POTENTIAL IMPACTS OF CLIMATE CHANGE IN RAPIDLY URBANIZING REGIONS-A CASE STUDY IN HANGZHOU (CHINA) REGION

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Abstract

Climate change is expected to be a major driving force of landscape in the coming decades. It will have a multitude of potential impacts that vary in intensity and effect according to region and sector. In the context of global warming, the climate of China has changed significantly in the recent 100 years. According to "China's National Climate Changes Programme", there are mainly five aspects about the fact of climate changes in China: Firstly, the annual average temperature increases; Secondly, regional precipitations fluctuate somehow largely; Thirdly, the frequency of extreme weather events increase in speed and in intensity; Fourthly, sea level rises; Fifthly, mountain glaciers retreat rapidly, and the trend accelerates. The reason of climate change in China caused by human activities is mainly the irrational land use, which chiefly results in the rapid industrialization and urbanization process. This paper explores the potential impacts of climate change for the Hangzhou region. The aim of this paper is to conclude on the one hand some of Hangzhou sensitivities in relation to the expected primary effects of climate change. On the other hand a reflection is made on methodology to formulate preconditions as a scientific basis for further research by design on integrated adaptation options for the future spatial developments in function to upgrade Hangzhou resilience in relation to climate change challenges.

Keywords

Climate change, Impact, Exposure, Adaptation, Resilience

1. Introduction

Since the 1980s, global climate change, characterized by global warming, has a great deal of attention from governments, international societies and scientific researchers. Climate change will have a multitude of potential impacts that vary in intensity and effect according to region and sector (e.g. EEA, 2008). In the context of global warming, the climate of China has changed significantly in the recent 100 years. The reason of climate change in China caused by human activities is mainly the irrational land use, which chiefly results in the rapid industrialization and urbanization process (Zhang et al., 2009).

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This paper examines the impacts of climate change in China through a study of Hangzhou region, with a focus on an integrated and comprehensive assessment. The object of the regional analysis and assessments is to provide the basis for understanding where, how, and why certain regions are affected by climate change. The following sections apply the indicator-based assessment method to explore impacts of climate change relevant for spatial development in Hangzhou region.

The framework for this impact assessment was built upon the concept suggested by the Intergovernmental Panel on Climate Change (IPCC) (2007), Fussel and Klein (2006) and Rannow et al., (2010). Impacts of climate change are a product of exposure and sensitivity to climate stimuli. In this context exposure describes the nature and degree to which a system is exposed to significant climatic variations, while sensitivity is the degree to which a system can be affected, either adversely or beneficially, by climate variability or change (IPCC, 2007).

2. Study area

Hangzhou locates along the southeast coast of China. The prefecture-level region of Hangzhou extends from the border with the hilly-country Anhui Province in the west, to the flat-land near Hangzhou Bay in the east. As a core city of the Yangtze River Delta, Hangzhou has a position on the Hangzhou Bay 180 kilometres southwest of Shanghai that gives it economic power. It has been one of the most renowned and prosperous cities of China for much of the last 1,000 years. The total area of Hangzhou region is 16,596 km^2 with a population of 8.70 million. The urban area of Hangzhou (Hangzhou city) and five counties (county-level cities)—Fuyang, Lin'an, Jiande, Tonglu, and Chun'an are under the jurisdiction of Hangzhou (Figure 1, Table 1).

Figure 1. Location of Hangzhou Region

Table 1. Population and Land Areas of Six Districts in Hangzhou Region, 2010 (Source: Hangzhou Statistical Yearbook, 2011; the sixth China's National Population Census, 2010)

	Hangzhou city	**Lin'an city**	**Fuyang city**	**Tonglu county**	**Chun'an county**	**Jiande city**
Land area(km^2)	3068	3124	1808	1780	4452	2364
Total population(1000)	6242	566.7	717.7	406.4	336.8	430.8

The recent research show that the main tendencies of climate changes in Hangzhou are as follows: (a) significant warming of the winter; (b) extreme heat during the summer and the autumn; (c) an increase of precipitation; (d) more frequent typhoons (Hangzhou Meteorological Bureau, 2011). In terms of the urbanization impact on local climate change, the average surface temperature has increased by about 0.26℃ per decade from the 1960s to now in Hangzhou. Since the 1990s, when Hangzhou phased into the high-speed urbanization process, the degree of increase in temperature was higher. A historical reference is listed for each impact, substantiating it (Table 2).

