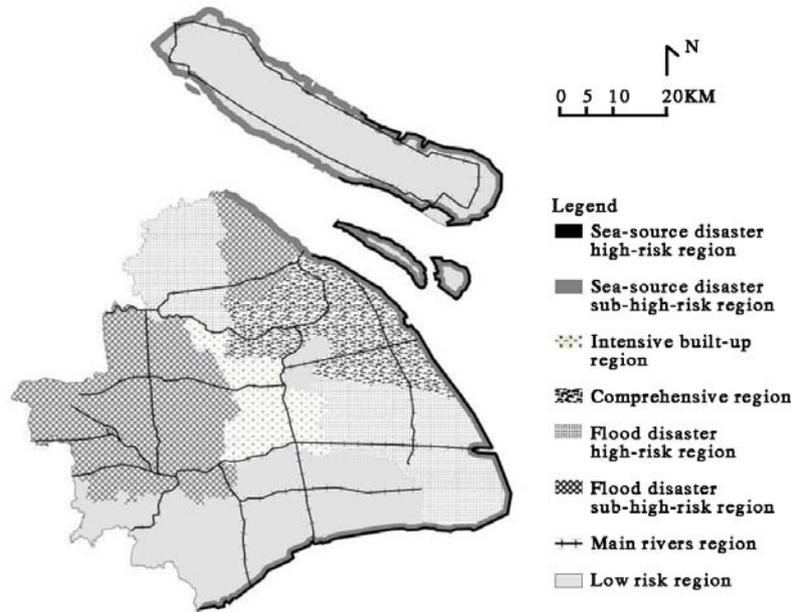


Figure 3. Spatial strategic plan of Green Infrastructure.

Table 1. Main risk types and suggested measures of each green infrastructure strategic region. (Risk types, R1=flood disaster risk, R2=sea-source disaster risk, R3=urban heat effect risk, R4=land subsidence risk. Mitigation measures, M1=vegetation carbon sinks [37,38], M2=ecological restoration of wasteland. Adaptation measures [39,40], A1=multi-level flood storage system [41,42], A2=sustainable storm water management [43], A3=resilience improvement of built-up area [44,45], A4=ventilation corridors [46,47].)

Green Infrastructure Strategic Regions	Risk Types	Responding Measures
Sea-source disaster region	R2, R4	M1, A1, A2, A3
Intensive built-up region	R3, R4	M1, M2, A1, A2, A3, A4
Comprehensive region	R1, R3, R4	M1, M2, A1, A2, A3, A4
Flood disaster high-risk region	R1, R4	M1, A1, A2,
Main rivers region	R3	M1, A4
Low risk region		M1, M2

4. Discussion and conclusion

The results of this study indicated that the methodology we developed in this research provides an approach for regional green infrastructure planning in coping with global climate change. By focusing on identification and evaluation of potential ecological risks caused by global climate change, spatial regionalization planning of green infrastructure involving with measures both mitigation and adaptation ones can be developed. Except for directly disaster control, it allows the fundamental mitigation of climate change which is crucial for long term sustainable development, however, has always been ignored among exist research results [16, 17].

In the case study of Shanghai, China, we identified four ecological risks, seven responding regions, and six responding measures for green infrastructure focusing on global climate change. Although it is just the first step for coping with global climate change, this methodology combining ecological risk

evaluation and spatial regionalization planning, provides a basis for a further comprehensive and operational tool for green infrastructure planning and implementation. In the practice of current sponge city construction in China, the emphasis of coping with climate change through green infrastructure will contribute to sustainable development.

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Appendix. Responding measures toward global climate change

Measures	Principles	Targeted risks	Approaches
Mitigation measures			
M1. Vegetation carbon sinks[37,38]	-To enhance the capacity of vegetation carbon pool; -To improve other ecosystem services;	-All of the identified 4 risks, esp. sea-source disaster, and heat island effect	-To expand vegetation cover by the means of coastal shelter forest, urban green space, and vertical greening; -To increase vegetation greenness by multi-layered plant communities.
M2. Ecological restoration of wasteland [39, 40]	-To improve various ecosystem services.	-All of the identified 4 risks , esp. flood disaster	-Soil restoration provides foundation for vegetation carbon storage; -Wetland Restoration contributes to flood disaster control.
Adaptation measures			
A1. Multi-scale flood storage system [41,42]	-To enhance the responding ability towards extreme rainfall; -To promote the surface infiltration and underground water recharge;	-Flood disaster, -Land subsidence -Sea-source disaster	-To optimize city spatial pattern; -To explore flood storage cultivated land and wood land surrounding urban area on city scale, urban parks on district scale, ponds and wetland on town scale, and greening on the community scale.
A2. Sustainable storm water management [43]	-To utilize rainwater resource; -To return rainwater back to ecosystem.	-Flood disaster -Urban heat island effect	-Locally rainwater infiltration, through the non-concreted ground to facilitate surface water infiltration and groundwater recharge; -Separation drainage system of rainwater and sewage, to promote respective utilization and treatment; -Decentralized processing, to focus on sub-systems of storm water management at a smaller scale.
A3. Resilience improvement of built-up area [44,45]	-To improve building standard of disaster prevention; -To increase resilience of built-up area.	-Flood disaster, - Sea-source disaster, -Land subsidence	-Comprehensive planning and design to combine with the construction of vegetation carbon storage, multi-scale flood storage system, and other ecological measures, to enhance disaster prevention capabilities of built-up area.

A4. Ventilation corridors [46,47]	-To Promote ventilation between urban and rural area; -To reduce temperature through vegetation and waters areas	-Urban heat island effect	-Along both sides of rivers, to maintain buffer area with a width of 100-200 m in rural area, and 50-100 m in urban area with a low building density and certain proportion of green belt.
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