

Drought Crisis: A Path-analysis in Beijing-Tianjin-Hebei Region

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Abstract. Urban drought has seriously hindered the sustainable development. Reducing urban drought vulnerability (UDV) entails more effective and systematic strategies. We discussed the ways to reduce UDV for government in the Beijing-Tianjin-Hebei (BTH) region from building vulnerability assessment model suitable for urban system, correlation analysis and path analysis. Results indicated that (1) the drought vulnerability of 13 cities in the BTH region fluctuated continuously from 1987 to 2016; (2) the factors affecting UDV are systemic and have the regional characteristic; and (3) the path analysis provide the specific directions for government. This study provides a theoretical basis for the government to manage drought risk.

1. Introduction

Drought is a serious natural disaster characterized by water deficit, which hinders sustainable urban development. Global economic losses caused by droughts are estimated at US\$ 6–8 billion per year, which is significantly more than that from other meteorological disasters (Desbureaux and Rodella, 2019; Smith and Katz, 2013). As the shelter of population and various economic activities, cities are especially vulnerable to drought disasters. Urban drought has become an extremely aggressive natural phenomenon that has direct and indirect impacts on a city's wellbeing, including the lives of residents and the development of economic activities (Zhang et al., 2019).

Many scholars had noticed the urgency of the drought and tried to mitigate urban drought. Studies in urban drought focused on urban water management and water scarcity. For “water management”, these studies are qualitatively described based on interviews and workshops with the inhabitants using social practices (Sletto et al., 2019; Workalemahu et al., 2019). Herslund and Mguni (2019) examined the water management practices of households based on interviews and workshops with the inhabitants at two case sites. For “water scarcity”, the modeling, prediction, and factor analysis of water scarcity have been extensively discussed (Clercq et al., 2018; Mashhadi Ali et al., 2017). Sharvelle et al. (2017) developed and demonstrated an Integrated Urban Water Model (IUWM) with the input data: land cover, imperviousness, population, households, daily climate and so on. However, previous studies were limited in system and comprehensiveness for research perspective.

The concept of vulnerability would give us a new perspective on drought risk reduction. Current studies have emphasized the transition from “crisis management” to “risk management” for disasters mitigation (Sharvelle et al., 2017). For drought vulnerability, many studies had provided various study frameworks and indicators. However, they are mostly concentrated in agriculture drought vulnerability (Hannaford, 2018). Rainfall variability, terrain, agricultural share of GDP, illiteracy rate and infrastructure are widely used in agricultural drought vulnerability (Li et al., 2016; Shen et al., 2019). It must be admitted that drought vulnerability studies at the urban scale are more referential and accurate. And based on literature review, we propose that urban drought vulnerability refers to the extent to which the balance of urban water demand and supply is disrupted by drought and the city is



unable to cope with. Due to the lack of relevant studies, most cities are poor in the basic knowledge of mitigating the adverse effects and risks of drought, and even lack the adaptive capacity to urban drought.

Therefore, this study is to provide the government with specific knowledge to manage the drought and reduce the adverse of urban drought. Based on this purpose, this study discusses urban drought vulnerability from the following aspects: 1) calculation of urban drought vulnerability through the research framework suitable for urban systems, 2) correlation analysis between indicators, and 3) path analysis based on structural equation model. This study would provide specific theoretical basis to understand how to reduce urban drought vulnerability and ease negative effects of urban drought.