The projections of climate change for the 21st century using the regional climate models indicate that, in 2071-2100, the surface air temperature in Hangzhou region will continue to increase (Figure 2).

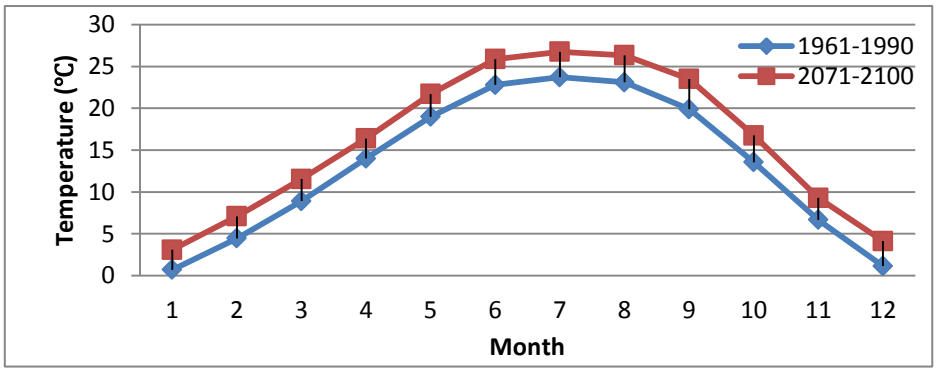

Figure 2. Comparison of Average Monthly Temperatures between 1961-1990 and 2071-2100 by the Regional Climate Model RegCM3 (Source: China's National Climate Centre)

Table 2. Climate Change Impact Table for Hangzhou Region (Source: own processing according to Hangzhou Meteorological Annals, Hangzhou Municipal Annals and Zhu et al., 2008)

exposure	Impact	Historical Reference	Adaptive Capacity in place
	Caused by extreme event:		
Temperature	Fluvial floods	Abundant rainfall events in summer (e.g. July 2002, June 1999, June 1996, May 1995, June 1994, June and July 1993,…, June 1901) induced several severe floods from rivers through history	Floods forecaster system in place
Precipitation			
Evaporation			
Storminess	Pluvial floods	Local floods in cities as a consequence of heavy showers in combination with an inadequate sewage system and no room for water(e.g. July 1997,Sept 1989,…, 1931)	
Drought			
Frost	Drought	Abundant drought events in summer, autumn and winter (e.g. July 2004, July-Oct 2003, March-Sept 2000, Dec 1996-June 1997, July 1994, Sept 1990, July-Dec 1988, Jan-June 1986, May-Oct 1967)	Drought forecaster system in place
Snow			
	Typhoon	Several typhoons are documented through history (e.g. Oct 2007, August 1997, August 1988, …, 1910)	Disaster weather forecaster system
	Heat waves	Several heat waves are documented through history in the summer (June-Sept 2003, Sept 1995, July 1995)	Awareness-warnings broadcasted on radio and television
	Cold waves	Several cold waves are documented through history in the winter (e.g. Feb 2008, March 1998, Jan 1996, Jan-Feb 1984, Jan 1977,…, 1916)	Awareness-warnings broadcasted on radio and television
	Hail and storm	Abundant hails and storms (e.g. June 2006, May 1991, April 1986, April 1977, April 1972, April 1962)	Disaster weather forecaster system
	Urban heat island effects	It is assumed that the historical cores and nucleuses are potential hotspots for UHIe.	Research in progress
	Not included effects caused by extreme event:		
	Summer smog Winter smog Ozone Forest fires	Several warming per year	Monitor system in place and broadcastings to raise awareness
	Caused by slow changes:		
	Water scarcity groundwater; surface water; rainwater; production water	Measurements show that Hangzhou region has yearly 2601m3 of water per person. This is a little less than national average level.	Monitor system in place and awareness raised.
	Loss of species and biodiversity	Rare species are being endangered in Hangzhou region.	Systematically monitored and awareness raised
	Increased Erosion (loss of soil)	Each year 5 million tons of soil erodes by water from 1980's.	Systematically monitored and awareness raised
	Other not included effects		
	Increased Energy demand (…)		

