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Urban Sustainable Development Based on the Framework of Sponge City: 71 Case Studies in China

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Abstract: Sponge city is a new urban stormwater management strategy proposed in China, which enables the city to absorb and save stormwater like a sponge, then release stormwater to solve the problems of urban waterlogging and water shortage. However, at present, sponge cities are confronted with such problems as high management cost and low management efficiency, a lack of research on collaborative management between cities and the feasibility of regional cooperation between sponge cities needs to be proved. Therefore, this article puts forward the theory of sponge city regional ecological cooperative management and builds a multivariate cluster analysis model of sponge city and conducts an empirical study on data of 71 Chinese cities. The research results show that under the multi-index linkage system, China's urban climate and ecological characteristics do have the characteristics of regional agglomeration and the basic conditions of interregional ecological cooperation, which proves the feasibility of the hypothesis of regional cooperation. Therefore, strengthening the ecological cooperation of sponge cities among regional cities is conducive to improving the supply efficiency of ecological environment quality and realizing the sustainable development of cities.

Keywords: sustainable development; sponge city; low impact development; regional ecological cooperation; management mode; multivariate clustering analysis

1. Introduction

Coordinated development between social economy and ecological environment is an important mode of sustainable development [1]. However, it is undeniable that, along with the rapid economic development, people are also facing severe challenges to their living environment [2]. Urbanization is also accompanied by the emergence of urban water environment problems and rapid urbanization has damaged the original hydrological ecological environment, resulting in urban flooding and other urban water environment problems [3,4]. For instance, China and other countries in the world face the problem of "urban diseases" caused by urban waterlogging, water shortage and water pollution occur from time to time [5–7]. These problems have caused serious external problems and restricted the healthy development of urban economy and society [8,9]. City is the engine of economic growth, the high quality of the ecological environment is the intrinsic motivation of urban economic growth, therefore, establishing and improving the ecological environment management system and focusing on solving the problem of urban ecological environment, especially for China with the increasing population and urbanization level, become the inevitable choice of sustainable development of social economy [10,11]. In 2013, to solve the serious urban water environment problems, the Chinese government put forward the sponge city strategy, which is an urban stormwater management system that enables the city to absorb and save the stormwater like a sponge and release the reserved water for use when the city is short of water, so that the sponge city can play an important role in the sustainable development of cities [12].

Theories of city such as ecological city [13], low-carbon city [14,15] and smart city [16,17] have been established for the purpose of achieving the coordination and unity between ecological environment and social and economic development, which provide reference for sponge city. In terms of urban stormwater management, foreign advanced experience has also played a positive role in the proposal of sponge cities in China and sponge city adds the Chinese style urban stormwater management concept into the worldwide urban stormwater management system [12]. Before sponge city, many countries in the world had put forward the corresponding urban rainwater management strategy, for instance, the United States put forward the low impact development (LID) [18–21], best management practices (BMPs) [22] and green infrastructure (GI) [23], Australia put forward water sensitive urban design (WSUD) [24,25], the United Kingdom put forward sustainable drainage systems (SUDS) [26–29], New Zealand put forward the low impact city design and development (LIUDD) [30,31]. Asian countries are making the same efforts, Singapore put forward ABC management of water system (ABC Plan) [32] and South Korea is also actively exploring and building LID [7]. Among them, the Low Impact Development (LID) proposed by the United States in the 1990s has a profound impact on China and its core is to maintain the hydrological characteristics of cities before and after development and reduce the adverse impact of development and construction on urban hydrological environment [33–35].

The importance of sponge city lies in the effective control of urban stormwater to solve problems above, the sponge city gives full play to the role of buildings, roads and water systems in stormwater absorption, infiltration storage and slow release, so as to improve the carrying capacity, conservation capacity and purification capacity of urban water ecological environment [36]. Compared to the past, the sponge city pays more attention to the new urban development concept, urban infrastructure of each plate, coordinate with each other, all the elements combined into a unified whole ecosystem, optimization of urban water resources management and configuration, give full play to the urban system of water environmental carrying capacity and the ability to adapt, so as to realize the source of urban water ecological environment control [37]. Through the treatment of water ecological environment, the precipitation that originally caused the burden of urban waterlogging and pollution is transformed into a favourable resource for urban production and construction, therefore, sponge city becomes an economic and effective method to solve the external problems of urban water ecological environment, realize the intensive utilization of water resources and promote the green development of urban economy [38].

The research on sponge city is still at the initial stage in China, some scholars have studied the connotation and construction approach to sponge city and considered that the individual heterogeneity of cities should be paid attention to in the construction of sponge city and different cities should be built according to their own conditions [12]. Some scholars have analysed the distribution of China's extreme precipitation across the country, indicating that China's extreme precipitation is spatially heterogeneous [39]. Other scholars have studied the smart sponge city and their research shows that big data, cloud computing, Internet of things and other technologies can be integrated into the management and construction of sponge city and the smart sponge city construction would be the development trend in the future [40]. Some scholars built a classifier model to improve the recognition efficiency of sponge city stormwater system to urban runoff [41]. Meanwhile, modelling and analysis of urban rainwater management based on data science has been followed up by relevant scholars in other countries in recent years [42–45].

However, most of the existing studies focus on the application of advanced hydrological technology in sponge city construction. While sponge city is faced with problems such as high management cost and low management efficiency, therefore, it is necessary to solve the above problems through the management framework [36,46,47]. At the same time, at present, most of the research objects of sponge city are single cities, with more emphasis on the individual heterogeneity between cities, while few studies focus on the homogeneity between cities in sponge city. The homogeneity between cities means that regional cooperation mechanism can be established between cities and such cooperation mechanism between regions can effectively improve the management efficiency of urban system in the region, which has reference significance for the management of sponge city [48–50].

Therefore, the research purpose of this article is to explore whether there is a certain homogeneity between cities in sponge city management elements and according to this homogeneity, build a regional sponge city management framework between cities and explore how the management framework can solve the current management problems of sponge cities.

2. Conceptual Framework

2.1. Construction of Framework of Regional Cooperative Management of Sponge City

Urban ecological and environmental management is conducive to the realization of green, coordinated and sustainable development of regional economy and can effectively promote the healthy growth of China's macro-economy [51,52]. According to the convergence theory of economic space clubs, economic activities between regions with similar economic structure and geographical location have the characteristics of aggregation [53]. Studies on China's regional economy show that the establishment of a reasonable and effective economic cooperation mechanism among regions with the convergence effect of spatial clubs is an important measure to improve the efficiency of economic operation and promote the coordinated development of regional economy [54]. Sponge city is a concept closely related to regional climate and ecological environment especially precipitation indicators, while China has a vast territory, complex and diverse meteorological and geographical conditions [55]. According to the proximity of regional space in the geographical sense and analogous to the convergence effect of regional economic space clubs, does the construction of sponge city also have the characteristics of regional aggregation in a certain sense? In particular, the management of public utilities and the formulation and implementation of policies are generally limited by administrative regions, such as provinces, cities, counties and communities. As you can imagine, if the characteristics of sponge city and related factors of management also presents the characteristics of the region gathered, so fusion sponge in regional economic cooperation mechanism under the framework of city construction, break through the management of the line between administrative regions and establishing regional cooperation between sponge city management mechanism, the urban space club and sponge are bound to the regional ecological civilization construction and the coordinated economic development play a positive promoting role. Therefore, Hypothesis 1 is proposed in this article:

Hypothesis 1: *Sponge city has interregional cooperability in the sense of management*.