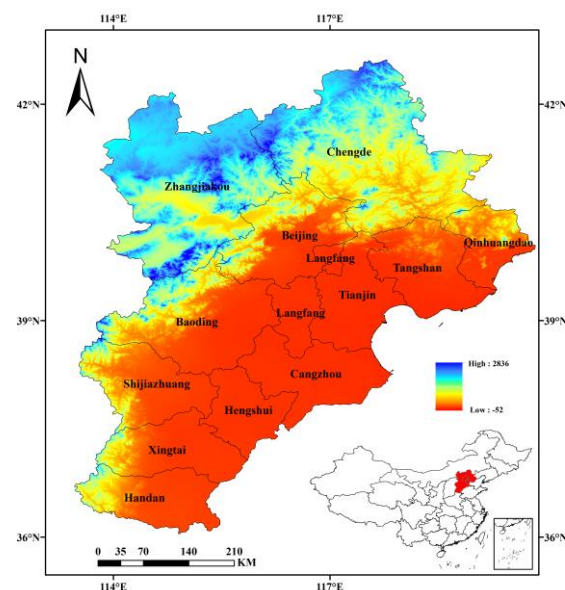


Figure 1. Hypsometric map of the Beijing-Tianjin-Hebei (BTH) region

2. Study Area

The Beijing-Tianjin-Hebei (BTH) region ($36^{\circ}01'N - 42^{\circ}37'N$, $113^{\circ}04'E - 119^{\circ}53'E$, Fig.1) is formed by two municipalities, Beijing and Tianjin, and 11 cities of the Hebei Province. The BTH region is the driving force of China's economic development and policy implementation. The BTH region has an area of 218,000 km^2 . In 2018, the GDP of the BTH region reached 8.5 trillion yuan. Since the implementation of Beijing-Tianjin-Hebei integration policy in 2014, the economy of BTH has developed rapidly and life services have become more convenient.

However, the BTH region is faced with the serious problem of drought. BTH region are more severe drought event happened in 1992, 1993, 1997, 1999, 2000, 2014. In addition, the water resources have been overexploited due to the increasing demand for water by economic and population growth. For example, the utilization of shallow groundwater is 130%.

3. Methodology

3.1 Urban Drought Vulnerability Model

3.1.1. Index selection

According to IPCC, we considered vulnerability as a function of sensitivity, adaptive capacity and exposure. In order to select indicators legitimately, we reviewed lots of studies related to water management, water shortage and agricultural drought vulnerability. Based on literature review and

regional characteristics, we selected 16 indicators suitable for the urban system, shown in Table X. Particularly, we calculated drought severity (DS) using SPI index. We chose a 12-month SPI index, which is usually tied to streamflows, reservoir levels, and even groundwater levels at longer timescales.

Table 1. Indicators of urban drought vulnerability.

Indicator	Category
Population density	Exposure
Built-up area	Exposure
Drought severity	Exposure
High temperature days	Exposure
Per GDP water consumption growth rate	Sensitivity
Unemployment rate	Sensitivity
Area of paved roads	Sensitivity
Gross of domestic product of secondary and tertiary industries	Sensitivity
Fixed investments	Sensitivity
Passenger traffic	Sensitivity
Coverage rate of afforestation in developed area	Adaptive capacity
Number of beds in health care institutions	Adaptive capacity
Production capacity of urban tap water	Adaptive capacity
Per capita disposable income	Adaptive capacity
Number of students enrolled in institutions of higher education	Adaptive capacity
Public Budget Expenditure	Adaptive capacity

3.1.2. Calculation of weighting

The weight of indicators can be divided into objective and subjective weighting. Subjective weighting depends on subjective factors, and the amount of qualitative data is larger than that of quantitative data. This study selected principal component analysis (PCA) to define weighting.

Weight is defined according to the rotated factor load matrix: first, square factor load is calculated; Then, the weighted factor internal load is calculated by dividing the square factor load by the variance proportion of each factor interpretation. Then, the weighted load between factors is obtained by dividing the weighted load within factors by the proportion of variance of each factor interpretation to the total accumulated variance of each factor. Finally, determine the final weight.

Exposure, sensitivity and adaptive capacity were calculated using the following formula:

$$E \text{ or } S \text{ or } A = \sum_{i=1}^n y_{ij} w_j \quad (1)$$

Following methods from IPCC, urban drought vulnerability (UDV) was calculated using the following formula:

$$UDV = E + S - A \quad (2)$$

3.2. Analysis of Urban Drought Vulnerability

Correlation analysis (based on weighting), and path analysis (based on SEM) was conducive for basic understanding and subsequent in-depth analysis.

