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Article

A Study of Urban Flood Safety Patterns in Built-up Areas of Bangkok Based on Complex Network Theory

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Abstract: With the development of the city, a large number of water networks in the built-up areas of Bangkok have been filled and hardened, resulting in poor urban flooding and aggravating flooding, causing loss of life and property of citizens. In this paper, on the basis of combing the current water networks and open space potential flood storage points in the built-up areas of Bangkok, the complex network diagram of the water system in the built-up areas of Bangkok is constructed by combining the theory of complex networks and analyzing the attribute parameters of the network and the characteristic parameters of the open space storage nodes and water system paths, and finding that the water system network in the built-up area of Bangkok has complex network characteristics such as robustness, clustering and hierarchy. By exploring the key storage points and water system connection paths, the researchers initially constructed a flood safety pattern in the built-up area of Bangkok with 145 key nodes and 127 river paths as the backbone, and conceptualized the development study of the flood safety pattern in both horizontal and vertical directions. The urban flood safety pattern based on complex network theory proposed in this paper provides a case reference and methodological ideas to scientifically solve the game conflict between the demand for construction land for urban development and the construction area of urban open space storage points and water storage network under the increasingly severe flooding situation.

Keywords: Complex network; flood safety patterns; Water Network; Built-up area of Bangkok

1.Introduction

1.1 Built-up area of Bangkok

Bangkok, the capital of Thailand and the second largest city in Southeast Asia, is located in the Chao Phraya River Delta, with a city area of 1,568.7 square kilometers. The Chao Phraya River flows through Bangkok from the north, dividing the city in two parts, and then flows 20km south into the Gulf of Thailand. The terrain of Bangkok is gentle, with an average elevation of 1-1.5 meters, and the river network is dense and long. With the rapid urban development and population growth in Bangkok, the lack of planning and arbitrary filling rivers to build the city has resulted in the reduction of water catchment area and poor water network disconnection. Frequent rainfall causes increased urban flooding，which threatens urban safety. As shown in Fig. 1 and Table 1, the comparison of Landsat5 TM and Landsat8 OLI data for four periods selected from 1990, 2000, 2010, and 2015 (HAN Ruidan, 2017), the

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built-up area of Bangkok increased more than one times in 25 years,which is from 406.12 km^2 in 1990 to 819.71 km^2 in 2015. The first 10 years (1990-2000) saw an average annual increase of 15.07 km^2 , and the middle 10 years (2000-2010) saw a slight decrease in the growth rate, with an average annual increase of 13.26 km^2 . However, starting from 2010, the size of the urban built-up area increased dramatically by 2015 at twice the original rate, reaching an average annual increase of 26.064 km^2 . Rapid urban construction has encroach on a large number of rivers, paddy fields and woodlands which can drain and store floodwater. Bangkok has a typical tropical monsoon climate, with the rainy season usually starting between May and July and lasting until September or even October, with at least 15 days of rain per month. Bangkok is also near the sea, which makes it susceptible to landfall typhoons that frequently cause flooding in the city. In particular, in July 2011, Bangkok was hit by a 50-year flood that killed at least 297 people, left some 110,000 people in temporary shelters, destroyed large areas of farmland, shut down many factories, and caused heavy economic losses. In order to combat frequent flooding, we need to preserve the original flooding network and storage wetlands in Bangkok, while urban development needs to fill the river and occupy the greenery to increase the land for construction, which forms a kind of game contradiction. It is of great practical significance how to increase the construction land required for urban development in the maximum amount under the premise of ensuring the safety of urban flood drainage in Bangkok.

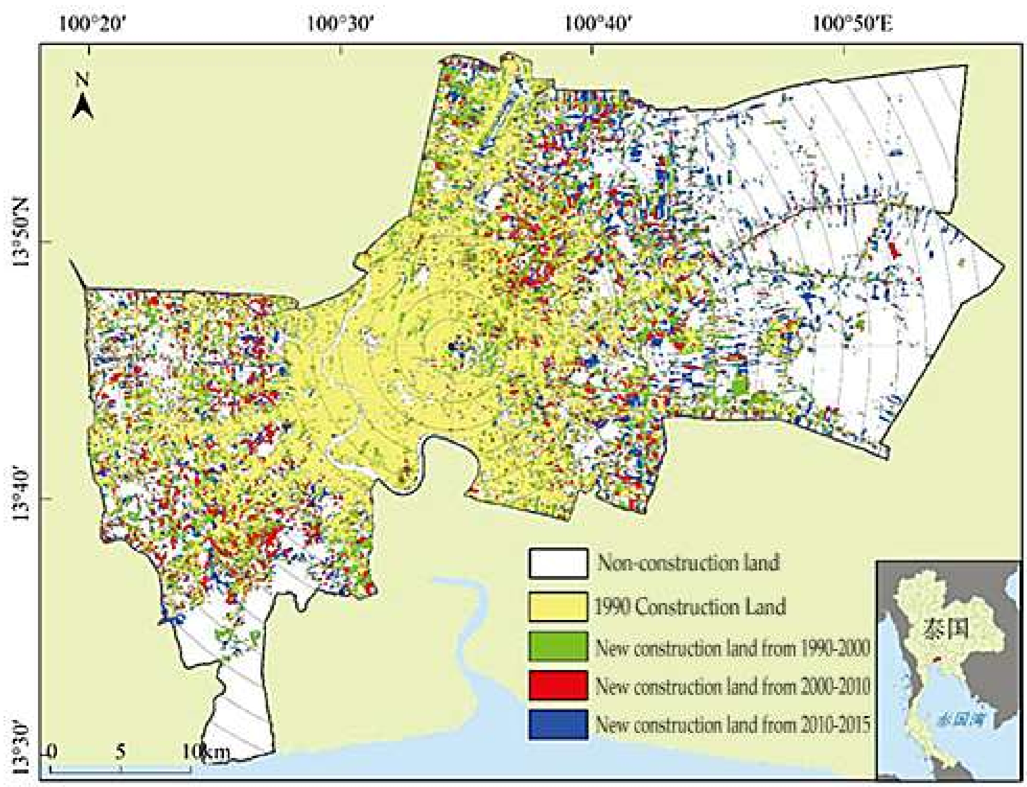

Fig. 1 Map of built-up area from 1990-2015

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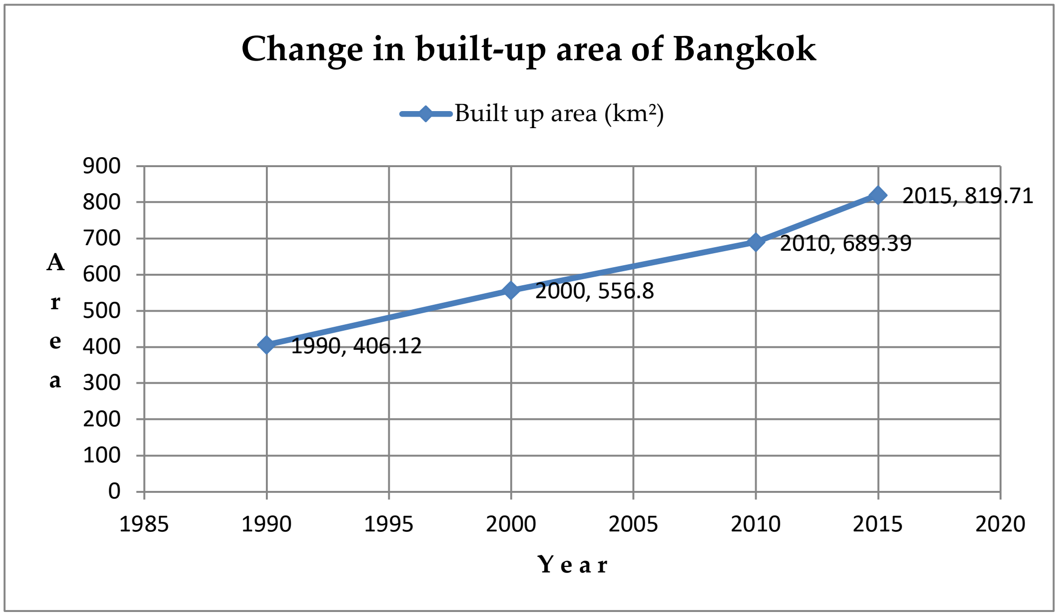
Table 1 Change in built-up area of Bangkok, 1990-2015



1.2 Urban Flood Safety Patterns

To achieve effective urban flood control, it is necessary to occupy strategic key spatial locations and connections, and the pattern formed by such strategic locations and connections is the urban flood safety pattern. These key spatial locations and connections are open spaces such as green areas, water bodies, squares and wetlands at important nodes in the city and their important contact water systems, which form a coherent and complementary flood storage and regulation system with each other and become a space for natural flood discharge to minimize the impact of flooding on the city. The urban flood safety pattern discussed in this paper is an efficient flood storage system composed of urban open space for flood regulation, stagnation and storage at key spatial locations and river systems with important liaison functions.

1.3 Complex network

A large number of complex systems that exist in nature can be described by networks of various shapes and sizes. In the late 1950s, scientists discovered that a large number of real networks are neither regular nor random networks, but networks with statistical characteristics that differ from both, and such networks are called complex networks (Newman, 2003). These networks generally have properties such as small-worldness, clustering, robustness, and power distribution of degree, and small-world network models, scale-free network models, and self-similar network models have emerged. Among them, key node discovery and community cluster discovery in the study of complex networks are important for understanding and studying network structure and function, improving network resistance and enhancing robustness.

1.4 Summary

A system is robust if it can maintain its basic functions despite internal and external errors. In networks, robustness is the ability of a system to perform its basic functions even after losing some nodes and links. The potential flood storage points such as existing water systems and open spaces in the built-up areas of Bangkok are modeled by combing them using the theory related to complex networks. By investigating the characteristic properties of the network model and the node parameters, the operationalization and feasibility of the network key nodes and community clusters are explored in an attempt to identify the critical areas, spatial locations and links in the flooding pattern of Bangkok. By combining the "robustness" of the network, an efficient flood storage system consisting of open spaces for flood regulation, detention and storage at key spatial locations and river systems with important linkage functions is constructed - a flood safety pattern for the built-up area of Bangkok.

2.Materials and Methods

2.1 Study Area

The scope of this study is bounded by the artificial surface connected in the CGLC30-2020 Bangkok surface coverage map (Fig. 2), covering the core area and the peripheral area of Bangkok (Fig. 3), with a total area of about 543.5 km^2 . The core area, with Bangkok City Hall as the center, has a radius of 10 km and basically covers the core built-up area of Bangkok with an area of about 320 km^2 . The outer zone extends 10 km to cover Bangkok's Langman International Airport in the northeast and the former capital of the Thonburi Dynasty on the west bank of the Chao Phraya River in the southwest, as well as Late Sukhumvit in the southeast, forming the outer zone with an area of about 220 km^2 (Fig. 2, Fig. 3). The northeastern and southwestern built-up areas of the periphery have been severely flooded in recent years, especially in the July 2011 floods, which were the most severe, as shown in Fig. 4, with darker colors indicating more severe damage (exclusive secrets, bangkok's next 7 potential investment golden places!, 2019). The built-up areas along the Chao Phraya River in the northwest and south of Bangkok are not part of the Bangkok city limits in terms of geographic jurisdiction, and large areas of agricultural land and water bodies exist in the eastern suburbs, and the built-up areas are severely fragmented; these two areas are not included in the scope of this study.