Sponge city is a complex system engineering, the control targets are not single, in addition to the total surface stormwater control target but also need to control the peak stormwater, stormwater pollution and other indicators, so the sponge city construction needs to build a management response mechanism for the above control targets and make a multi-objective correlation analysis [36]. At the same time, the administrative functions and powers involved in sponge city management and construction are diversified, involving multiple administrative functions such as urban and rural planning, housing, urban and rural construction and water conservancy [56]. The establishment of interdepartmental sponge city cooperation and communication mechanism can effectively avoid the management chaos caused by multi-department management and improve the efficiency of urban water ecological environment management. Meanwhile, the application of modern information technologies such as big data, cloud computing and Internet of things can effectively improve the intelligent management level of cities [57]. Sponge city involves a wide geographical area and many administrative departments. Cooperation between sponge city regions and departments needs to break down the barriers of information communication. Therefore, efficient management of sponge city cannot be separated from the support of modern information technology and the construction of management information system. Therefore, based on the collaborative management of multi-administrative departments in sponge city, this article proposes Hypothesis 2:

Hypothesis 2: *Under the framework of regional cooperation, there is linkage between sponge city management and control elements.*

Based on the above hypothesis, this article integrates the management elements of regional cooperation and multiple linkage into the same micro-cycle, so as to explore the synergistic relationship between the two management elements and build the regional cooperation management framework of sponge city (see Figure 1).

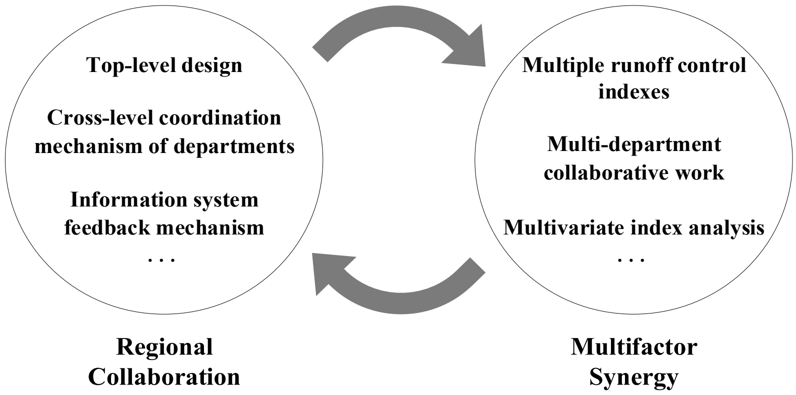

Figure 1. Macro-management framework of sponge city based on the idea of regional coordination and multi-linkage.

As shown in Figure 1, regional cooperation is based on the concept of top-level design and emphasizes the macro-control of sponge city management and construction nationwide. Firstly, the collaborative mechanism has the characteristics of levelling. Under the assumption that the indicators related to sponge city management and construction show the characteristics of the regional aggregation, the cross-regional cooperation mechanism of sponge city management and construction led by relevant government departments can be established between regions with similar geographical conditions and adjacent spatial locations. Cross-regional cooperation mechanism can make management resources more centralized and unified, avoid the situation of individual fighting, effectively save management costs and improve the efficiency of collaborative management between cooperative regions. At the same time, the establishment of cross-regional work coordination mechanism makes the regions with similar conditions structure fall into one category, reduces the dimension of regional management, effectively improves the decision-making efficiency of sponge city management and construction of higher departments and facilitates the macro control of sponge city management and construction of China by higher level departments. Second, cross-regional work coordination mechanism has the characteristics of the vertical mode, in particular, cross-regional work coordination mechanism is not only the synergy between geographical regions, provinces, cities and between cities, between prefectures and counties until streets and streets are set up a corresponding level of synergy mechanism, by establishing hierarchical management information interaction, make the sponge urban construction situation, the status of urban water environment to the grassroots regional uploaded to a higher level, the higher level of regional division decision information to feedback to the area, thus realizing the vertical top-down management so as to improve the efficiency of management. Sponge city involves geographical area widely, therefore, the realization of the sponge city level and vertical management between regional cooperation mechanism, needs to depend on unified information platform and integrate the province to the secondary administrative areas to the platform. Through information and systematic management, make originally scattered regions becoming one organic integration, so as to realize the sponge of regional urban work coordination mechanism.

Multiple linkage has three meanings:

(1) Linkage of multi-functional departments. Sponge city management and construction is a systematic engineering, including preliminary planning and design, infrastructure construction in mid-term, rebuilding of water system, park green space construction and late water environment monitoring and early warning, et al. So the sponge city involves multiple functions of administrative permission, however, the scattering of administrative authority is difficult to maximize the efficiency of management of the sponge city. Therefore, the establishment of a work exchange mechanism between departments of natural resources, urban and rural planning, ecological environment, emergency management and so on and the collaborative management of sponge city are effective ways to realize centralized statistics of management resources.

(2) Linkage of multiple control factors. Sponge city has the characteristics of multiple control objectives. It should not only control the total stormwater but also control the peak stormwater and pollution caused by stormwater. Accordingly, appropriate management mechanism should be established according to different control objectives. For example, in response to the pressure caused by the peak stormwater, sponge city system should strengthen the management of infrastructure carrying capacity and establish an effective emergency management mechanism for situations where the peak may exceed the bearing range of infrastructure. Another example is stormwater pollution. While controlling the total stormwater and stormwater pollution, sponge cities should also consider the diffusion of pollution with surface stormwater and extend the observation range from precipitation to pollution. In addition, the management system of sponge city should be improved to the greatest extent by controlling the adaptability of climate conditions, the feasibility of sponge city system construction and the public satisfaction of sponge city. Sponge cities, in the process of urban construction, therefore, need to investigate related characteristic indexes, such as the environmental impact of investigates overall classification do not establish control target, in the same framework to correlation analysis and multivariate control target allows multiple targets to synergy, eventually improve the overall management system, improve the sponge city urban management system of the overall goal of the operation efficiency.