3. Materials and Method

3.1 Identification of climate change impacts relevant for spatial analysis

To focus on the spatial analysis a multitude of impacts of climate change were examined. The impacts were analyses in terms of their relevance for spatial development. Eight types of climate change impact of primary relevance for spatial development on a regional level in Hangzhou (large river floods, heavy rain and flash floods, heat waves, mass movement, forest fires, destruction of infrastructure, loss of soil by water erosion and loss of species and biodiversity) were identified. They are grouped into impacts caused by extreme weather events and impacts caused by slow climatic changes.

3.2 Assessment framework

The assessment framework defined the way the assessment procedure for every impact is organised (Figure 3). Each indicator provides useful information about single aspects of climate change impacts, but absolute numbers provided by indicators are only of limited value for an integrated assessment of impacts (Metzger et al., 2008). Three assessment classes (or categorical values) were used. Every indicator was classified to represent low (1), medium (2) and high (3) risks or low (1), medium (2) and high (3) sensitivity status. Assessment matrices were used to join and reclassify the indicators and provide a common index. This procedure provides comparable results for every impact regardless of the number of indicators used for the assessment. This classification remains coarse and thus emphasises the qualitative character of the assessment results. For the reclassification of exposure and sensitivity indicators the assessment matrix shown in Figure 3 was used.

The application of this framework for every impact allowed a comprehensive evaluation and comparison of the results. Figure 3 presents a scheme of the applied approach. In Table 4 and Table 6 the indicators and input data for the assessment are listed.

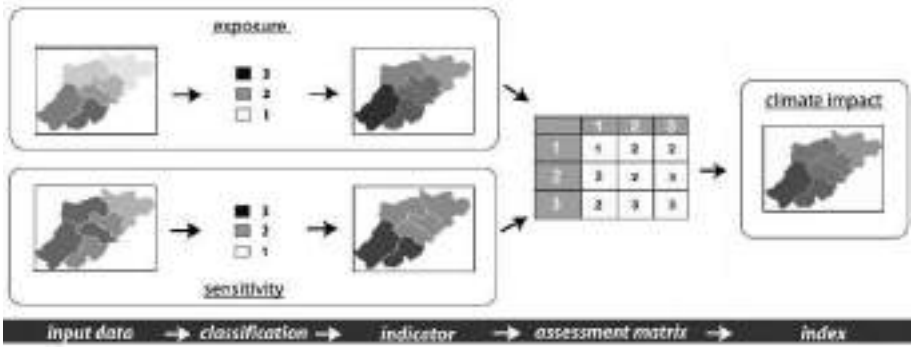

Figure 3. Assessment Framework for the Indicator Based Assessment of Climate Change Impacts (Source: in accordance with Rannow et al., 2010)

3.2.1 Assessing exposure

In order to calculate and assess indicators for regional exposure to climate stimuli the data sets from Hangzhou Meteorological Annals were extracted. Climatic parameters included information on precipitation (mm/month) in rainy season, days/year with heavy rain (Daily precipitation>50mm), hot days/year (T_{max} >37℃), percentage of summer months with low precipitation, Precipitation in month with erosion and yearly mean temperature (Table 3).

Table 3. Available Input Data of Six Districts in Hangzhou Region, 1986-2005 (Source: own processing according to Hangzhou Meteorological Annals)

	Hangzhou city	**Lin'an city**	**Fuyang city**	**Tonglu county**	**Chun'an county**	**Jiande city**
Precipitation in rainy season	277.4	283.2	284.6	299.5	332.9	332.4
Days/year with heavy rain (Daily precipitation>50mm)	3.70d	3.75d	4.00d	3.65d	5.20d	4.75d
Hot days/year (T_{max} >37℃)	8.2d	13.55d	10.8d	14.8d	14.65d	9.3d
Percentage of summer months with low precipitation	45%	35%	40%	65%	65%	55%
Precipitation in month with erosion	303.5mm	293.0mm	315.0mm	328.5mm	375.1mm	355.8mm
Yearly mean temperature	16.45℃	15.8℃	16.3℃	16.0℃	17.4℃	17.0℃

The results were averaged for each administrative district in Hangzhou region. The results are stored as a database with each administrative region referring to a database record. The records are referenced for further mapping and regional assessment.