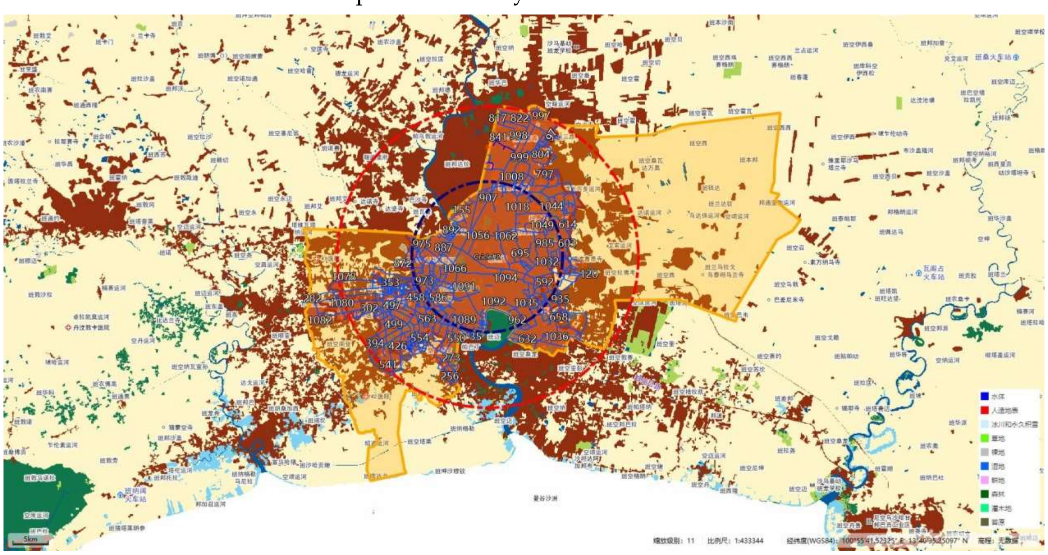


Fig. 2 Study area of the built-up area of Bangkok

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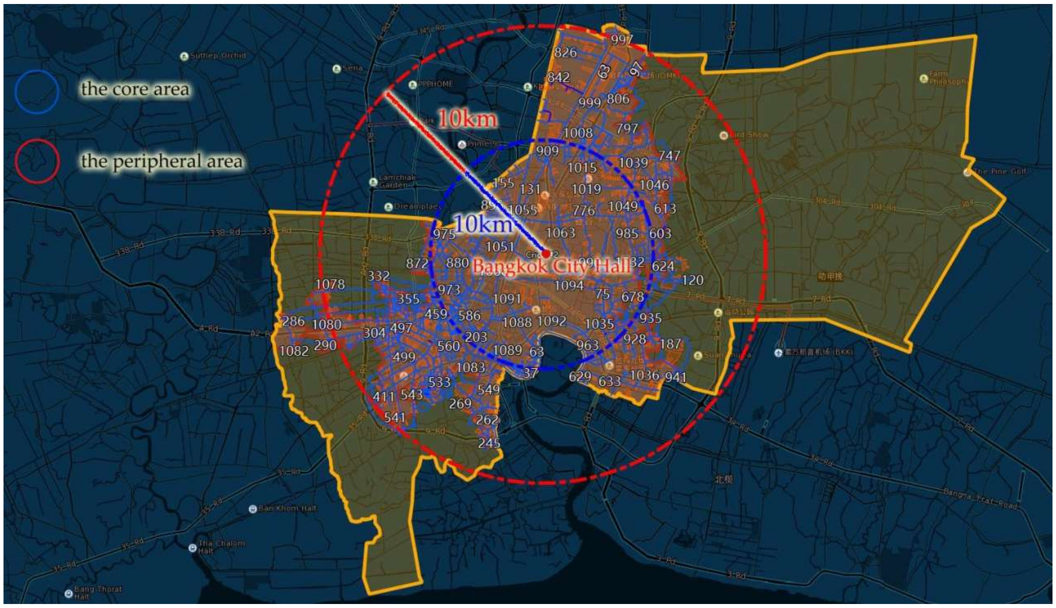

Fig. 3 Distribution of water network and storage points in the built-up area of Bangkok

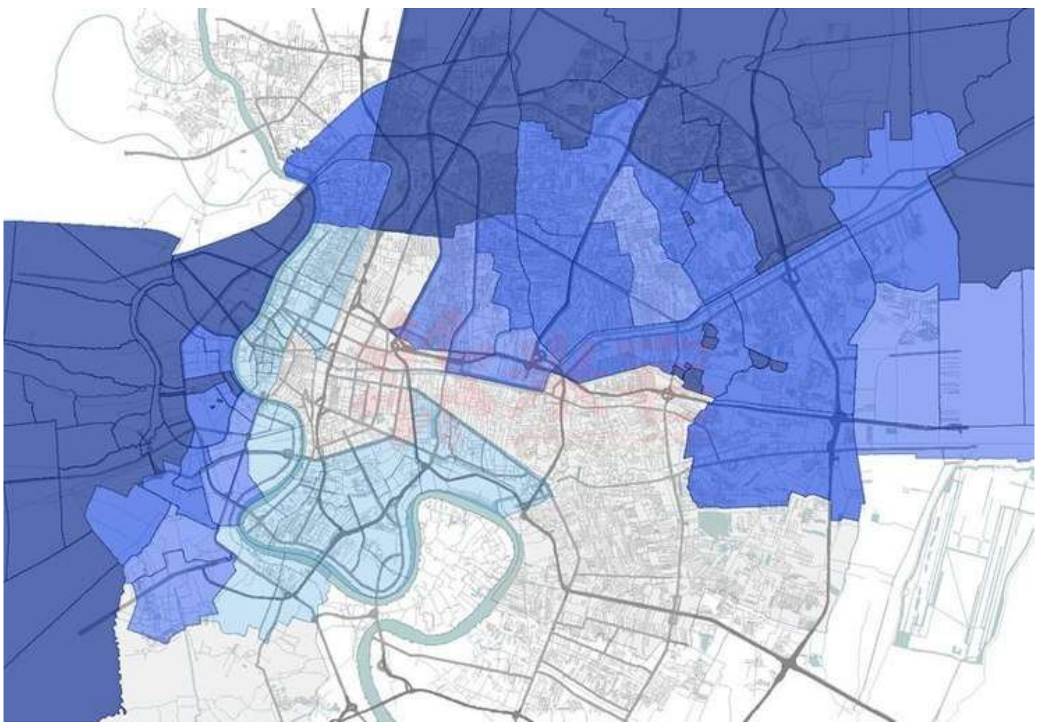

Fig. 4 Bangkok disaster map in 2011

Statistics using Google earth Pro and MegoMap software show that there are 586 sections of water systems within the study area, with a total length of 960.7 km (shown in blue in Fig. 3), with an average of 1.77 km of water network per square kilometer; 1,087 open spaces of various types of green areas, open spaces, squares, large parking lots, water bodies, woodlands, stadiums, and farmland in the fringe area, with a land area is 77.3 square kilometers (shown in orange in Fig. 3), with an average open space area of 0.14 km^2 per

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kilometer and an area share of 14%. Taking the maximum 24-hour rainfall of 300 mm in mid-September 2020 in Bangkok as an example, the total rainfall per square kilometer of built-up area is 79.2 million gallons. The built-up area has 0.14 km^2 of water storage site and 1.77 km of watercourse per square kilometer. The water storage site can store 73.92 million gallons of water based on an average excavation depth of 2 meters, and the waterway can store 3.51 million gallons of water based on an average width of 5 meters and a water depth of 1.5 meters, for a total of 77.43 million gallons of water per square kilometer. The existing water network and storage points can theoretically accommodate the maximum rainfall in Bangkok during the rainy season and can solve urban stormwater flooding.

2.2 Data Sources

Through Google earth Pro's 2019 high-definition satellite film and field verification, the potential 1087 Bangkok urban flood storage points and 586 sections of the current water system were depicted and counted. The KML files were generated using Google earth Pro software and imported into MegoMap and AutoCAD software for vectorization of the storage points and water system paths. The area of the storage node and the length of the water system path were counted, and the CSV file was output, which was imported into Gephi software for processing. Using the area of the storage point as the node weight and 100 times the reciprocal of the water system length as the edge weight, the node, edge and association parameters are counted and visualized.

2.3 Methodology

The green areas, vacand land, squares, large parking lots, water bodies, woodlands, stadiums, and farmlands in the fringe areas within the study area are defined as potential urban flood storage points. The area of the storage points is the weight of the network nodes, the larger the area, the larger the amount of water to be stored during flooding, and the greater the weight. The current urban water system that connects each storage point is defined as the network path edge. Considering the urban flooding, it is easy to produce rainwater diffusion, and the flow direction is uncertain, so it is defined as an undirected edge, and the weight of the edge is defined as 100 times of the inverse of the length of the water system (to facilitate numerical calculation). The longer the water system between two storage points, the weaker its flooding capacity and the smaller the weight. Using these storage points and the current water system, a water system network map of the built-up area of Bangkok was constructed.

First, the Gephi software was used to sort out and analyze the important parameter attributes of each node and edge in the water system network in the built-up area of Bangkok, including degree, weight degree, closness centrality, harmonic closness centrality, betweenness centrality, eigenvector centrality, pageranks, clustering coefficient, modularity_class, etc., to investigate the critical nodes and important paths in the flood safety pattern.

Second, through statistical analysis of global characteristic attributes such as network average degree, average weighted degree, network diameter, graph density, modularity, average clustering coefficient, eigenvector centrality, and average path length, we study the network structure and functional characteristics, explore the water network model, and lay a quantitative foundation for building a flood safety pattern.

Third, using the results of the above quantitative analysis, the key spatial locations and important water system paths in the water network of the built-up area of Bangkok are identified, and an urban flood safety pattern with key storage points and important water system paths as the backbone is constructed. Combining with the urban development needs and water network characteristics of Bangkok, the flood safety pattern will be adjusted and optimized in time to finally form an open, operable and defensible dynamic hierarchical flood safety pattern to achieve a balance between urban development and flood control.

3.Results and ana Analysis

By digitizing the network of potential storage points and water system connection paths in the built-up area of Bangkok, a water system storage network map (Fig. 5) and complex network visualization map (Fig. 6,Fig. 7) with 580 nodes and 1063 paths in the built-up area of Bangkok were constructed. 580 storage nodes have a total area of 72.6 km^2 and 1063 water paths have a total length of 905.4 km, and the average width of the water system is 5 m, with a total area of 4.5 km^2 , accounting for 14.2% of the built-up area of Bangkok (543.5 km^2). On average, there are 1.07 storage points per square kilometer, with an area of 13.36 hectares. The storage points are all calculated at a depth of 2 meters, which can store 70.22 million gallons of water; the waterways are all calculated at a depth of 1.5 meters, which can store 3.31 million gallons of water per square kilometer of the built-up area's water system path, for a total of 73.53 million gallons of water. The theoretical equivalent of 278.5 mm of very heavy rainfall can be stored.