(3) Multi-dimensional linkage of development. Sponge city's goal is to promote the development of the city green, strengthening the construction of ecological civilization of the city and the economic development and construction of ecological civilization are inseparable, therefore, from the dimension of development, cannot be a sponge city as urban management and construction in isolation but should put sponge urban construction in the key position between the ecological civilization construction and economic construction. The sponge in the construction of urban management and should fully carry out the new development concept, to carry out the ecological civilization construction of the new requirements and combined with the requirements of urban economic construction, give full play to the sponge city of urban water resources management configuration, construction of intensive urban sponge, reduce caused by environmental externalities of urban management cost.

To sum up, sponge city should start from multiple dimensions of development, establish the coordination and management mechanism between sponge city, ecological civilization development and economic development and give full play to the role of sponge city in promoting sustainable urban development.

Efficient management information system provides technical support for the implementation of regional cooperative management mechanism and multiple linkage management mechanism. Under the framework of regional cooperation mechanism, centring on the central core management system, each administrative region at each level is integrated into the same information system platform for the work communication of sponge city management and construction (as shown in

Figure 2). Therefore, the efficient operation of the platform is inseparable from the construction of management information system. Sponge city management information system enables various regions to overcome the difficulties of long spatial distance and large geographical span and realize geographic connectivity in the virtual sense, which is the technical basis for realizing work coordination among different regions. Information system can effectively integrate various management information and Internet technology can classify the state information of urban water environment collected by grass-roots monitoring endpoints into categories and then transfer the information to the corresponding functional departments of administrative functions. The relevant departments then make feedback of management on the feedback information. The information system integrates and analyses the feedback from multiple departments to form a unified decision-making opinion, which is then transmitted to the grass-roots departments for work implementation, thus improving the efficiency of the multi-department cooperation management mechanism. Sponge city needs correlation analysis of multiple control objectives, which leads to the diversification of information processing. Therefore, information system needs to integrate multiple control information to achieve correlation analysis. The application of big data, Internet technology and the fusion of artificial intelligence methods make it possible for the efficient operation of regional cooperation mechanism and multi-linkage mechanism.

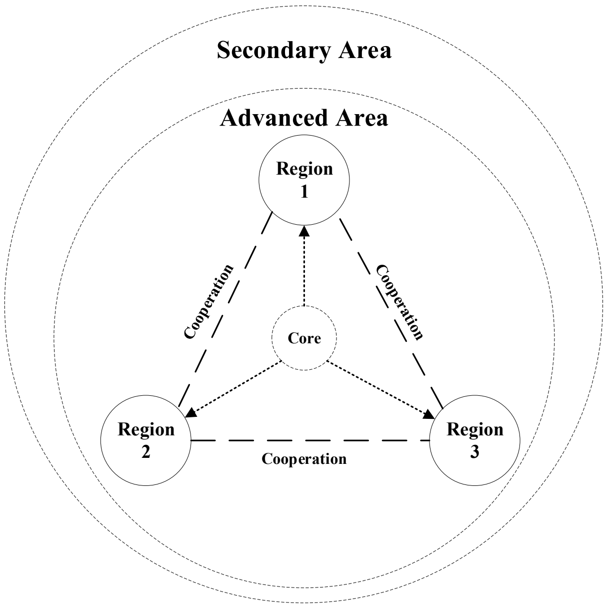

Figure 2. Management framework of sponge city based on regional ecological cooperation.

To sum up, the above mechanism from the supply side, start from the top design, dredge sponge management and each link of the construction of the city. Regional cooperation reflects the macro control of sponge city, multiple linkage is the implementation way of sponge city management and construction and efficiency orientation constitutes the basic guarantee of efficient operation of sponge city. The two mechanisms are interrelated and support each other, making sponge cities dynamic and efficient. The micro-cycle of sponge city management composed of regional cooperation and multiple linkage fully embodies the five development concepts of "innovation, coordination, green, open and sharing." Sponge city management and construction under this framework can effectively improve the synergistic efficiency among various management elements of the ecosystem, further optimize the urban ecological structure, realize the effective allocation of urban water resources and realize the efficient supply of high-quality ecological environment. Therefore, in the coordinated development of regional economy, will the sponge city operating mechanism combined with economic cooperation mechanism, to build a green, intensive and efficient economic coordinated development model, to improve regional economy intrinsic vitality, optimizing urban ecological space, with quality and efficient ecological environmental governance system to drive regional economy in the direction of the green, coordinated and sustainable development.

2.2. The Significance of Sponge City Regional Cooperation Framework

The regional cooperation management framework of sponge city constructed in this article also has its economic significance:

(1) Solve the external problems of ecological environment. The regional cooperation management framework of sponge city constructed in this article provides further solutions to the ecological environmental externalities. Through regional cooperation and multiple linkage, the construction of single-point sponge city, which was originally a city unit, was raised to the regional level. A collaborative mechanism of interregional sponge city management and construction should be established to enable all cities in the region to share a set of sponge city construction scheme and a set of sponge city management mode. The sharing of ecological and environmental resources within the region, to a certain extent, realizes the effective allocation of regional water ecological and environmental resources, optimizes the ecological environment and solves external problems.

(2) Reduce the cost of ecological and environmental management. Under the action of regional cooperation mechanism, the relevant administrative functional departments of each district gather in the same management system platform. In the multi-linkage environment, relevant management departments of various industries in the region have established a working linkage mechanism, so as to have a more comprehensive survey of sponge city management elements. Under the efficiency-oriented mechanism, information technology can be fully used in the construction of sponge city. To some extent, these mechanisms realize the efficient circulation of management information, which effectively reduces the management cost of regional ecological environment under the framework of sponge city in the whole process from decision-making to feedback.

(3) Improve the operating efficiency of ecological and economic systems. The regional cooperation management framework of sponge city realizes the organic combination of various management elements of sponge city. Efficiency mechanism aims to break the communication barriers between urban management elements of sponge cities. The senior macro management departments in each region can establish a collaborative mechanism and the related professional departments in the region can effectively assemble their positions. The control objectives between departments can achieve unified planning and implementation and emergency feedback can be fast and effective.

Further, aiming at the hypothesis of sponge city regional cooperative management, this article adopts the clustering method and combines the relevant meteorological data of some Chinese cities with the means of target decomposition and multi-variable gradual accumulation for empirical analysis.

3. Empirical Research Methods and Data

3.1. Construction of Model

Two research hypotheses of this article are reviewed again: Hypothesis 1: sponge city has interregional cooperation in the sense of management; Hypothesis 2: under the framework of regional cooperation, there is linkage between sponge city management and control elements. The premise of these two hypotheses is that there is regional connectivity between sponge cities on related elements of management and control. That is, related elements of management and control of sponge cities show regional clustering characteristics and certain regions have similarities in the elements of management and control. The clustering characteristics of management elements between regions are the premise of the regional cooperative management mechanism of sponge cities. Therefore, it is necessary to explore the similarity of management elements between regions with the clustering analysis method empirically to prove the feasibility of the mechanism. At the same time, this article assumes that there is linkage between sponge cities on the elements of management and construction. Therefore, on the basis of clustering analysis, a diversified clustering index system should be constructed to prove the feasibility of multiple linkage mechanism under the condition of regional cooperation mechanism. To sum up, this article uses meteorological indicators to represent the management and control factors of sponge cities and builds a spatial clustering model of multiple meteorological indicators to prove the hypothesis of this article.