Following the general framework in Figure 3 every climatic parameter that was used as an exposure indicator was classified into low, medium or high risks (Table 4).

Table 4. Input Data and Classification Used to Assess the Exposure to Climate Change Stimuli on the Base of the Information from 1986 to 2005. (Source: in accordance with Rannow et al., 2010)

Impact	**Available input data**	**classification**	
Caused by extreme events			
Large river floods	Precipitation in rainy season	<250mm 250-300mm >300mm	Low Medium High

	Days/year with heavy rain (Daily precipitation >50mm)	<4d 4-5d >5d	Low Medium High
Heavy rain and flash floods	Days/year with heavy rain (Daily precipitation>50mm)	<4d 4-5d >5d	Low Medium High
Heat waves	Hot days/year (T_{max} >37◦C)	<9d 9-12d >12d	Low Medium High
Mass movement	Days/year with heavy rain (Daily precipitation>50mm)	<4d 4-5d >5d	Low Medium High
Forest fires	Hot days/year (T_{max} >37℃) Summer months with low precipitation	<9d 9-12d >12d <40% 40-60% >60%	Low Medium High Low Medium High
Destruction of infrastructure	Days/year with heavy rain (Daily precipitation>50mm) Hot days/year (T_{max} >37℃)	<4d 4-5d >5d <9d 9-12d >12d	Low Medium High Low Medium High
Caused by slow changes			
Loss of soil by water erosion	Days/year with heavy rain (Daily precipitation>50mm) Precipitation in month with erosion	<4d 4-5d >5d <300mm 300-350mm >350mm	Low Medium High Low Medium High
Loss of species and biodiversity	Yearly mean temperature	<16℃ 16-17℃ >17℃	Low Medium High

3.2.2 Assessing sensitivity

Sensitivity to climate stimuli is determined by endogenous factors and main regional characteristics. The interdependencies (or the interplay) of these bio-physical, social and political factors and processes influence the degree of sensitivity (Rannow et al., 2010). Therefore, indicators for the main social and structural factors are needed to model sensitivity.

Most data were selected from the public databases of the Hangzhou Statistical Office (Table 5). The data cover aspects of (a) land use (e.g. percentage of water erosion area, forest or area protected by nature conservation law); (b) social issues (e.g. percentage of people older than 65 years); (c) built environment or technical infrastructure (e.g. percentage of area covered by streets, main roads, etc.) and (d) hazard risks (e.g. percentage of flood year, assessment of landslide hazards).

Following the general framework in Figure 3 all sensitivity indicators were classified using three classes (Table 6). The limits for each class were obtained by expert assessment of the available input data or based on the literature (e.g. Rannow et al., 2010; Yu et al., 2011).

Table 5. Available Input Data of Six Distracts in Hangzhou Region (Source: own calculation from Hangzhou Meteorological Annals 1986-2005, Zhejiang Construction Information Port, 2007; Hangzhou Statistical Yearbook, 2011; Hangzhou Forestry and Water Conservancy Bureau, 2001, 2010; Hangzhou Environmental Protection Bureau, 2004; Huang et al., 2008, Yu et al., 2011)

	Hangzhou city	**Lin'an city**	**Fuyang city**	**Tonglu county**	**Chun'an county**	**Jiande city**
Percentage of flood year	60%	64%	52%	57%	64%	67%
Percentage of built-up area	11.23%	0.37%	1.37%	0.82%	0.21%	0.33%
Percentage of people older than 65 years	17.5%	16.5%	15.5%	17%	15.8%	17.5%
Assessment of landslide hazard risk	Low	High	Medium	High	Medium	High
Percentage of forest	28.45%	77.76%	63.18%	71.43%	75.19%	75.25%
Percentage of area covered by streets and other infrastructure Fraction of highway	No data available	No data available	No data available	No data available	No data available	No data available
Percentage of water erosion area	6.37%	20.05%	24.48%	18.97%	32.92%	21.02%
Percentage of area protected by nature conservation law	6.05%	8.09%	1.07%	2.63%	21.35%	9.05%