The Pearson correlation coefficient algorithm is chosen to realize feature selection through dimensionality reduction, which has many advantages, such as high efficiency, accurate calculation, strong practicability (Peng et al., 2018). The correlation coefficient r is used to measure the correlation between variable x and y , and the value range of r is $[-1,1]$; we define:

$$r = \frac{\sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^n (x_i - \bar{x})^2} \sqrt{\sum_{i=1}^n (y_i - \bar{y})^2}} \quad (3)$$

Where \bar{x} and \bar{y} represented the mean of data set x and y , respectively. When $r > 0$, it indicates that variable x and variable y are positively correlated, and when $r < 0$, it indicates that variable x and variable y are negatively correlated. The larger $|r|$ is, the more significant relationship between x and y . Generally, the variable correlation degrees can be measured as in Table 2.

Table 2. Correlation coefficients

Ranges	Descriptions
$0.8 < r \leq 1$	Extremely correlated
$0.6 < r \leq 0.8$	Strong correlation
$0.4 < r \leq 0.6$	Medium correlation
$0.2 < r \leq 0.4$	Weak correlation
$0 < r \leq 0.2$	Hardly correlated

4. Results and Discussion

4.1. UDV Scores of 13 Cities

The results of weighting of exposure, sensitivity and adaptive capacity were shown in Fig.2. Sensitivity and adaptive capacity are the dominant factors contributing to UDV in BTH region. Both dimensions accounted for more than 75% in all cities. And seven cities (Tianjin, Shijiazhuang, etc.) account for more than 80% of drought vulnerability. Among them, Shijiazhuang was the largest, at 84.33%. Thus, the decrease of sensitivity is as important as the improvement of adaptive capacity. This implied that decrease sensitivity and improving adaptive capacity play important roles in reducing urban drought vulnerability.

Based on principal component analysis, we calculated the UDV scores of 13 cities from 1887 to 2016 (Fig.3). The drought vulnerability of 13 cities was constantly fluctuating and irregular. This will present a great challenge for the government to manage drought risk.

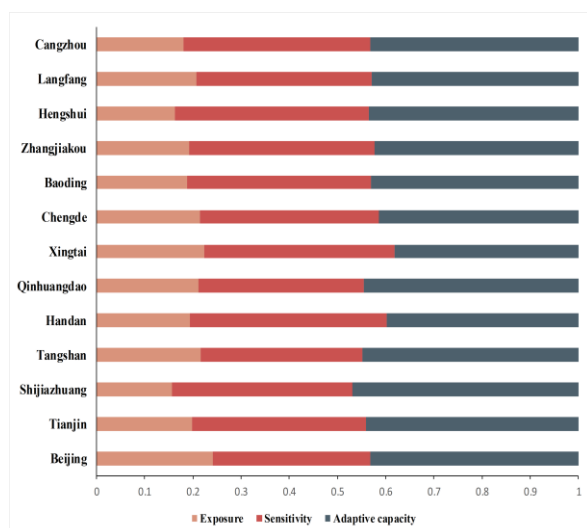


Figure 2. Contribution of three dimensions to UDV

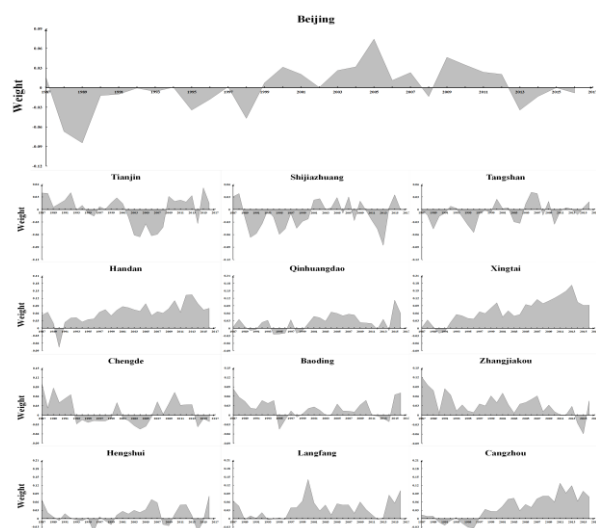


Figure 3. UDV trend graph for 13 cities

4.2. Correlation Analysis

Correlation analysis is an important method to explore how to reduce urban drought vulnerability. Based on the correlation analysis of 16 indicators in each city, we found that the indicators were significantly correlated in generally. This indicates that the factors affecting UDV are systematic. It is understandable that cities are complex systems, which consist of many sub-systems, such as socio-economic sub-systems, infrastructure sub-systems, and so on. This is where the difficulty and

the key to reducing vulnerability to urban drought. What's more, the indicators of 13 cities in semi-arid areas showed different correlation results in detail. This suggests the regionalism characteristics of UDV. Thus, it is necessary to reduce drought vulnerability from a system perspective. The formulation of policies should be based on the characteristics of each city.