Clustering analysis model cannot do without the support of data. Meteorological indicators are closely related to the distribution characteristics of climate and precipitation and the meteorological indicators between cities are similar, which creates conditions for clustering analysis. Based on the framework of sponge city regional cooperation management, this article conducts k-means clustering analysis on the 30 years' meteorological data of 71 cities belonging to various geographical regions of China. This article makes a preliminary study on the manifestation of sponge city characteristics in different regions and cities in China and tries to find out the general laws reflected in sponge city management and construction indexes between different regions and cities and demonstrates the macro-management framework of sponge city. The mechanism is shown as follows:

Figure 3 is the modelling process of clustering analysis used in this article. The detailed steps are as follows:

(1) The modelling process starts with sample city selection as the far left side of Figure 3. The sample cities to be studied are first determined, as shown below, 71 Chinese cities were selected as sample cities.
(2) The second step is to select the original data corresponding to the sample city according to the sample city determined in the first step. Since the research object of this paper is sponge city, which is inseparable from meteorological factors, the original data selected in this step is the meteorological data of the sample cities. The reasons for the selection of meteorological data are also discussed in detail below.
(3) The third step is to determine the indicators for cluster analysis. As shown below, 8 indicators were selected as cluster analysis indicators in this article.
(4) The fourth step is "annual averaging treatment." Because the original data are the meteorological data of each year of 30 years in each city and for the purpose of this paper, the meteorological data of these single years need to be aggregated and averaged.
(5) The fifth step is the standardization of data processing, which is used to uniform dimension and eliminate the adverse effects caused by the inconsistency of each indicator unit of the original data.
(6) The sixth step is to complete the pre-processing of sample data and make the data enter the stage of cluster analysis.
(7) Steps 7 to 10 in the dotted box are the calculation processes of clustering process. The seventh step is to determine the centre of clustering, that is, to determine the data to be processed into several categories. As shown below, 7 clustering centres were finally determined in this paper.
(8) In this step, we calculate the Euclidean distance between the data of 71 sample cities and 7 clustering centres respectively and only cities close to the clustering centre will be included in this category.
(9) In step 9, the clustering centre is updated because it needs to be recalibrated to ensure that the distances of the seven clustering centres are appropriate.
(10) In step 10, the square sum of the distance between the sample city data and the clustering centre is calculated to minimize the distance between the cities in each category and the clustering centre of this category, so that the clustering result is more stable. It should be noted that from step 8 to step 10, this is an iterative calculation process and the centre of the cluster is constantly updated and the distance of the data is calculated, until the centre of the cluster and the clustering result do not change significantly.

(11) In this step, we have completed the whole process of clustering calculation and obtained stable clustering results. We also output the results of clustering.
(12) This is the last step of cluster analysis, that is, analyse the clustering results obtained in the previous step and formulate appropriate policies and measures according to the clustering results of the sample cities.

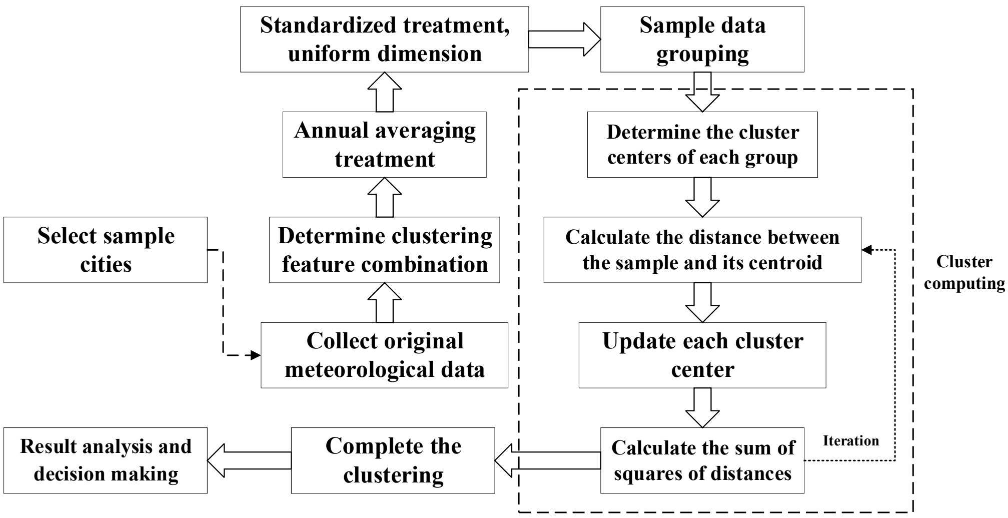

Figure 3. Modelling process of cluster analysis in this research.

The index system of clustering analysis model adopted in this article is the combination of n-dimensional clustering features: $\xi = (\xi_1, \xi_2, \cdots, \xi_n)$, where ξ_j represents the clustering features of the j-dimension. The data used in the clustering model are the annual meteorological data under the combination of specific indicators of each city, whose matrix is expressed as follows:

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & \ddots & & x_{2n} \\ \vdots & & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix}, (0 < m \leq 365) \quad (1)$$

where, the matrix X represents the multivariate feature annual meteorological data value of a city and x_{ij} represents the annual average value corresponding to the meteorological feature j of the sample day i of a city. The calculation formula is as follows:

$$x_{ij} = \frac{\sum_{m=1}^{n} \alpha_{ijm}}{n} \quad (2)$$

where, α_{ijk} represents the actual data value corresponding to the m year of the characteristic variable j on the day of sample day i, x_{ij} is accumulated and averaged from years of data. In order to eliminate dimensional differences, the data entering the clustering model are processed in a standardized way, so as to keep the measurement standards of data consistent and avoid some variables with a large order of magnitude from affecting the final classification results. The standardization method used in this article is maximum and minimum value standardization and the standardization formula is:

$$x_{ij}^{*} = \frac{x_{ij} - x_{\min}}{x_{\max} - x_{\min}} \quad (3)$$

where, x_{ij} represents the variable, x^*_{ij} represents the standardized variable, $x_{\min}$ represents the minimum value in the value of the corresponding variable column and $x_{\max}$ represents the maximum value in the value of the corresponding variable column. The standardized meteorological data matrix is shown as follows:

$$X^* = \begin{bmatrix} x^*_{11} & x^*_{12} & \cdots & x^*_{1n} \\ x^*_{21} & \ddots & & x^*_{2n} \\ \vdots & & \ddots & \vdots \\ x^*_{m1} & x^*_{m2} & \cdots & x^*_{mn} \end{bmatrix}, (0 < m \leq 365) \quad (4)$$