Table 6. Input Data and Classification Used to Assess the Sensitivity to Climate Change Stimuli on the Basis of Different Data Sources (Source: in accordance with Rannow et al., 2010)

Impact	Optimal input data	Available input data	Data source	Classification	
Caused by extreme events					
Large river floods	Area impacted by dam failure	Percentage of flood year	Hangzhou Meteorological Annals,1986-2005	≤49.9% 50–59.9% ≥60%	Low Medium High
Heavy rain and flash floods	Percentage of paved surface	Percentage of built-up area	Zhejiang Construction Information Port, 2007	≤14.9% 15–29.9% ≥30%	Low Medium High
Heat waves	Percentage of population sensitive to heat waves Area sensitive due to urban heat island effects	Percentage of people older than 65 years Percentage of built-up area	Hangzhou Statistical Yearbook, 2011 Zhejiang Construction Information Port, 2007	≤18.9% 19–20.9% ≥21% ≤14.9% 15–29.9% ≥30%	Low Medium High Low Medium High
Mass movement	Area sensitive to mass movements	Assessment of landslide hazard risk	Bu et al.,2011	Low hazard Medium hazard Major hazard	Low Medium High
Forest fires	Area of forest cover sensitive to forest fire	Percentage of forest	Hangzhou Forestry and Water Conservancy Bureau, 2010	≤19.9% 20–39.9% ≥40%	Low Medium High
Destruction of infrastructure	Amount of infrastructure Importance of infrastructure	Percentage of area covered by streets and other infrastructure Fraction of highway	No data available No data available	≤4.9% 5–9.9% ≥10% ≤99.9m/km2 100–199.9m/km2 ≥200m/km2	Low Medium High Low Medium High
Caused by slow changes					
Loss of soil by water erosion	Area sensitive to water erosion	Percentage of water erosion area	Hangzhou Forestry and Water Conservancy Bureau, 2001	≤14.9% 15–24.9% ≥25%	Low Medium High
Loss of special and biodiversity	Number of species and habitats endangered by climate change	Percentage of area protected by nature conservation law	Hangzhou Environmental Protection Bureau, 2004	≤6.9% 7–13.9% ≥14%	Low Medium High

3.2.3 Assessing impacts

After exposure indices and sensitivity indices were quantified, they were merged to represent an index for each impact of climate change. The result was documented in maps showing the spatial distribution of every index for an impact of climate change at local level. In this way, maps of impacts of climate change in Hangzhou were created.

4. Results

The results from the impact assessment as well as the input data on exposure and sensitivity are presented below.

4.1 Exposure

Based on the data from Hangzhou Meteorological Annals, the map of local exposure to climate change risks in recently past is represented in Figure 4. The map shows that Chun'an county is the highest risk district. In addition, some hilly area like Jiangde city, Tonglu county and Fuyang city also show considerable exposure. And the analysis indicates most districts are exposed to heat waves. This is due to extreme heat of summer and a high grade of urbanisation aggravating heat wave events.

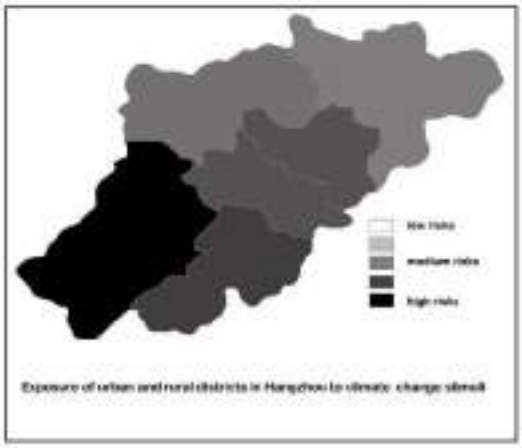

Figure 4. Local Exposure to Climate Change Risks

4.2 Sensitivity

Based on the indicators derived from social and economical statistics the sensitivity of six districts was analysed for all eight impacts. The results are documented in maps for every impact.