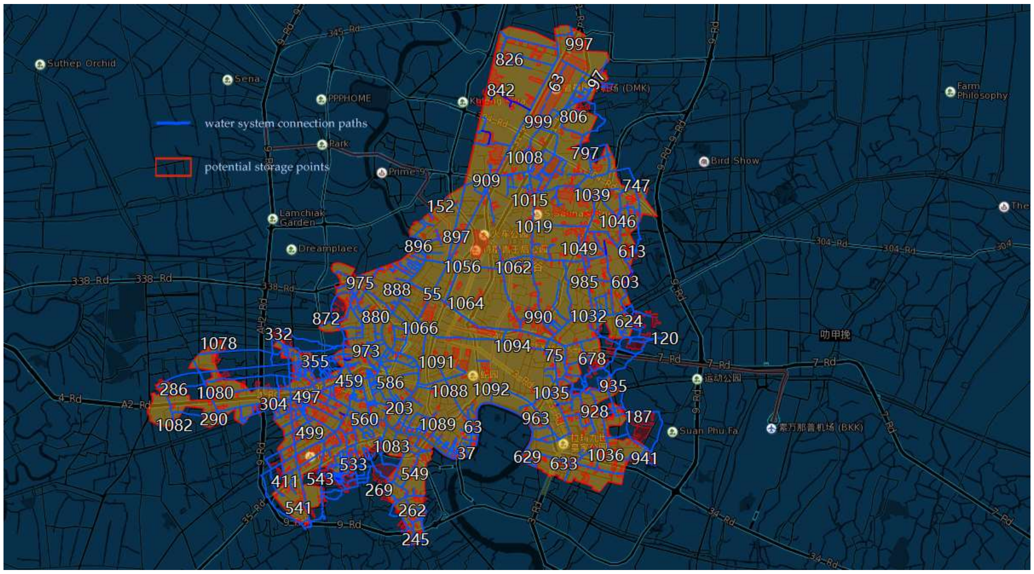

Fig. 5 Map of the water system storage network in the built-up area of Bangkok

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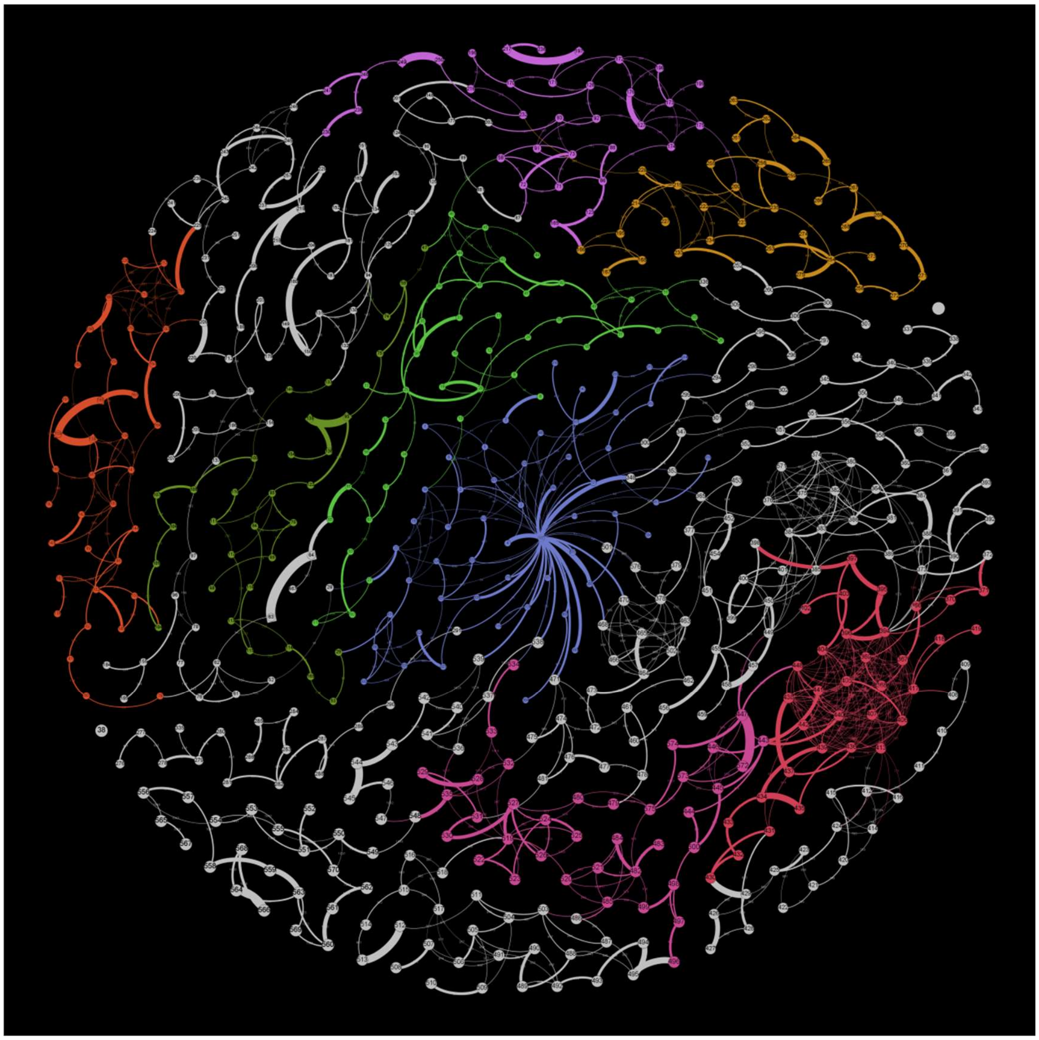

Fig. 6 Visualization of the complex network of storage points-water systems in the built-up area of Bangkok(Fruchterman Reingold Layout)

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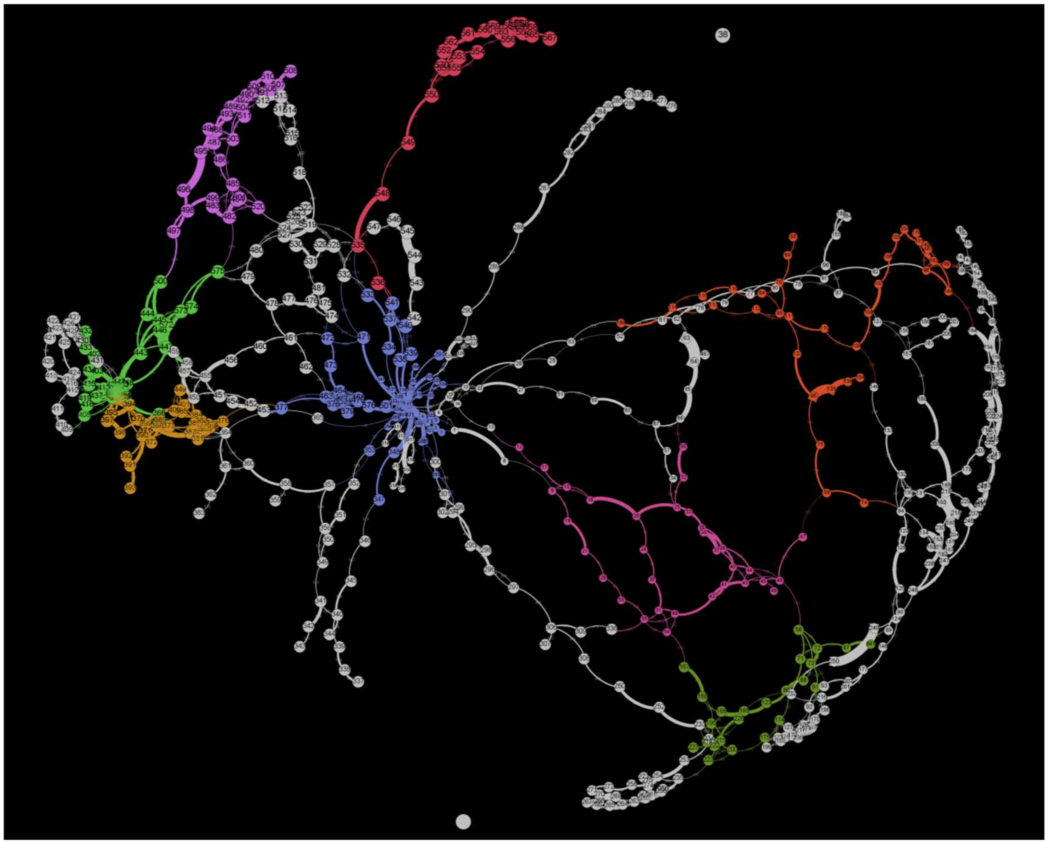

Fig. 7 Visualization of the complex network of storage points-water systems in the built-up area of Bangkok(OpenOrd Layout)

The total length of 1063 path sides is 1589.5 km, excluding the overlapping part of the water system and no connection to the network water system, the total length of the water network path is 905.4 km. The average length of the water system paths between the storage points is 0.85 km, which matches the scale of modern city 0.8 km neighborhoods and the scale of urban arterial traffic network (0.8 km-1 km), and has a good basis for coupling modern urban pattern, forming a water-land dual transportation system and unique urban structure and appearance.

3.1 Analysis of the main characteristic parameters of the water system storage network

（1）Degree Centrality and Weighted Degree

Degree Centrality is the most direct measure of node centrality in network analysis. The greater the degree of a node means the higher the degree centrality of the node, the more important the node is in the network. As shown in Table 2 and Table 3, the degree values of the built-up area storage points in Bangkok are exponentially distributed, which has the characteristics of scale-free network model, with a few core nodes having very high degree values and other nodes having exponentially lower degree values. In the scale-free network model, the nodes with small degree values have less influence on the structure and function of the network, and their removal does not cause great damage to the whole network, so the scale-free network is robust. There are 19 nodes with degree values greater than or equal to 17,

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accounting for 3.26% of the total number of nodes in this network. The three nodes with the highest degree values are node 17 (degree 45), node 394 (degree 23) and node 413 (degree 21). Node 17 is the Chao Phraya River, which runs through the main urban area of Bangkok, where the water systems on both the east and west banks converge into the river, and is the absolute core node in the built-up area of Bangkok and the main channel for flood discharge. 394 is located in the northwest area of the river bank, where the water network is extensive and the storage points are interconnected, and the degree values of several nodes are greater than 17, forming a cluster of high value nodes. As shown in Fig. 8, there are 37 nodes with degree values above 8, and this region accounts for 35 of them. The remaining two nodes, 519 and 100, are the core points of the southwestern region and the northeastern region, respectively, and are important key storage points for these two regions.

In the weighted degree statistics in Table 4 and Fig. 9, node 17 (Chao Phraya River) has a larger catchment area and its weighted degree is much higher than the other nodes. The cluster of height-valued nodes in the west is more concentrated, the interconnection path is shorter, the weight of the edge is larger, and its weighted degree is relatively high, forming an important key space in the western region. The southwestern and eastern part of the built-up area in Fig. 9, although the degree centrality is not high, the weighted degree is higher because of the shorter length of the interconnection path of the water system in the region and the greater weight of the edges, which becomes an important node in the region.