The above is the pre-processing process of the original meteorological data. After the pre-processing, the standardized meteorological data matrix X^* is put into the clustering model for calculation. In this article, *k*-means method is adopted for clustering analysis, Euclidean distance is taken as similarity measure value and the sum of squares of distances between samples and clustering centres is taken as the clustering objective to reach the minimum. Firstly, according to the research purpose, the sample data is divided into *k* groups, to calculate the mean groups of sample data and determine the *k* corresponding to the clustering centres. Give the clustering centre features under the combination of sample values and then calculate the rest of the sample and the Euclidean distance between the *k* cluster centre. Then iterate the process and update the clustering centre, until the distance between the sample with the corresponding clustering centre, to minimize the sum of iterative calculation and make sure the clustering centre is changeless. The sample data gather into *k* clusters finally. The measurement objective function applied by the clustering model is as follows:

$$SSE = f(\mu) = \sum_k \sum_i (x_{ki} - \mu_k)^2 \quad (5)$$

where, SSE is the square sum of the distance between the sample value and the clustering centre; x_{ki} is the sample *i* value of the subordinate *k* group; μ_k is the mean value of the corresponding sample data of the *k* group; and the final clustering objective is achieved by minimizing the value of the objective function $f(\mu)$.

The premise of efficient operation of sponge city is to identify and control the characteristics of related management elements. The relationship between sponge city and natural meteorology is inseparable, so the management and construction of sponge city need the technical support of meteorological data. The existing meteorological data mainly include the city's temperature, wind speed, water vapor pressure, precipitation and other meteorological information. The specific data structure includes the average temperature, maximum temperature, average wind speed, average precipitation, average water vapor pressure and other elements constitute. These meteorological elements show the monitoring point in the region of the time-sharing meteorological conditions. Meteorological environment is characterized by geographical connectivity, that is, cities and regions with similar geographical locations and similar features of mountains and landforms have certain similarity in meteorological performance and even unconnected geographical regions show certain laws in meteorological conditions, especially in the characteristics of certain meteorological elements. Therefore, the mining of meteorological data composed of the above elements and the exploration of the general law of meteorological data can enable each city to have a deep and clear understanding of its own conditions and provide reference basis for the formulation of sponge city plans and the preliminary exploration, planning and design of system construction in various regions. The planning and construction of low-impact development rainwater system and the subsequent monitoring and evaluation of low-impact development rainwater system between cities and regions with similar geographical location and geomorphological features can be linked and coordinated. This approach improves the overall efficiency of sponge city construction. The consistency of meteorological indexes between cities is conducive to the linkage of the overall planning of sponge city construction plans of national, administrative and municipal government departments at all levels and to the improvement of the work efficiency from early design and development to late evaluation and maintenance of the system.

In this article, according to the idea of zoning, sponge city macro-management area is divided according to China's geographical regions. The original control indexes are decomposed and other control indexes such as invalid precipitation time and seasonal precipitation factors are introduced to carry out further analysis, so as to dig into and explain the consistency of control indexes between cities and the relevant laws presented. The final clustering results of data are determined by the index variables that constitute the data and the final clustering results of data points reflect the law of data on the clustering index variables. The processing and analysis of the regional meteorological data is an important part of the construction of sponge city. In order to ensure that the data remain general in time series, the time span of the data should be no less than 30 years and the research index should be the perennial meteorological index [36]. Some scholars have conducted decomposition studies on the annual stormwater total control rate index, detailed the impact of the index on the target value of sponge city construction and decomposed the sponge city construction index and it is conducive to the specific implementation of low-impact development rainwater system construction, providing data support for system construction [58]. In order to further explore the general law of meteorological indexes in Chinese cities, this article decomposes the rainfall indexes according to the year, day and season. At the same time, other meteorological indexes related to rainfall are introduced into the data set to be processed, so as to explore the interaction between multiple indexes and the law of their presentation.

The sponge city construction takes the city as the unit and the meteorological conditions between adjacent cities in geographical space are consistent [55]. According to the standard geographical division of China, the cities selected in this article cover all seven geographical divisions of central China, north China, south China, southwest, northwest, northeast and east China. According to the research purpose, eight meteorological indicators finally entered the cluster analysis model, respectively is: average annual daily temperature of 30 years (unit: °C), average annual daily precipitation of 30 years (unit: mm), average annual daily precipitation in spring of 30 years (unit: mm), average annual daily precipitation in summer of 30 years (unit: mm), average annual daily precipitation in autumn of 30 years (unit: mm), average annual daily precipitation in winter of 30 years (unit: mm), average annual total precipitation of 30 years (unit: mm), average annual days of ineffective precipitation of 30 years (unit: day).

In terms of index variable processing and selection, this article extends the control target, further decompose and refine indexes such as precipitation and introduce other control elements. The meteorological clustering index and its corresponding control target elements and administrative departments are shown in Table 1. The method of index processing in this article is mainly based on the following considerations:

(1) Introduce seasonal factors into meteorological indicators. It can be seen from the geographical characteristics of precipitation distribution and climate distribution in China that there are differences between summer and winter precipitation in most regions of China. For example, the temperate continental climatic belt shows that precipitation is concentrated in summer, while the monsoon climatic belt shows that there is more precipitation in summer and less precipitation in winter. In order to reflect the possible problem of seasonal water shortage or excessive rainfall, seasonal factors were taken into account in the modelling stage. The average daily precipitation in spring, summer, autumn and winter of the sample cities were calculated on the basis of seasons.

(2) Introduce the concept of ADIP. In this article, the number of days when the average daily precipitation of 30 years of each sample city is less than or equal to 2.0 mm is counted as the value of ADIP, which is added into the clustering model as a variable. The index of ADIP examines the annual precipitation distribution of sample cities from the perspective of time and whether the precipitation distribution is uniform throughout the year. For example, some southern regions of China are "drought," the annual precipitation is relatively abundant but prone to drought

in summer and the communication situation, the influence of low development of rain water system construction should be considered when in invalid precipitation period how to improve the water conservation function.

(3) Introduce temperature index. The existing reference indexes of sponge city construction are mainly rainfall indexes and other important meteorological indexes are not referred to, while air temperature has an important interaction relationship with rainfall and non-point source pollution. Therefore, this article introduces the annual average daily temperature index in the model, corresponding to the annual average daily precipitation and conducts clustering analysis.

Table 1. Clustering index and its corresponding control objectives and administrative departments.