Based on the finding, we further analyzed the correlation between policy indicators (public budget expenditure) and other indicators, as shown in Fig 4. There is a significant correlation between policy indicators and most indicators. This indicates the relationship between policy indicators and other indicators. Revealing their internal links would give governments a clear direction in managing drought risk.

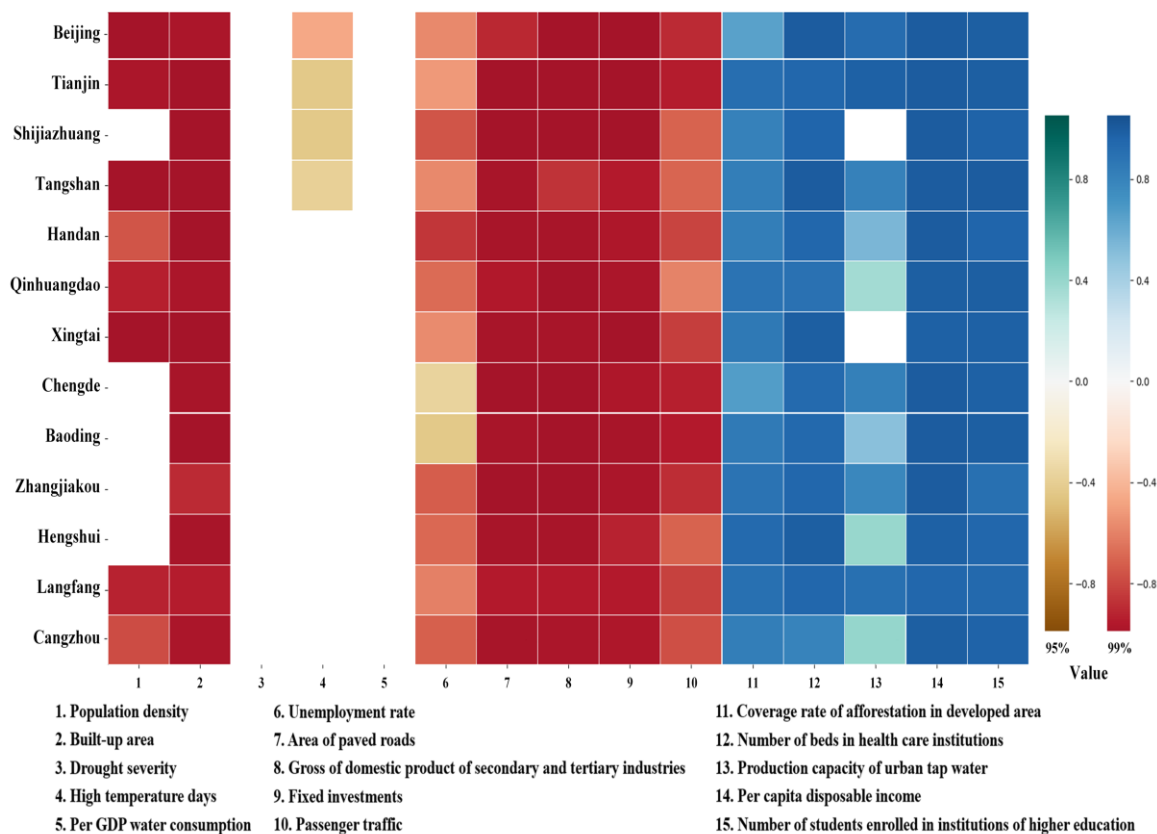


Figure 4. Correlation between “public budget expenditure” and the other 15 indicators in 13 cities