Table 2 Nodal degree statistics table

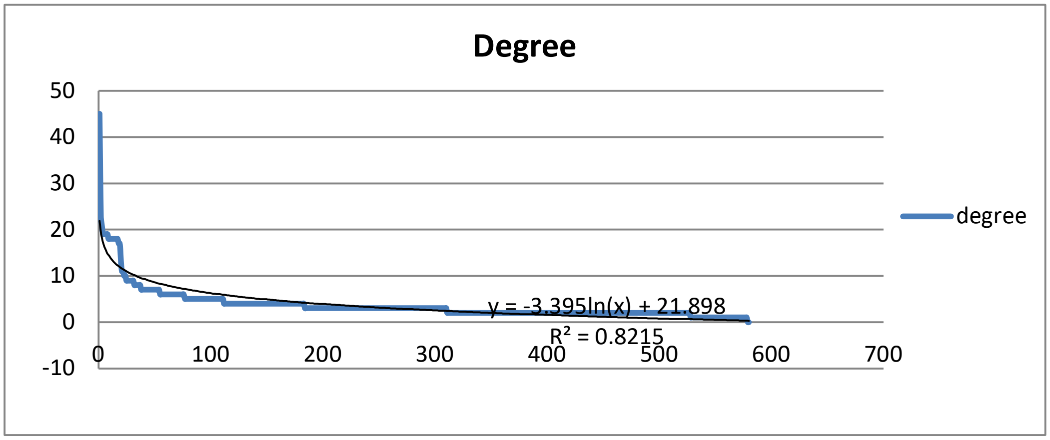

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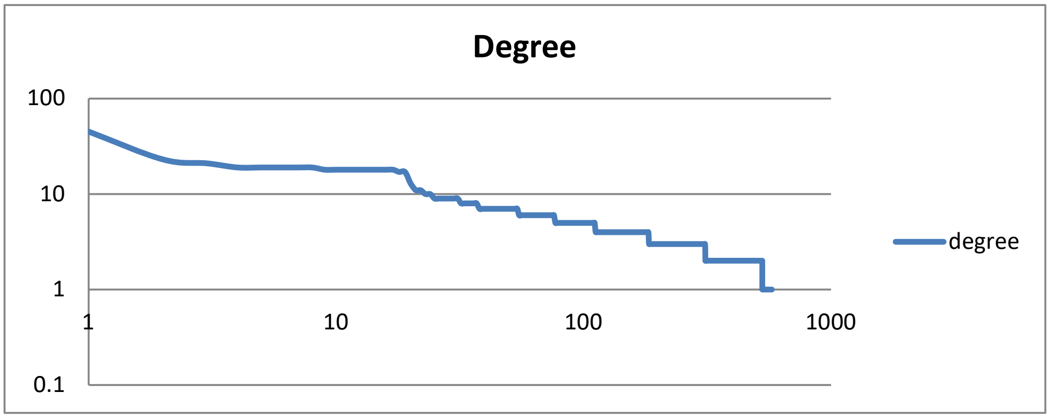
Table 3 Statistical table of nodal degree index



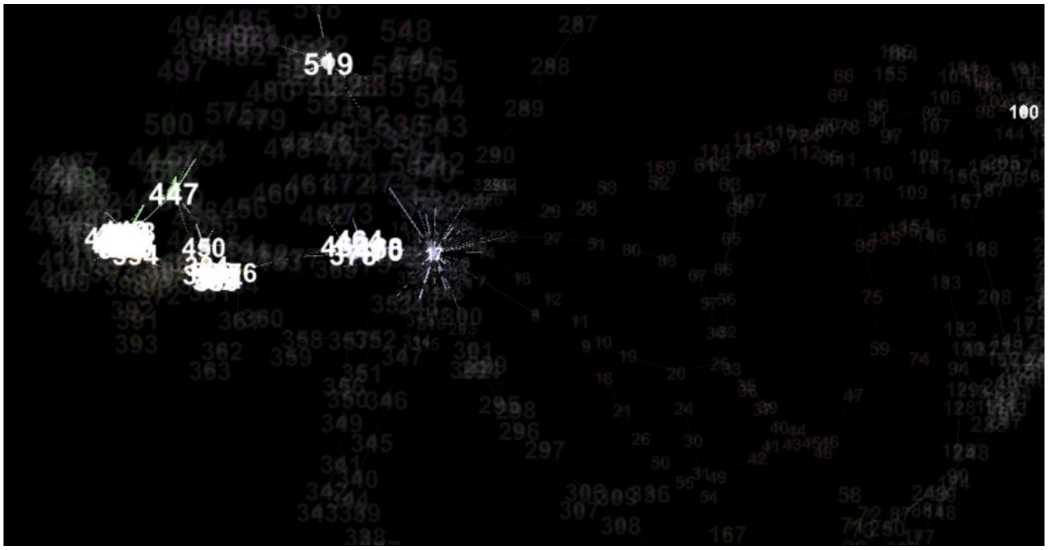
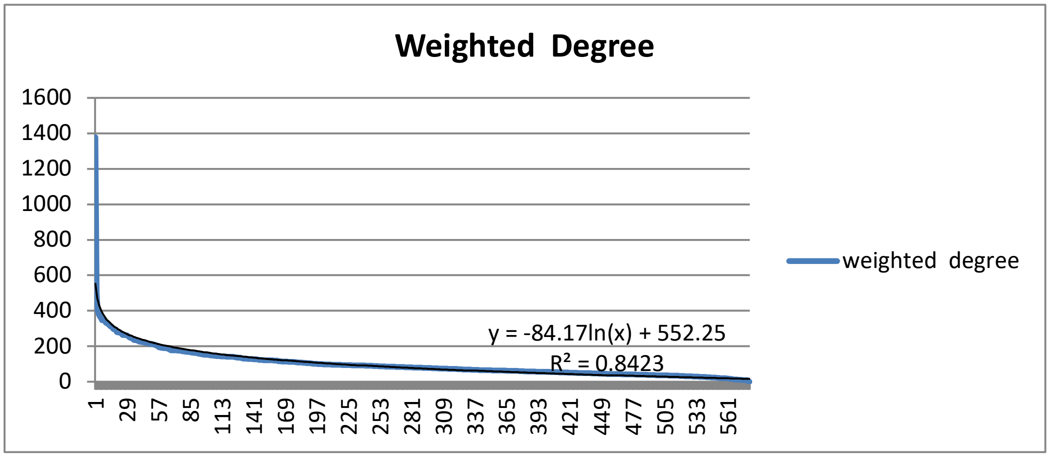


Fig. 8 Distribution of higher degree network nodes

Table 4 Nodal weighted degree distribution table



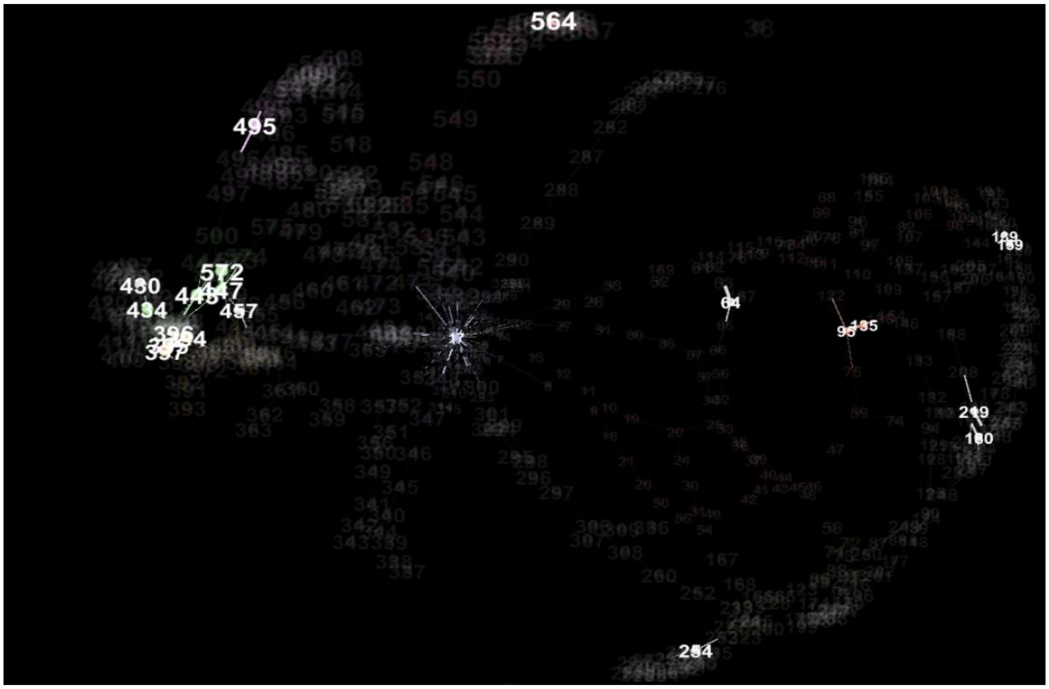


Fig. 9 Distribution of network nodes with higher average weighted degree

（2）Closeness Centrality and Harmonic Closness Centrality

In the field of topology and related mathematics, closeness centrality is a fundamental concept in topological spaces. The closeness centrality of a point is the average of its distance to all other nodes. The higher the closeness centrality of a point, the closer the point is to all other points in the network in general, enabling faster and more efficient material exchange and energy transfer with neighboring nodes. For example, to select a storage point as the core node in a regional water network, so that it can be connected to the surrounding nodes for rapid water storage when flooding occurs, it is required to have the closest spatial distance to other storage points in general, then one way is to find the storage point with the highest closeness centrality. Harmonic closeness centrality is a variant of closeness centrality, which is mainly used to deal with disconnected networks. The overall trend of the closeness centrality and the harmonic closeness centrality values of the nodes in Table 5 are the same. The closeness centrality of node 17 in Table 5,6 and 7 is much higher than other nodes, and the closeness centrality of the first 40 nodes decreases gently and linearly starting from node 22, which is ranked 2nd, and the closeness centrality of the later nodes decreases faster, forming a cluster of nodes with node 17 as the core and 40 nodes as the sub-center with high closeness centrality. In Fig. 10 and Fig. 11, the nodes with high closeness centrality and harmonic closeness centrality all have node 17 as the core and nodes 22, 23, 365, 471, 300, 14, 16, 7, 15 and 534 as the secondary cores, in contrast to the reality that most of the water networks in the east and west regions are discharged into the Chao Phraya River through the secondary core storage points on the banks of the Chao Phraya River. In Table 5 and Fig. 11, the harmonic closeness centrality of nodes 394 and 413 is also high, and in reality these two nodes

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are located in the northwest region, which are connected to several surrounding nodes in close proximity and are the core storage points in the region.