Clustering Index	Abbreviations	Control Objectives	Administrative Department
Average annual daily temperature of 30 years	ADT	Air temperature, pollution	Meteorology, planning, water supply and drainage, et al.
Average annual daily precipitation of 30 years	ADP	Average daily precipitation and pollution	Meteorology, planning, natural resources, emergency management, et al.
Average annual daily precipitation in spring of 30 years	ADSP	Seasonal precipitation, pollution	Environmental protection, meteorology, planning, emergency management, et al.
Average annual daily precipitation in summer of 30 years	ADSU	Seasonal precipitation, pollution	Environmental protection, meteorology, planning, emergency management, et al.
Average annual daily precipitation in autumn of 30 years	ADAU	Seasonal precipitation, pollution	Environmental protection, meteorology, planning, emergency management, et al.
Average annual daily precipitation in winter of 30 years	ADWI	Seasonal precipitation, pollution	Environmental protection, meteorology, planning, emergency management, et al.
Average annual total precipitation of 30 years	ATP	Seasonal precipitation, pollution	Meteorology, planning, water supply and drainage, et al.
Average annual days of ineffective precipitation of 30 years	ADIP	Seasonal precipitation, pollution	Emergency management, water supply and drainage, et al.

In order to deeply explore the influence of various variables on the clustering results, this article adopts the method of gradual accumulation of multiple variables based on clustering analysis. From average value of rainfall of accumulated years, cluster analysis is carried out for many times in the form of multiple variable combinations, gradually accumulating variables and variable combinations that are processed by clustering. For example, variables such as ADP, ADSU, ATP and ADIP were taken as clustering variables to cluster 71 data records separately and the clustering results at this time were observed and recorded. Then, variables such as annual average daily precipitation and annual average ineffective precipitation time were combined to observe and record the clustering of data corresponding to different variable combinations.

3.2. Data Selection

In order to ensure the accuracy of the data, the meteorological data used in this article are from the China meteorological data network sponsored by the China meteorological administration. Selection of data sets on duty *Chinese Ground Annual Value Data Set (1981–2010)*, The data set is compiled from the monthly report informatization documents of China's basic, benchmark and general ground meteorological observation stations. It is the daily climate standard data including air pressure, temperature, precipitation, wind speed and other elements. The time is 1 January 1981 to 31 December 2010 and the span is 30 years.

Since the purpose of this study is to explore the clustering characteristics in the sense of sponge city between cities in mainland China, the following considerations should be taken into consideration in the selection of sample cities in this paper: (1) Sample cities should be distributed as far as possible within each large geographical area of mainland China and each large geographical area should contain a certain number of cities; (2) At the administrative level, each province in mainland China should also contain a certain number of cities; (3) Due to the importance of capitals within administrative regions, it is necessary to ensure that each administrative capital has access to the sample set; (4) The urban data entered into the sample set should be consistent in the statistical time span. Therefore, this paper finally selected 71 cities as samples for analysis. However, meteorological data of some cities, especially those of administrative capitals, cannot be included in the sample set due to the inconsistency of statistical calibre. The data structure includes nominal variables and meteorological indicators, including the city name, station number, daily serial number and various meteorological indicators. The form is the average value of the meteorological data of the city for 30 years, a total of 365 records, arranged in ascending order from 1 to 365.

On the basis of the original data, this article takes ADP of the city as the average accumulated daily precipitation index and ADT in the original data as the average accumulated daily temperature index of the city. At the same time, this article deals with ADP in the original data: (1) Calculate the average daily precipitation of each quarter according to the annual distribution of the four seasons. Spring is the march, April and May of the year and the daily serial number ranges from 60–151, a total of 92 days; Summer is the whole year in June, July and August, the day serial number range is 152–243, a total of 92 days; Autumn is September, October and November of the year. The serial number ranges from 244 to 334 days, a total of 91 days. Winter is the whole year in January, February, December, the day serial number range is 1–59 and 335–365, a total of 90 days. In the data of each city, ADSP, ADSU, ADAU and ADWI are calculated in the range of daily serial number according to the season length. (2) In the data of each city, ATP is taken as the average accumulated total precipitation of the city for 30 years according to the statistical value of daily serial number 1–365. (3) Daily precipitation events with precipitation less than or equal to 2.0 mm are deleted from the data of each city. According to the annual distribution of daily precipitation events that meet the above conditions, ADIP of the city is determined.

In this article, a total of 71 sample cities were selected from 7 standard geographical regions in China for cluster analysis and the average values of indicators of each geographical region were calculated respectively according to the meteorological data of the cities belonging to each geographical region. The number of sample cities of each geographical region and the average values of each index were shown in Table 2.

Table 2. The number of sample cities in geographical regions and the average value of each index.

Index	Geographical Partition						
	Northwest	**North**	**Northeast**	**Southwest**	**Central**	**East**	**South**
ADT	10.1	10.7	6.0	14.1	16.3	16.2	21.3
ADP	0.6	1.3	1.6	2.5	3.0	3.3	4.3
ADSP	0.5	0.8	1.0	1.9	3.2	3.6	4.8
ADSU	1.3	3.2	4.1	5.4	5.1	5.6	8.0
ADAU	0.6	1.0	1.1	2.2	2.3	2.3	2.6
ADWI	0.1	0.1	0.2	0.5	1.2	1.7	1.6
ATP	229.6	463.0	590.9	910.6	1072.7	1200.4	1571.0
ADIP	331	286	265	205	170	154	132
Number of Samples	13	9	10	9	10	10	10

As can be seen from Table 2, among the seven geographical regions in China, the value of ADT is the lowest in northeast China and the highest in south China. In terms of precipitation, ADP, ADSP, ADSU, ADAU, ADWI and ATP in northwest China are all at the lowest level and ADIP is the longest. ADP, ADSP, ADSU, ADAU and ATP in south China are all at the highest level and ADIP is the shortest. ADWI is at its highest in eastern China.

4. Empirical Results and Analysis

In this article, cluster analysis was carried out on the standardized meteorological data of 71 cities processed above. Taking the city name as the case marker, 8 indexes were selected as cluster variables. In the process of determining the classification number (k value), it is necessary to ensure that the clustering centre keeps convergence on the limited number of iterations under the given k value and the clustering results can objectively reflect the distribution of urban meteorological conditions. The final k value for clustering in this article is 7. The iteration record of the clustering model is shown in Table 3. The minimum distance between the initial centres is 0.564. When the iteration number is 3, the clustering model has no change or small change in the centre and reaches convergence.

Table 3. Iteration record of clustering centres.

Iteration	Changes in the Cluster Centre						
	1	2	3	4	5	6	7
1	0.325	0.377	0.195	0.190	0.202	0.193	0.207
2	0.119	0.040	0.000	0.000	0.000	0.000	0.000
3	0.000	0.000	0.000	0.000	0.000	0.000	0.000

In the process of clustering, iterative process from the initial clustering centre to the final clustering centre is completed. The final clustering centre of this article is shown in Table 4:

Table 4. The final cluster centres.