Most districts are sensitive to forest fires. This is due to the mountain region with abundance of forest resources. Also the sensitivity towards river floods is high.

This is related to the high frequency of flood year in all of districts of Hangzhou region. For destruction of infrastructure no sensitivity indicator could be obtained because of missing data.

After the assessment for each sensitivity index in isolation the results for each district were summarised. The map of the accumulated sensitivity indices for all impacts analysed is shown in Figure 5. Jiangde city, Lin'an city and Chun'an county are the most sensitive to the eight impacts analysed. The comparison of sensitivity indices gave a first indication of areas at risk of negative impacts of climate change. This status quo analysis provides information about areas where resilience to climate change needs to be enhanced.

Figure 5. Local Sensitivity to Impacts of Climate Change

4.3 Impacts

For the assessment and spatial analysis of each climate change induced impact the relevant indices of sensitivity and exposure were compared. Individual impacts show differing spatial distributions (Figure 6).

The analysis indicates a concentration of major impacts on Chun'an county, where a major climatic change stimulus meets high sensitivity. The impact of large river floods is concentrated on Chun'an county and Jiande city. The risk of forest fires is mostly relevant for Tonglu county and Chun'an county. The impact of heat waves is strongest in western hilly area, but north-eastern flatland is especially sensitive because of its high percentage of high urbanized areas.

The increase of temperature shows special relevance for the high value nature conservation areas and the highly urbanised centres. The risk of soil erosion by water is high to Chun'an county with abundance of water resources. The impact of heavy rain and flash floods is generally higher for hilly area than flatland. The potential mass movements are mostly relevant for all mountain ranges in central

and southern Hangzhou region. Lacking a qualified indicator for sensitivity, the destruction of infrastructure is solely influenced by heavy rain days and hot days. Nevertheless, Chun'an county is indicated as the location of major exposure.