Table 5 Nodal closeness centrality and harmonic closeness centrality value table

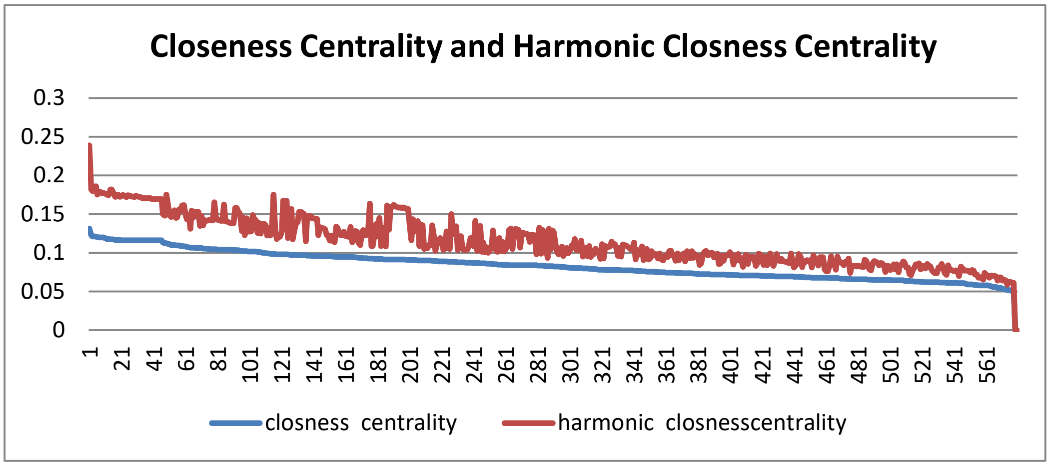


Table 6 Nodal closeness centrality value table

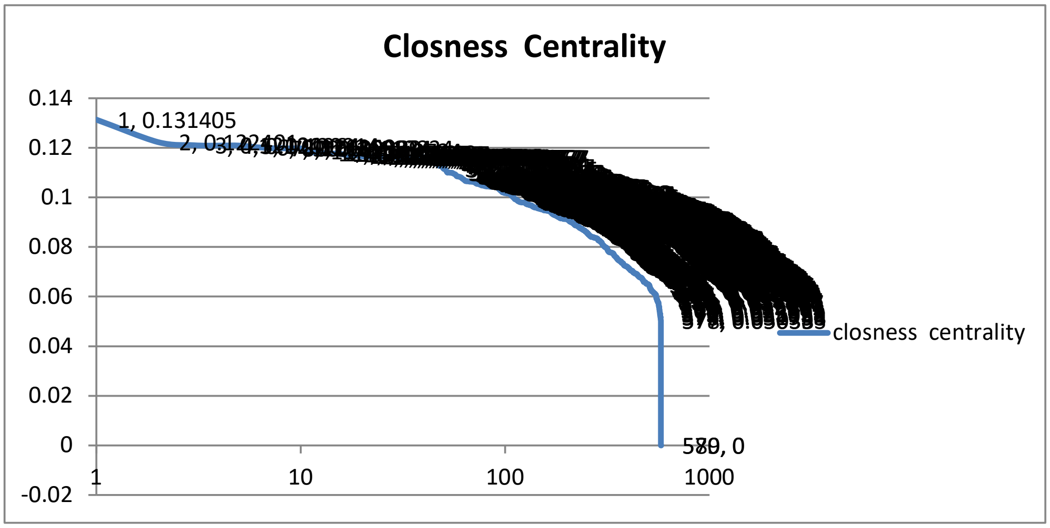
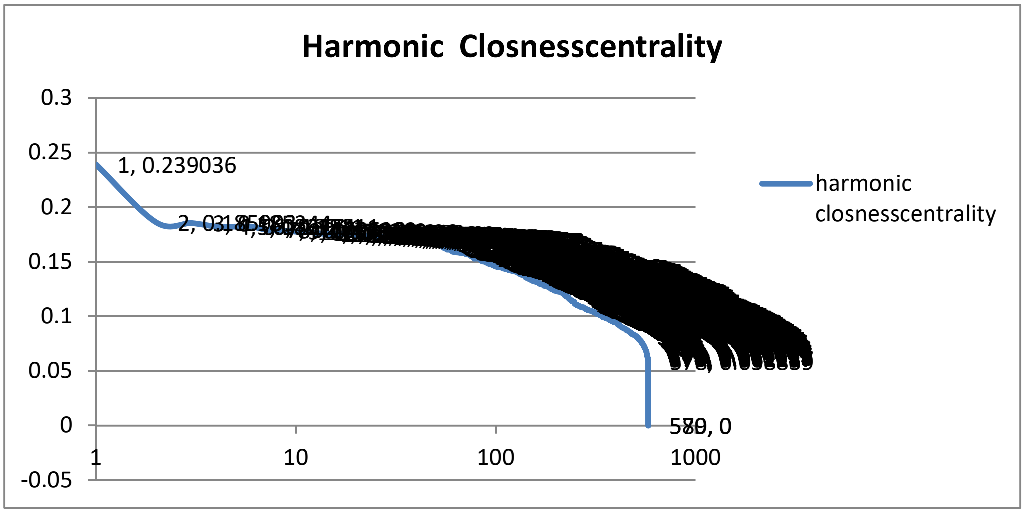


Table 7 Nodal harmonic closeness centrality value table



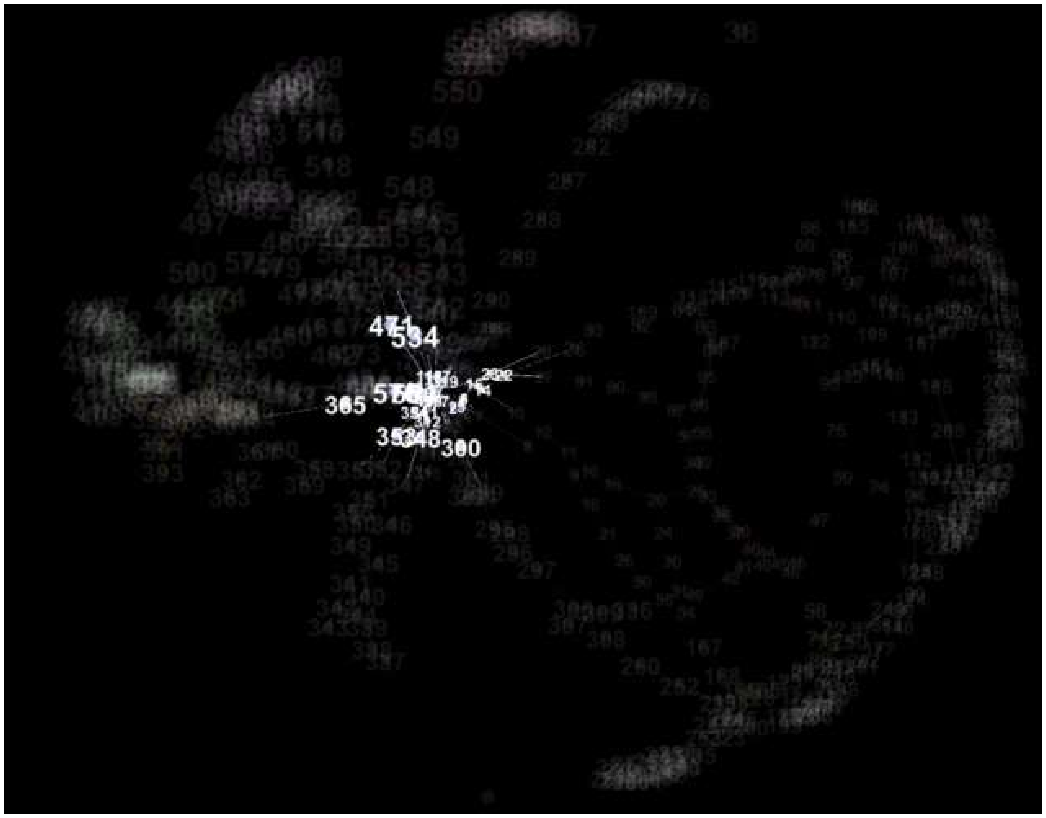


Fig. 10 Distribution of nodes with high values of closeness centrality

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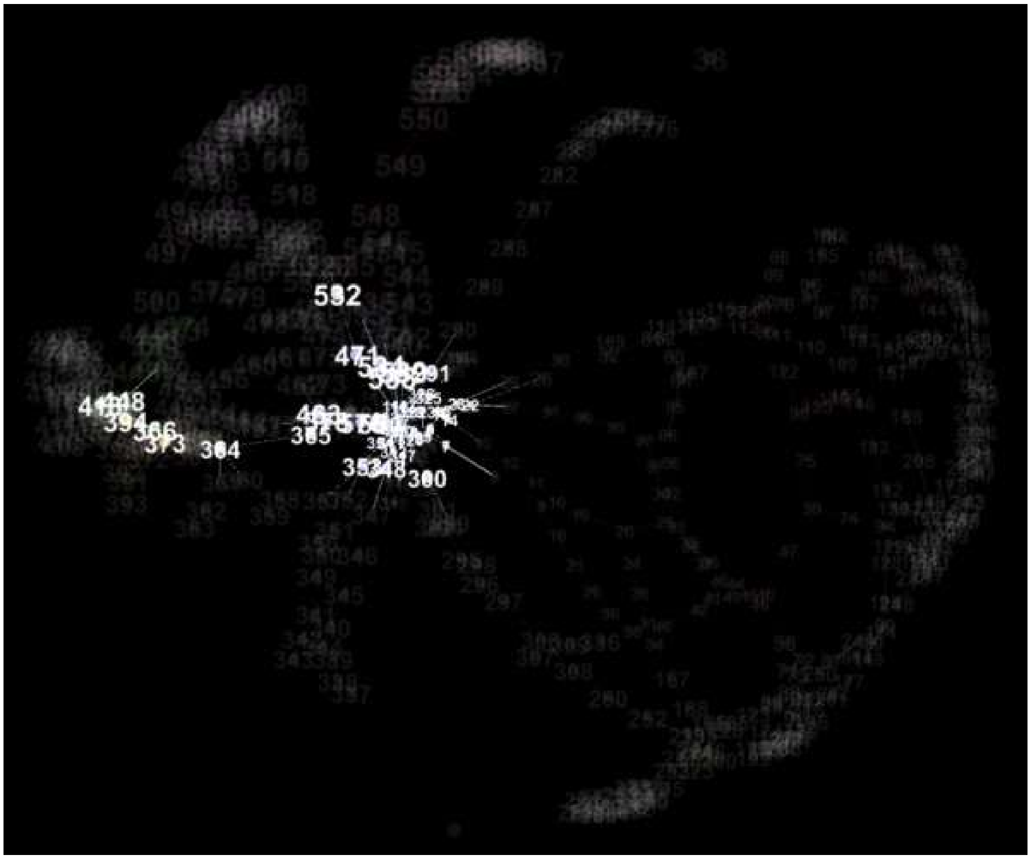

Fig. 11 Distribution of nodes with high values of harmonic closeness centrality

（3）Betweenness Centrality

Betweenness centrality is a metric that portrays the importance of a node in terms of the number of shortest paths through a node, and is the number of times a node acts as a bridge for the shortest path between two other nodes (Newman B. W., 2006). Betweenness centrality is a test of the degree to which a node influences the flow of information in a network. The more times a node acts as an "intermediary", the greater its Betweenness centrality, indicating that many, even all, of the shortest paths between other points must pass through it, and the more important its influence on the flow of information in the network. If this point disappears, then communication between other points will become difficult or may even be disconnected. Table 8 show that node 17 has extremely high values of betweenness centrality, and six nodes, including 364, 365, 22, 471, 28, and 52, also have values over 30,000, corresponding to the status quo in which these nodes are the transit centers of the western and northeastern water networks, respectively. As shown in Fig. 12, the final formation of the node 17 as the core, with 28 high betweenness centrality as the backbone, radiating eastward, northeastward, southeastward, westward and southwestward network of five water flow "intermediary" belts.

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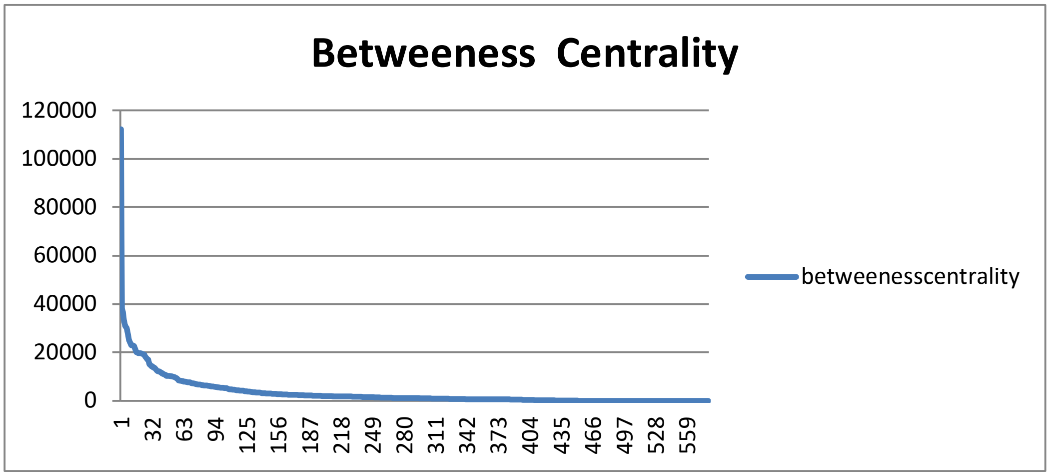
Table 8 Nodal betweenness centrality value table