Index	Clusters						
	1	2	3	4	5	6	7
ADT	0.375	0.303	0.648	0.771	0.772	0.821	0.991
ADP	0.048	0.243	0.401	0.563	0.663	0.773	0.908
ADSP	0.034	0.122	0.242	0.496	0.665	0.930	0.493
ADSU	0.039	0.255	0.365	0.432	0.413	0.488	0.920
ADAU	0.066	0.283	0.559	0.613	0.768	0.595	0.987
ADWI	0.014	0.060	0.189	0.504	0.814	0.879	0.464
ATP	0.045	0.239	0.400	0.565	0.668	0.777	0.908
ADIP	0.982	0.678	0.478	0.252	0.062	0.071	0.225
Number of Sample Cites	10	22	17	10	5	5	2

At the same time, the distance between the centres of the final clustering is obtained by clustering processing in this article. The distance between the centres is shown in Table 5:

Table 5. The distance between the final clustering centres.

Cluster	1	2	3	4	5	6	7
1		0.527	1.001	1.460	1.855	2.030	2.115
2	0.527		0.573	1.042	1.443	1.638	1.675
3	1.001	0.573		0.539	0.972	1.201	1.152
4	1.460	1.042	0.539		0.454	0.676	0.816
5	1.855	1.443	0.972	0.454		0.370	0.805
6	2.030	1.638	1.201	0.676	0.370		0.889
7	2.115	1.675	1.152	0.816	0.805	0.889	

Under the comprehensive effect of the combination of 8 clustering variables, 7 classifications were formed for 71 cities in China according to the principle of compact distance from the clustering centre as the same category in terms of clustering variables and the final clustering results and the number of various sample cities were shown in Table 6. Combined with Tables 4 and 6 in the order of 1–7, the precipitation related indexes of clustering results show a trend of increasing in turn. Among them, ADP and ATP, two indexes reflecting the annual average precipitation, are increased in this order. The two indexes of cities in category 1 are the smallest and the two indexes of cities in category 7 are the largest. The trend of other precipitation indexes is roughly the same as that of this order but there are differences. In this order, the detailed average precipitation indexes for four seasons do not fully conform to the trend of annual average and annual total precipitation indexes. Among them, ADSP and ADWI of cities in category 6 are higher than those of cities in category 7. At the same time, according to the distribution of the final clustering centre, ADSU of cities in categories 4, 5 and 6 are less different from that of other indexes and indexes of cites in categories 4, 5 and 6 are more similar.

It can be seen from ADSU and ADAU of cities in categories 4, 5 and 6 that there is no increasing trend according to the clustering sequence. After introducing seasonal factors into the precipitation index, the distributions of ADSU and ADWI of a city do not show a consistent trend with ADP, ATP and other characteristic variables reflecting the total precipitation of a city. Under the condition of seasonal subdivision, the characteristics of seasonal precipitation show a trend different from that of annual total precipitation. This result proves that the influence of seasonal rainfall should be taken into account when building sponge cities. Although the ATP of cities in category 7 maintains the highest level, the ADIP is not the minimum value in the seven clustering results and this shows that although the total precipitation of cities in category 7 is the most abundant, the ADIP is not the least. The rainfall of cites in category 5 and category 6 is not rich than those in category 7 but they have relatively less value of ADIP. The value of ADIP of cities in category 5 is the minimum value of total 7 categories and cites in category 5 have the most abundant precipitation distribution level throughout the year. It also suggests that the average indexes cannot reflect the actual situation of the city weather, joining the seasonal rainfall index can better explain the water level of the city.

In addition, the trend of ADT is the same as that of the above order but there are also differences. The ADT of cities in category 2 is lower than that of cities in category 1. As a result of the above clustering results, apart from some clustering indexes showing some different trends and differences, 71 cities generally follow the clustering order of 1–7 and their precipitation is gradually abundant and the value of the precipitation index is significantly increased. The relevant indexes of sponge cities within each cluster show the characteristics of spatial aggregation.

Table 6. Final clustering results.

Categories	Cites	Count
1	Jiuquan, Wuwei, Baiyin, Golmud, Yinchuan, Zhongwei, Karamay, Turpan, Kashi, Hami	10
2	Tianjin, Zhangjiakou, Handan, Baoding, Chengde, Taiyuan, Datong, Jincheng, Hohhot, Tieling, Shenyang, Dalian, Harbin, Qiqihar, Yichun, Jiamusi, Changchun, Baicheng, Baishan, Linzhi, Changdu, Xining	22
3	Zhengzhou, Nanyang, Zhumadian, Xiangyang, Shiyan, Baise, Qingdao, Xuzhou, Bengbu, Yibin, Zigong, Bijie, Kunming, Lijiang, Qujing, Baoji, Hanzhong	17
4	Wuhan, Yichang, Zhangjiajie, Laibin, Liuzhou, Nanning, Nanjing, Wuxi, Hefei, Tongren	10
5	Changsha, Xiangtan, Yunfu, Hangzhou, Shaoxing	5
6	Shaoguan, Hezhou, Guilin, Nanchang, Jingdezhen	5
7	Qinzhou, Beihai	2

The precipitation trend shows the characteristics of “less north and more south, less west and more east” in the figure, such as Xinjiang Uygur autonomous region, the northeast and north China. The situation of the south of the Yangtze river is also complex. The areas with the highest precipitation in the figure are distributed evenly across China’s equatorial regions, such as the southern region of Guangxi Zhuang autonomous region. Therefore, the administrative departments of this region can establish a collaborative mechanism for precipitation. Meanwhile, the results of clustering analysis in this article reflect the “latitude” of sponge city. For example, as shown in Table 6, northeast China is divided into two categories, cities in Qinghai province are divided into two different regions (category 1 and 2) and cities in the whole Yangtze river basin are clustered into categories 3 and 4. The clustering characteristics of sponge cities are also reflected in this article, such as the urban clustering characteristics of the Yangtze river economic belt and northeast China, are feasible in the sense of regional cooperation. At the same time, taking each cluster as the unit, this article calculated the mean value of each cluster index of each sample city, as shown in Table 7:

Table 7. The mean values of indexes of sample cities in the clustering results.