4.3. Path Analysis

Structural Equation Modeling, which is widely used in travel behavior analysis, can reflect the relationship analysis among variables. Due to the large number of cities, we selected Beijing as the main research object. Beijing is the core of China's socio-economic development. Climate change, rapid population growth and vigorous economic development have led a great pressure of urban drought to Beijing. From the above analysis results, it can be found that the drought vulnerability of Beijing is extremely unstable during 1987-2016. And high sensitivity is dominant reason contributed to urban drought vulnerability. Based on the correlation analysis, we explored the relationship between public budget expenditure and 13 other indicators. According to China statistical methods and dimensions, public budget expenditure indicator involves multifarious elements: general public service, education, science, technology, culture, media, social security, employment, healthcare, transportation, and so on. Fig 5 showed the constructed SEM for urban drought vulnerability, in which “indicator” in this figure come from the 13 indicators in Table 3. And Table 3 listed the results of effects of 13 indicators on drought vulnerability reduction when policies were proposed and effectively

implemented. More clearly, other things being equal, for every unit increase in the policy related to per capita disposable, the UDV will be reduced by 0.95 units. From the results, we found that the policies are most effective in reducing “gross of domestic product of secondary and tertiary industries”. However, it is admitted the difficulty to achieve in the process of urbanization. Therefore, for some indicators that are prone to change, such as medical infrastructure (0.9) and higher education (0.77), the government should formulate targeted policies for them.

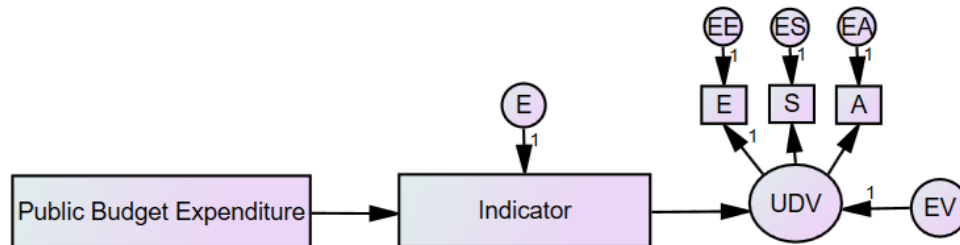


Figure 5. SEM of UDV reduction

Table 3. Results of paths and effects

Path	Effects
Public Budget Expenditure - >Population density - > UDV	
Public Budget Expenditure - >Built-up area - > UDV	-0.91
Public Budget Expenditure - >Area of paved roads - > UDV	-0.76
Public Budget Expenditure - >Gross of domestic product of secondary and tertiary industries - > UDV	-0.64
Public Budget Expenditure - >Fixed investments - > UDV	-0.99
Public Budget Expenditure - >Passenger traffic - > UDV	-0.95
Public Budget Expenditure - >Coverage rate of afforestation in developed area - > UDV	-0.65
Public Budget Expenditure - >Number of beds in health care institutions - > UDV	-0.57
Public Budget Expenditure - >Production capacity of urban tap water - > UDV	-0.90
Public Budget Expenditure - >Per capita disposable income - > UDV	-0.77
Public Budget Expenditure - >Number of students enrolled in institutions of higher education - > UDV	-0.95
	-0.77

5. Conclusions

This study assessed urban drought vulnerability and explored the pathways that reduce urban drought vulnerability from a system perspective.

The weighting results showed that 13 cities in BTH region have the characteristics of high sensitivity and high adaptability. The UDV score indicates that the vulnerability of 13 cities in the BTH region to drought fluctuated continuously from 1987 to 2016. This will present a great challenge for the government to manage the risk of drought.

Correlation analysis gave us a new perspective to reduce UDV. The 16 indicators of 13 cities are significantly correlated in generally, but the correlation varies among cities. We observed that the factors affecting UDV are systematic interactions and have regional characteristics.

For providing the government with a clear direction to reduce drought vulnerability, based on correlation results and path analysis, we found that Beijing should focus on the adjustable factors. Among them, the improvement of per capita disposable income and the improvement of medical infrastructure are relatively important directions.

6. Acknowledgement

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