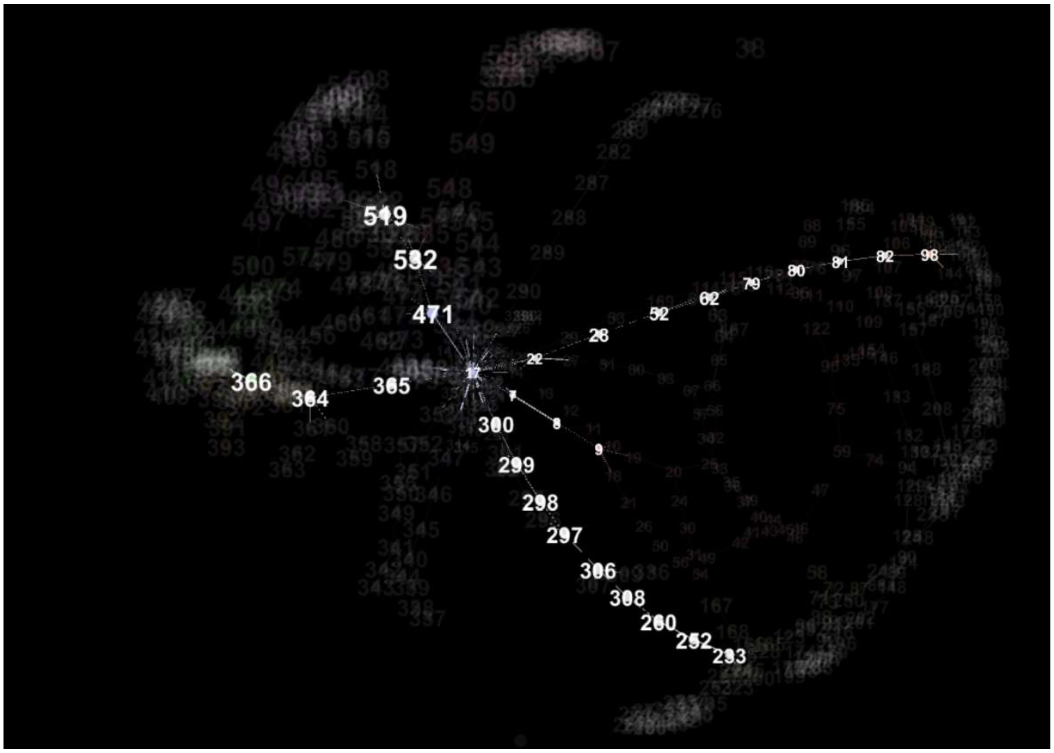


Fig. 12 Five "intermediary" belts of network water flow with high median centrality

（4）Eigenvector Centrality

Eigenvector centrality measures the importance of a node by considering the importance of neighboring nodes, and is an algorithm for measuring the transfer of influence or connectivity between nodes. The main principle is that connections from important nodes (measured by Degree Centrality) are more valuable than connections from unimportant nodes, and that connections to nodes with high scores yield a greater contribution than connections to nodes with low scores. For example, a node with 300 very popular friends has a higher eigenvector centrality than someone with 300 relatively unpopular friends. All nodes

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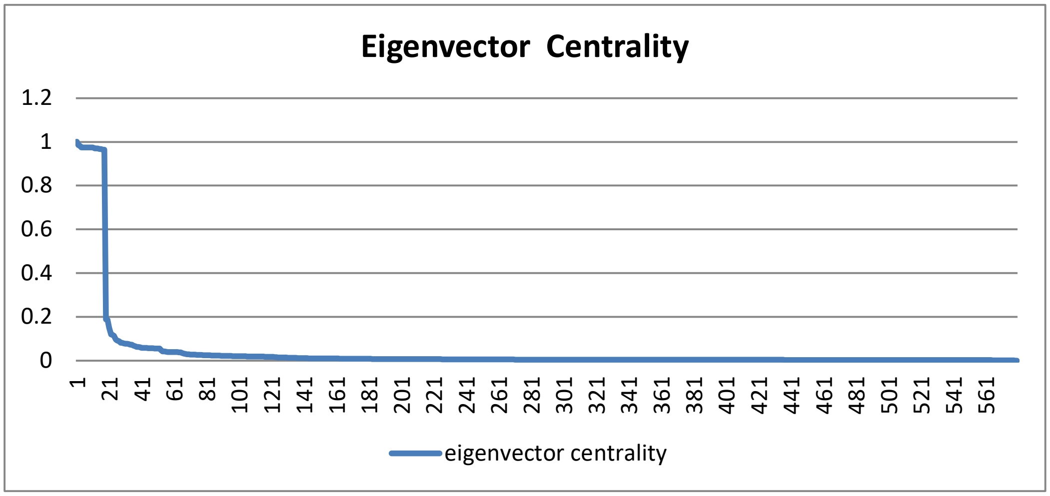
start equally, but as the computation proceeds, nodes with more edges start to become more and more important. Their importance propagates to the connected nodes, and after several iterations of the calculation, these values stabilize, resulting in the final value of eigenvector centrality (S.Boccaletti, 2006). As shown in Table 9, the eigenvector centrality of the first 18 nodes is greater than 0.9, and the 19th node eigenvector centrality falls precipitously to 0.18. Fig. 13 shows the network visualization of the 18 nodes with high values of eigenvector centrality, which are located in the western part of the Chao Phraya River. The water network in this region is uniformly dense, and each storage point is spatially staggered through each other, and the spatial water network tends to be a regular network model with a good basis for flood storage.Fig. 14 shows the viewable view of eigenvector centrality value greater than 0.1, and the number of nodes increases to 24, which is basically also located in the western region. The only node 17 (Chao Phraya River with a value of 0.15) is added, which also has a relatively high eigenvector centrality as the core point of the entire network catchment.

Table 9 Nodal eigenvector centrality value table



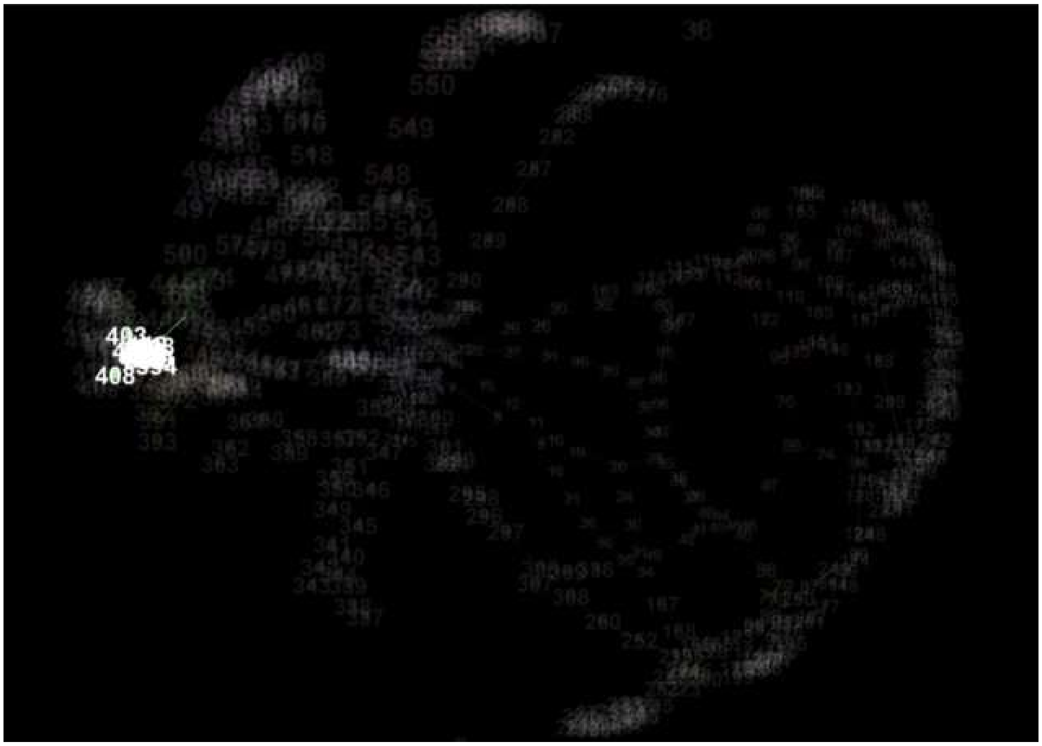


Fig.13 Distribution of nodes with eigenvector centrality number values > 0.9

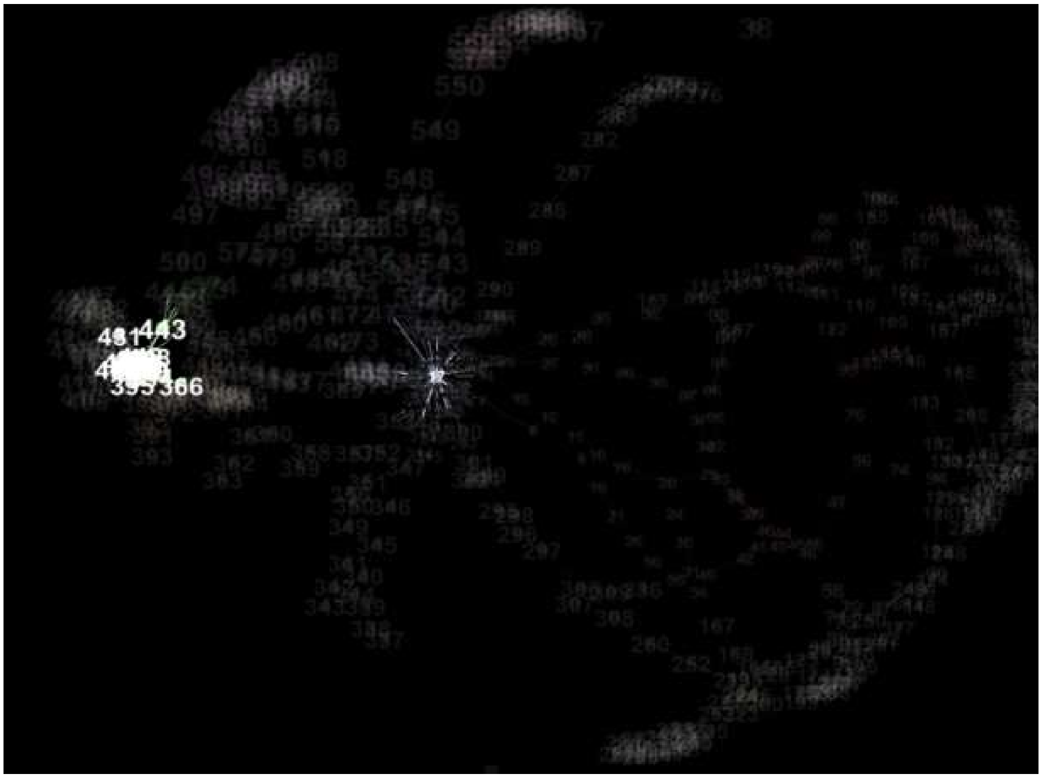


Fig.14 Distribution of nodes with eigenvector centrality number values > 0.1

（5）Pagerank and Clustering Coefficient

PageRank is Google's proprietary algorithm for measuring the importance of a particular web page relative to other pages in the search engine index. In complex networks, nodes that can be reached from more places are usually more important and therefore have higher PageRank. (Ben-Naim, 2004) Table 10 and Fig. 15 show that nodes with high PageRank values in the network are divided into two cases. One is such as node 17, its own degree value is high, there are many surrounding water system paths to the node, so the PageRank value is high, becoming the regional core point; the second is such as 135,159,544 nodes, its own degree value and the number of arrival paths is not high, but its node weighted degree and access paths weighted high, as shown in the current site spatial water network that is the storage point water area is larger, connected to the water system The paths are shorter and the calculated PageRank values are higher. Fig. 15 shows that there are 24 nodes (groups) with high PageRank values in this network, which become strategic key points in the water storage network. When flooding occurs, regional flood water is quickly gathered to these storage points through the connected water system, which greatly alleviates the flooding situation. At the same time, according to the regional flood storage volume, the sink area of nodes (groups) with high PageRank and the number and length of connected water systems are optimized and adjusted to control key storage nodes (groups), simplify the network structure, enhance network stability and defensibility, and improve the flood storage function.