Index	Cluster						
	1	2	3	4	5	6	7
ADT	9.7	8.2	15.5	18.1	18.1	19.2	22.8
ADP	0.3	1.5	2.4	3.4	4.0	4.6	5.5
ADSP	0.3	0.9	1.8	3.7	4.9	6.9	3.7
ADSU	0.6	3.6	5.1	6.1	5.8	6.8	12.8
ADAU	0.3	1.1	2.1	2.3	2.9	2.3	3.8
ADWI	0.0	0.2	0.5	1.4	2.3	2.5	1.3
ATP	110.1	529.8	877.1	1233.1	1457.3	1692.7	1974.3
ADIP	360	272	214	149	94	96	141
Number of Sample Cites	10	22	17	10	5	5	2

According to the analysis in Tables 6 and 7 combining the geographical location information of each city, the clustering situation of 71 cities is generally stable and the clustering results show the following characteristics:

(1) The meteorological conditions of some cities with geographical connectivity are consistent. Cities in the same geographical region are consistent, provinces and autonomous region such as Xinjiang, Ningxia and Gansu in the northwest and Heilongjiang, Jilin and Liaoning provinces in the northeast, where the urban meteorological conditions are highly consistent and the classification is stable. Cities at the same administrative level also show certain meteorological commonness, just as the meteorological conditions of Hangzhou city and Shaoxing city in Zhejiang province are consistent and stable. However, the consistency caused by geographical connectivity is not absolute. In cities of the same region, the meteorological conditions of the same geographical region or province are not completely the same and some cities have different clustering conditions. For example, Wuhan city and Yichang city in the same province belong to different classifications as Xiangyang city and Shiyan city in the same Hubei province. On the other hand, the meteorological conditions of cities in different geographical regions can be consistent, such as Shenyang city in northeast China and Linzhi city in southwest China. For cities with consistent meteorological characteristics, including their administrative regions, a cross-regional joint management mechanism of sponge cities should be established to integrate the concept of cooperation into the whole process of planning, design and management of sponge cities in the collaboration, so as to achieve win-win cooperation.

(2) Cities belonging to the same administrative region may not have the same clustering results. In multivariate clustering characteristics, city of clustering situation is not consistent with the distribution may, for example: Xining city, Qinghai province with higher value of ATP was not close to Geermu city in the same province but similar to Yinchuan city, Wuwei city and other cities category 2 in Table 6 (Harbin city, Changchun city, et al.); Jingdezhen city, Jiangxi province has abundant annual precipitation and its annual average total precipitation is even classified into one category with Guilin city, Shaoguan city and other cities with abundant precipitation. The results also show that the meteorological classification of the area south of the Yangtze river in China is more complex. Therefore, even if the cities are located in the same province and region, their plans of management and construction of sponge cities should be adapted to local conditions, because some provinces and regions, the same management plan may not be applicable to the whole city of the province and region. In addition, the clustering results also show that under the influence of

ADIP, some cities such as Zhengzhou city, becomes "outliers" in that its ADIP is relatively longer than cites in the same region. However, under the comprehensive effect of the eight indicators, cities with phenomenon of "outlier," such as Zhengzhou city, are finally aggregated into one category with cities in the same province in the region, which indicates that the synergistic effect of other indicators neutralizes the effect of the indicators causing phenomenon of "outlier" on the results. These cities need the special attention of administrative authorities, which face more severe water shortages than other cities in the province. Especially on the index of ADIP, the emergency management mechanism of replenishing water should be established.

(3) The characteristic of "small cluster" also appears between the cities of the same categories. In this article, the distance between urban indexes is further analysed by using the method of centroid linkage. Results show that although belong to the same category but within each cluster between cities, the composed of eight clustering indexes on the index system of centroid distance is slightly different. For example, Turpan city in category 1 is far away from other cities in category 1 due to its extreme situation that the average daily precipitation is almost zero. For another example, the distance between the centre of cluster of Tieling city, Shenyang city and Linzhi city is closer. The distance between the centre of cluster of Yichun city and Baishan city is closer. Among the cities in category 5, the distance between the centre of cluster of Changsha city and Xiangtan city is closer and the distance between the centre of cluster of Hangzhou city and Shaoxing city is closer. Even if cities are located in different provinces and regions with close distance, collaborative sponge city management mechanism could be established to improve the efficiency of ecological and environmental management. The idea is also applicable to cites in other countries and regions in the world that face the same urban water ecological environment problems.

To sum up, under the linkage mechanism, the results show that multiple indicators relevant to management and control factors of sponge cities presents a regional clustering features, the similarity between the management control factors between the specific area. Therefore, cities could be collaborative on management and construction of sponge cities and control elements relevant to management of sponge cities can be correlated, it also proves the hypothesis in this article.

5. Conclusions and Policy Recommendations

This article constructs the management framework of a sponge city and proves its rationality by cluster analysis. The clustering results showed that 71 cities were clustered into 7 categories under the combined action of 8 indexes. Cluster analysis proves that Chinese cities show the characteristics of regional clustering under the conditions of diverse climatic and ecological characteristics and even the regions and cities with very distant space are equipped with the management mechanism to construct the interregional cooperation of sponge cities, which also proves the accuracy of the hypothesis of a sponge city regional cooperation management framework. Therefore, under the framework of a regional economic cooperation mechanism, the regional cooperation mechanism integrating sponge city management and construction and the establishment of multi-functional departments, multi-control objectives and multi-development dimensions linkage management mechanism, are conducive to improving the supply efficiency of a high-quality ecological environment. Although this article focuses on analysis of Chinese cities, we also believe that urban rainwater management is the of the major problems facing all countries in the world, therefore this work has significance for urban sustainable development in more cities throughout the world within the scope of regional cooperation.

Based on the conclusion, this article gives the following policy suggestions for sponge city management and construction in China. At the same time, these suggestions are also applicable to cities in other countries and regions in the world facing urban water environment problems:

(1) The top-level design of sponge city construction should be strengthened in the policy-making of regional urban ecological environment. From the perspective of ecological supply side, a regional cooperative development mechanism suitable for sponge city construction and

economic construction could be established in China and other countries. It is necessary to formulate appropriate sponge city management schemes according to the ecological structure characteristics of different regions in light of local conditions, break through the boundaries of administrative regions, establish cooperative framework mechanism of sponge city management and construction among regions with similar ecological conditions and adjacent geographical spaces and improve the efficiency of sponge city macro management.

(2) Multiple linkage based on administrative departments and control targets should be paid attention to in the management and construction of a sponge city. It includes not only the coordination of related functional departments but also the linkage of control objectives and management elements. Not only confined to the mean index analysis level, should also pay attention to the average does not reflect the reasons behind, such as sponges should be considered in the construction of urban management and seasonal factors, such as establishing more functions, the control objectives and development dimension, the linkage mechanism between maximum intensive sponge urban management resources, reduce the management cost of the city, improving the efficiency of the sponge urban management. Through the construction of a sponge city, realize the coordinated development of ecological civilization and economic construction;

(3) Efficiency should be the orientation in sponge city management and construction. Modern information technologies such as artificial intelligence, big data and Internet are integrated into the process of management and construction of a sponge city. Through the management information system to achieve the organic connection between the components of sponge city, improve the efficiency of information communication between elements and then improve the overall efficiency of sponge city management and construction. In the construction of sponge cities and other urban stormwater systems in the future, China and some other countries all over the world should strengthen the input of information technology in urban stormwater management system, take efficiency as the driving force and promote the healthy developments of green, coordinated and sustainable regional economy.

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