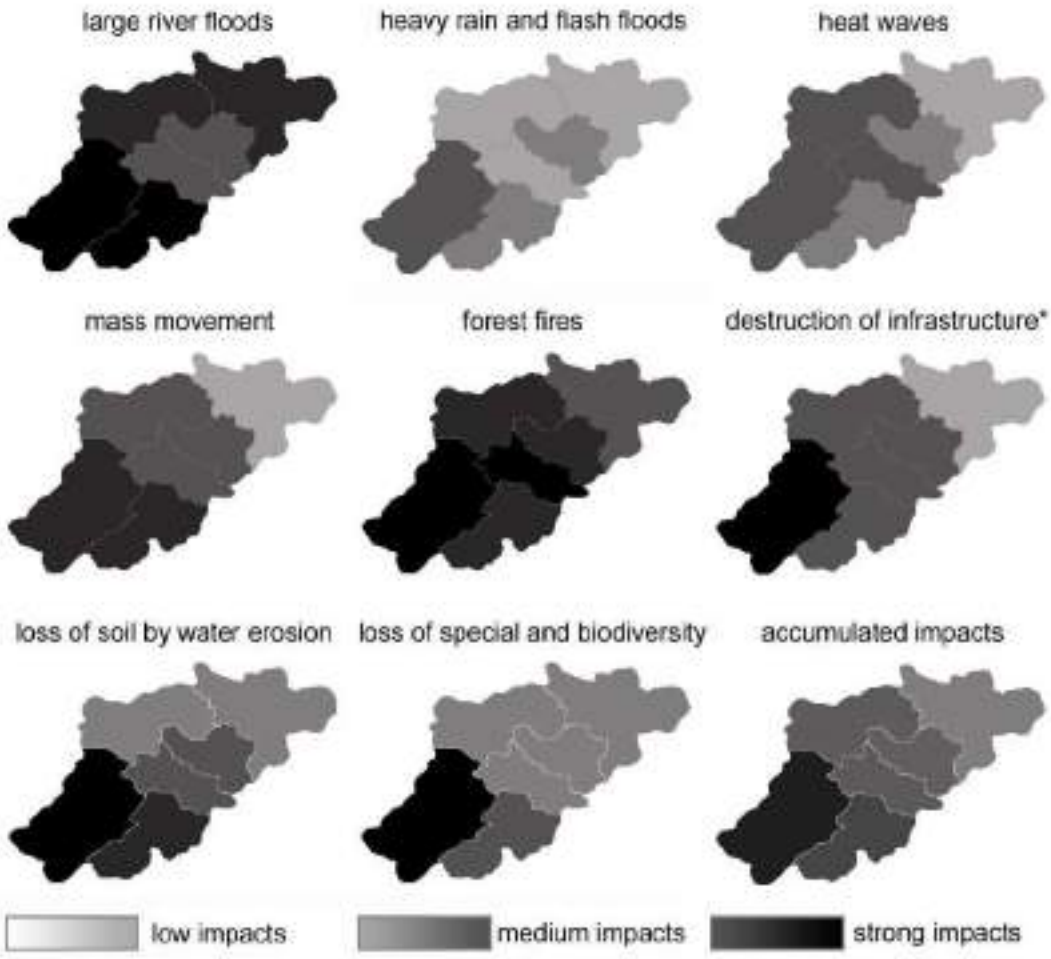

Figure 6. Results of the Indicator Based Assessment of Climate Change Induced Impacts.
*Lacking a qualified indicator for sensitivity, the destruction of infrastructure is solely influenced by changes in heavy rain days and hot days.

Based on assessing exposure and sensitivity, this research represents a picture of the impacts of climate change in six districts of Hangzhou region. In sum, the impacts of climate change from northeast to southwest had an increasing tendency. The hilly-country like Chun'an county, Jiangde city, and so on, is relative high risk.

4.4 Gaps and future research

It is very hard to describe the vulnerability without knowing which kinds of impacts are expected. In the case of Germany, Rannow et al. look in for available input data about potential impacts of climate change. However, there is not enough available data in Hangzhou/China. For example, based on the regional climate change model RegCM3[4], China's national climate centre only provides to date the data on temperature (T_{max}, T_{min}, T_{mean}) and average amount of precipitation from 2071 to 2100 for the IPCC scenarios A2[5]. But other data is still forthcoming, such as the information on the average number of summer or hot days, the average number of frost days and the average number of heavy precipitation days for the IPCC scenarios A2 and on the relative ones for the IPCC scenarios A1B[6] and B1[7]. In the present study, it is hard to assess and spatially analyse potential impacts of climate change without sufficient available input data to calculate and assess indicators for exposure to future climate stimuli.

Another gap which shall be required to be addressed is the urbanization stress on local climate change in Hangzhou region. Recently research shows that there is an objective dynamic coupling relationship between urbanization and regional climate change in China, which consists of the multi-level network effects of climate change on urban "social-economic-nature" complex ecosystems, the pressure of social-economic development, energy requirement and urban land sprawl in the process of urbanization on regional climate change (Fang, 1989; Huang, Fang, 2003; Wang, 2010). Reducing the negative impacts of climate change and increasing the resilience of physical and social structures within the rapidly urbanizing regions requires pro-active adaptation strategies. Understanding the impacts of climate change on land uses and the urbanization stress on local climate change is an essential basis for the development and application of adaptation strategies.

It is also necessary to enhance the database for the input data and provide more detailed information. In addition, further evaluation of the appropriate scale with regard to input data and assessment result is needed (Rannow et al., 2010).

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4 RegCM3 is a 3-dimensional, sigma-coordinate, primitive equation regional climate model.

5 The IPCC scenario A2 describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines.

6 The IPCC scenario A1B is one of the three A1 groups and its technological emphasis is a balance across all sources.

7 The IPCC scenario B1describes a convergent world with the same global population, that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource-efficient technologies.

Even though there are further improvements to be made, this study enables a primary understanding of where, how and why certain areas in Hangzhou region are effected by climate change. This information is essential for adaptation activities.