In graph theory, the clustering coefficient is a parameter that indicates the degree of aggregation of nodes in a graph. (Noble, 2009) Specifically, it is the degree to which the neighboring points of a point are connected to each other. In Fig. 16, the nodes with an clustering coefficient of 1 have their neighboring nodes connected to each other, forming a cluster of open networks with relatively high density. In the current spatial water network, these nodes with high aggregation coefficients are more evenly distributed throughout the network space, and form multiple clusters with higher densities with neighboring nodes, showing a homogeneous water network on a global macroscopic scale, and a large heterogeneity on a local microscopic scale. This pattern does not form a core key point in the local area, but exists as a group of key points connected to each other. This is conducive to combining the site geography and urban planning and development requirements to flexibly adjust individual nodes without affecting the overall storage transfer capability. Each node in the cluster is replaceable, and the importance of individual nodes is not emphasized, only the integrated storage capacity of the cluster nodes needs to be controlled.

These two parameter algorithms give different meanings to the network nodes, which are analyzed and compared together to facilitate the measurement of the network status and value of the nodes. Based on the quantitative analysis results of node pagerank and clustering coefficient, combined with the current geographical conditions and urban development needs, the node location, area and the number and length of water system paths are appropriately integrated, and the parameter attributes are adjusted and optimized to explore a stable, efficient and synergistic development of flood safety pattern.

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Table 10 Nodal pageranks value table

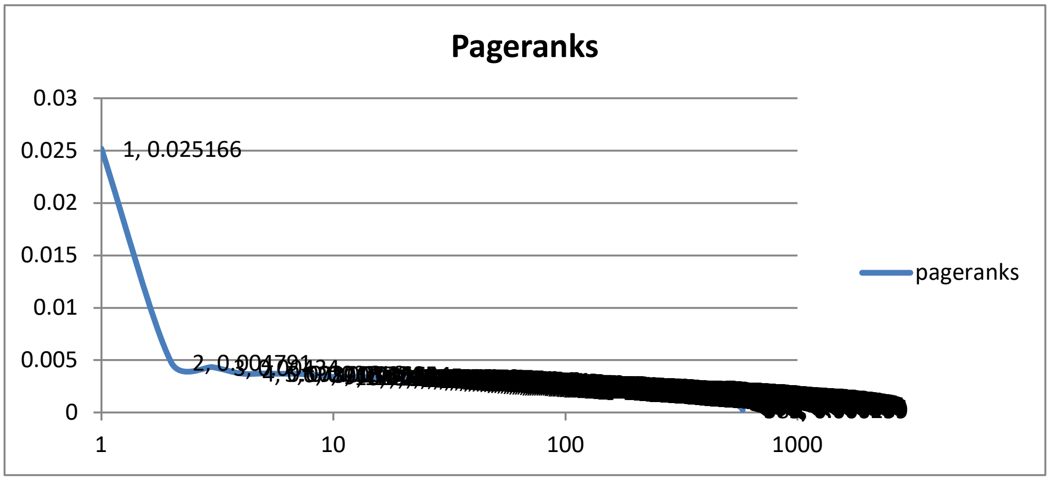
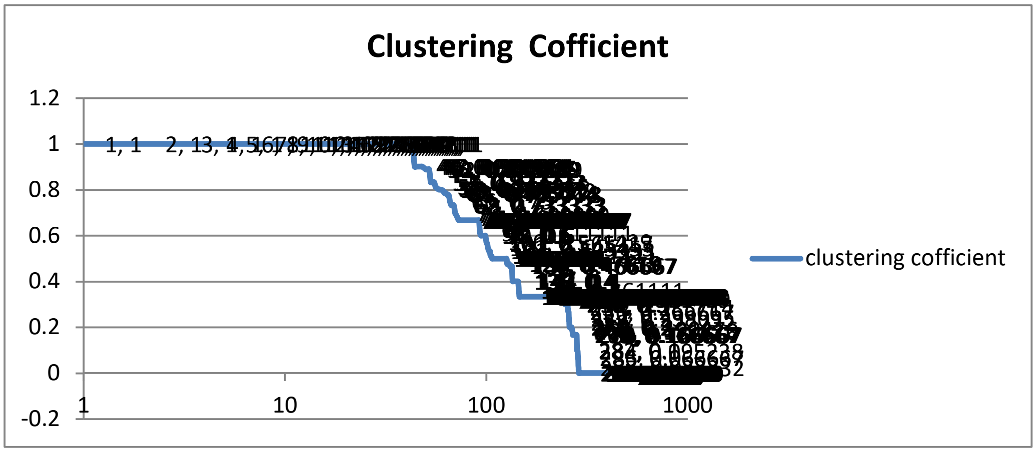


Table 11 Nodal clustering coefficient value table



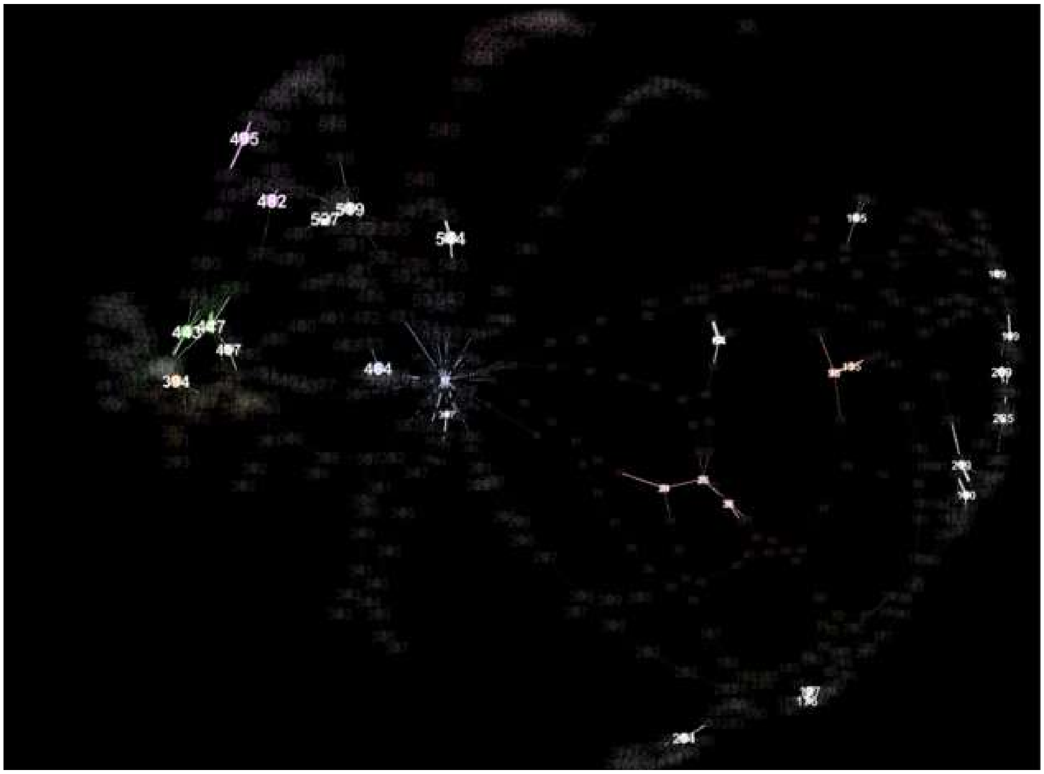


Fig.15 Network distribution of nodes (groups) with higher Pagerank values

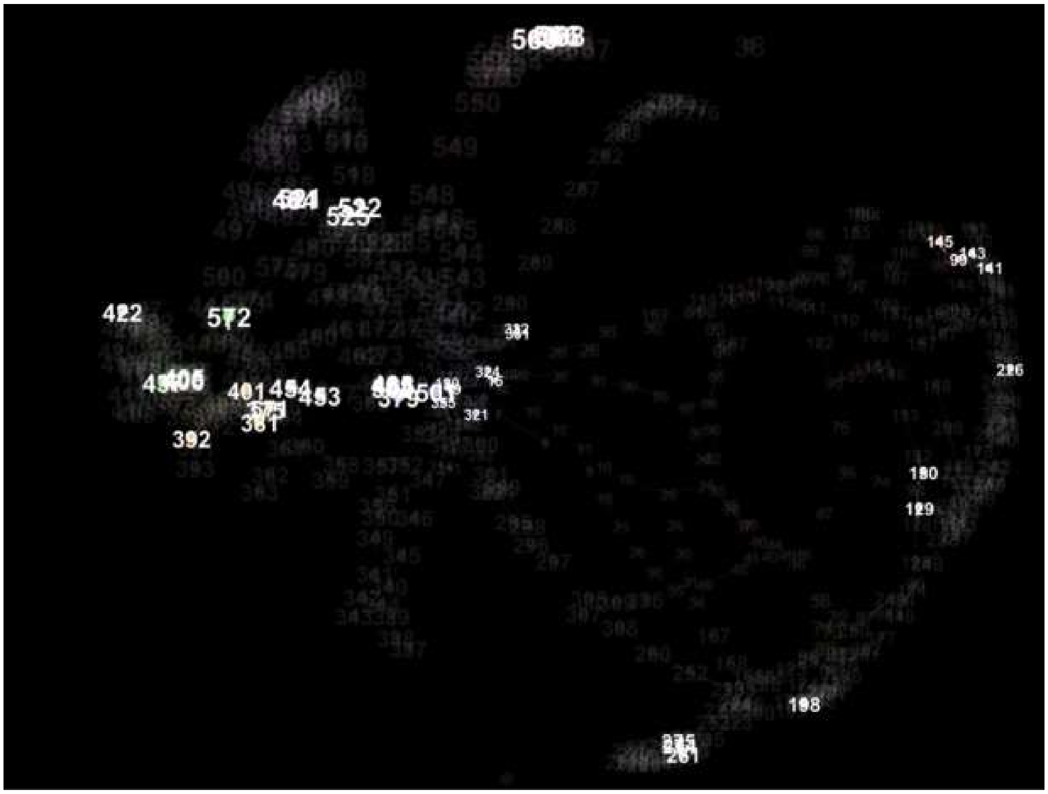


Fig.16 Network distribution of nodes (groups) with clustering coefficient of 1

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（6）modularity_class

Modularity_class is an important community evaluation metric that utilizes the definition of community structure, where nodes within a community are more closely connected and the probability of two nodes in a community having an edge is higher than the probability of two nodes in a random graph having an edge (Albert R, 2002) . The community structure is a reflection of the nature of the network at the mesoscopic scale, and the study of the structure of the communities in the network is an important way to understand the structure and function of the whole network. As shown in Table 12, the whole network is divided into 27 associations, among which there are 4 associations with more than 30 nodes. As shown in Fig.17, with Node 17 (Chao Phraya River) as the core, the community with 57 nodes as the largest association is distributed radially to form the core of the entire network. The other three large societies are located in the eastern, northeastern, and western regions of the Chao Phraya River Society. The eastern society are arranged in a ring shape, the northeastern society are arranged in a tandem shape, and the western society are distributed in a composite shape (both tandem and ring), and these three major societies are the core societies in each region. The 11 major societies with nodes in the range of 20-30 are shown in Fig.18, forming a radial structure that connects the core societies with other end societies and forms the main society structure of the network with the 4 major core societies. Through node modularity_class analysis, a clear network structure and community hierarchy is obtained, which lays the foundation for building a flood safety pattern.