Furthermore, additional research will address the following issues about Hangzhou region in the near future: a) An assessment and spatial analysis for exposure to future climate stimuli; b) Identifying potential "hot-spots" of climate change by means of GIS-based overlay technique; c) Identification of interaction between urbanization and local change climate.

5. Discussion and conclusion

What is adaptation to climate change? Figure 7 shows vulnerability is determined by the exposure to primary effects of climate change, the sensitivity of structures of human activity and the adaptive capacity of systems under stress. Exposure and sensitivity determined the impacts of climate change; these are the secondary effects of climate change. As a reminder, the social ad spatial characteristics of the system are a function of the sensitivity, i.e. factors and driving forces. These are the socioeconomic, environmental, demographic and political factors, which are in turn controlled by drivers, such as the degree of economic diversification, the degree of education, etc. (Füssel and Klein, 2006) Mitigation enables us to adapt the exposure side, while adaptation enables us to adapt the sensitivity of a system.

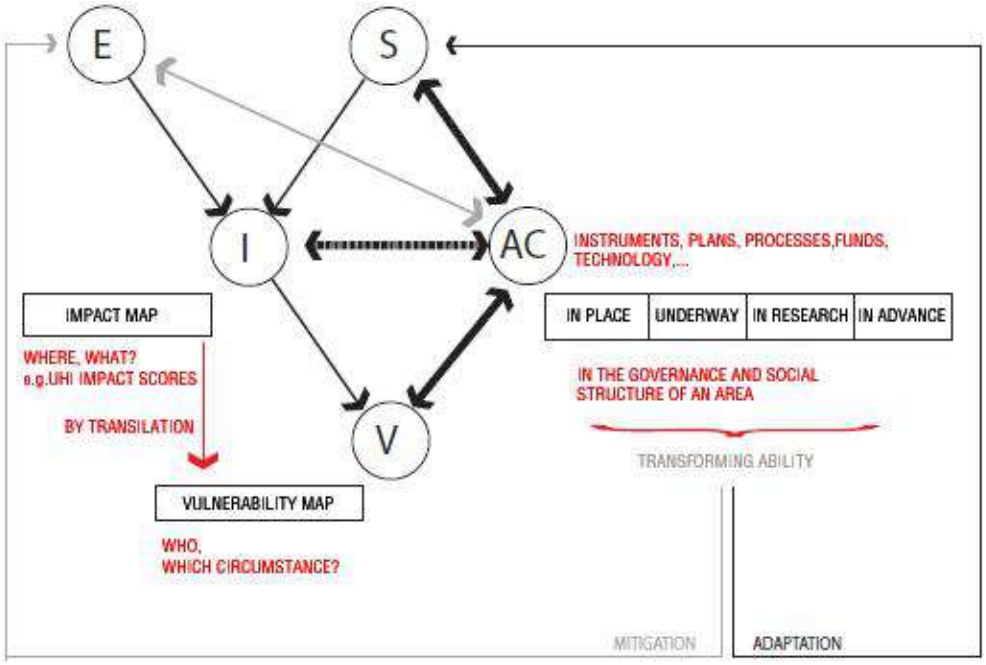

Figure 7. Integrated Vulnerability/Resilience Framework (Source: Verhofstede, 2012)

Hangzhou municipal government to date mainly focuses on mitigation of climate change by reducing greenhouse-gas emissions and enhancing sinks. According to "Hangzhou development planning of Low Carbon City", there are some strategies to meet the challenges of climate change. These strategies are: (a) to establish Low-carbon industries Agglomeration district; (b) to promote clean energy; (c) to build ecological zones and to enhance sinks; (d) to optimize the urban function; (e) to promote Low-carbon buildings; (f) to develop public transport. Furthermore, Hangzhou's adaptive capacity in place to climate change mainly emphasizes on forecaster system and monitor system in place. It has to date not been sufficiently considered to integrate adaptation options into planning procedures in Hangzhou. In face with both climate change pressure and population pressure, it is necessary to improve adaptive capacity of climate change in Chinese cities, Hangzhou included. Both adaptation and mitigation are now essential. There are researches which try to lead to the implementation of new planning strategies in Europe, while there is still a long way to go in China.

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