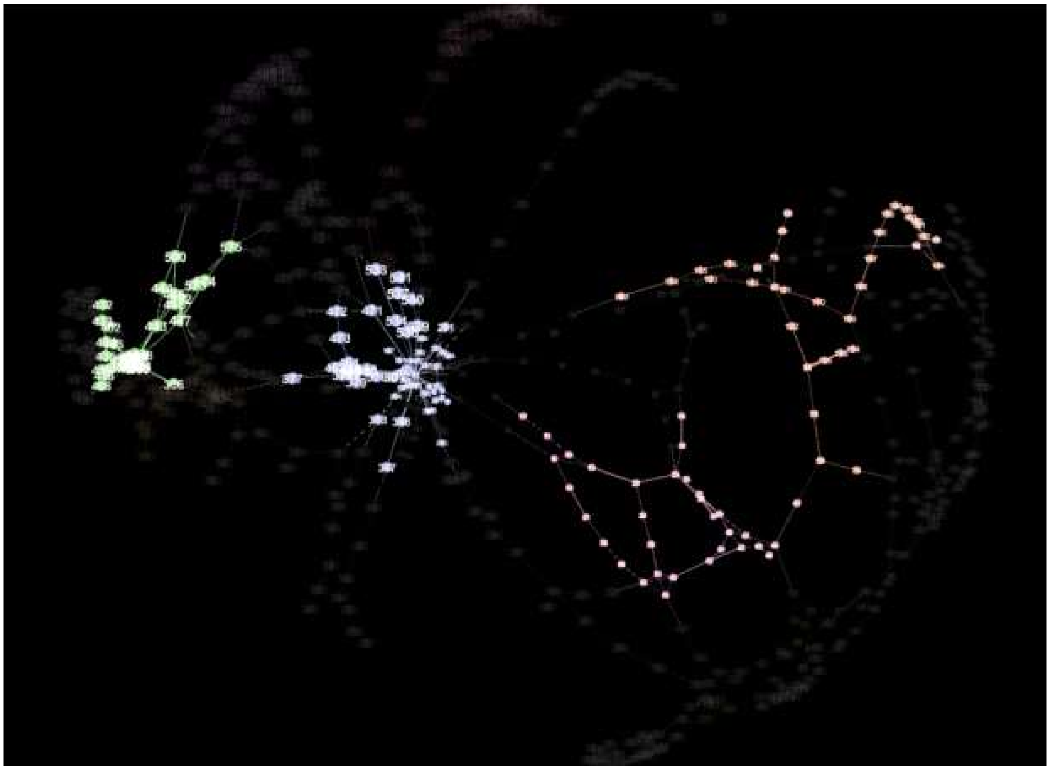

Fig.17 Network distribution of the four core associations

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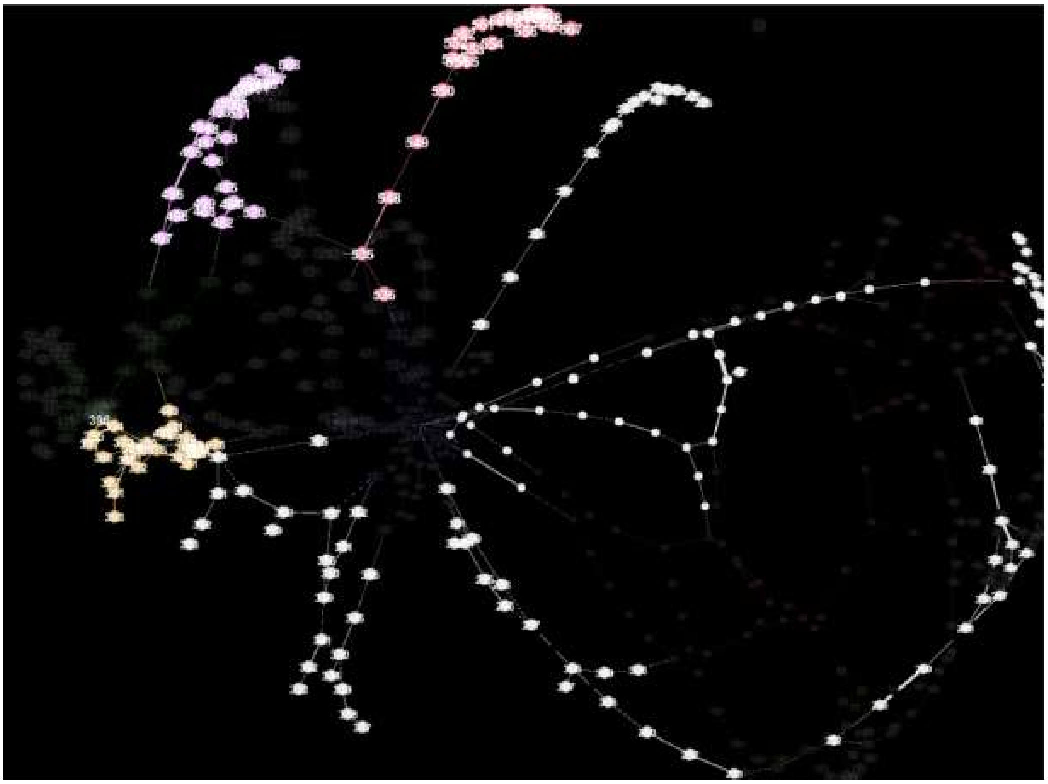
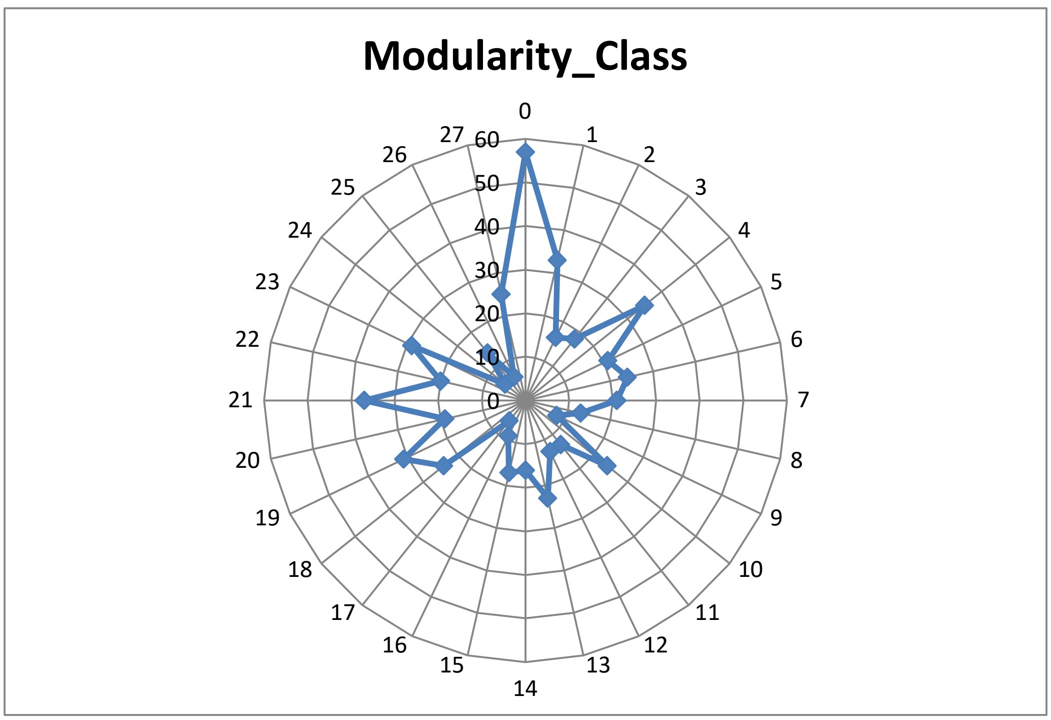


Fig.18 Network distribution of 11 major associations

Table 12 Nodal number distribution of the 27 associations



3.2 Network evolution model

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The average degree measures the activity of the overall network nodes, with lower degree values indicating less interaction between nodes and conversely more connections. Using Gephi software, the average degree of the water network in the built-up area of Bangkok is 3.666, indicating that on average each storage point is connected to 3.7 surrounding storage points. In a water network with a planar spatial layout, this connectivity degree is high, indicating that the Bangkok water system network has a good basis for flood storage. The average weighted degree is calculated as the node degree based on the weights of connected edges, and then the average degree is calculated based on the weighted degree, which is the sum of the weighted degrees of all nodes divided by the number of nodes. The average degree is a special case of the average weighted degree, and the weight of each edge of the average degree is 1. The value of the weight of the edge in this water network is defined as 100 times the inverse of the length of the water system path, and the average weighted degree of the water system storage network is calculated as 100.232 with a weighted degree of 27.34. The length of the edge of the entire network weighted path is 0.4 km, which coincides with the scale of a small modern urban neighborhood(0.4 km x 0.4 km).

The diameter of this water system network is 31, and based on the average water system length of 1.5 km between the transfer points (the total length of 1063 path sides is 1589.5 km), the length of the network diameter is 46.5 km, which is consistent with the distance between the farthest east and west points of the built-up area of Bangkok. The network graph density is 0.006, which indicates that the network nodes are loosely connected and belong to a sparse network. This is because the distance between water network storage points is limited by flat space, unlike virtual networks such as the Internet, interpersonal networks, and social networks, which are not limited by spatial distance and will have a high degree of closeness. The lower graph density is a characteristic of geospatial physical networks.

Network modularity is used to measure whether the division of a community is a relatively good result. A relatively good result has a high similarity of nodes inside the community and a low similarity of nodes outside the community. The magnitude of modularity is defined as the ratio of the total number of edges inside the community to the total number of edges in the network minus an expectation value. This expectation value is the magnitude of the ratio of the total number of edges within the community formed by the same community assignment to the total number of edges in the network when the network is set as a random network (Watts D J, 1998).The degree of modularity is expressed as a Q-value ranging from 0 to 1. A larger Q-value indicates a more accurate community structure for network partitioning. In real networks, the highest Q values generally occur between 0.3 and 0.7. The modularity of this water system network is 0.899, which is a high value, indicating that the community structure level of the whole water system network is very obvious, and further analysis of each community structure level and key storage points has important practical significance and basis for the layout planning of the water network geospatially.

The clustering coefficient describes the likelihood that neighboring nodes of individuals in the network are also neighbors of each other. In general, the magnitude of the clustering coefficient affects the propagation dynamics on the network, and the larger the average node

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clustering coefficient, the slower the propagation when other parameters are constant (Watts D J, 1998). The average clustering coefficient of 0.28 for this network is a low value, indicating that the connectivity between a storage point and its surrounding storage points is not tight, which is limited by the characteristics of the planar geospatial network. The low clustering coefficient ensures the timely spatial transport and diffusion of the stored water, which facilitates the rapid deployment of inter-regional flooding.

The eigenvector centrality of this water network is 0.032, and the network tends to be randomized. Combined with the node degree parameter distribution, there are a few important key points in the network in the absolute core position, making the network again has scale-free network characteristics. Using the robustness characteristics of the scale-free network to occupy key storage points and important water system paths is important for rapid urban flood discharge and flooding.

The average path length of the water network is 12.466. Based on the average water system length of 1.5 km between the storage points, the average path length of the network is 18.7 km, which is slightly smaller than the diameter of the core built-up area of Bangkok (20 km), indicating that the constructed network conforms to the current geospatial characteristics. For planar spatial networks such as geoscape and water system storage networks, identifying the key locations, nodes and paths in their networks is an important purpose of studying the networks. By identifying these key nodes and important paths to simplify the network structure and optimize the spatial layout, the scientific and quantitative design of geoscape and water system storage network is realized.

In summary, the constructed water system storage network is a typical flat geospatial network, which is different from the Internet, social networks, interpersonal networks, communication networks and other networks that are not constrained by space. Through the verification of each characteristic parameter, the simulated constructed water system storage network is consistent with the characteristics of complex networks and can be scientifically quantified and analyzed. This lays the foundation for the planning, layout and optimization of the water system storage network in the built-up area of Bangkok by using the theory related to complex networks, and introduces a new research method for the analysis, planning and evaluation of urban water networks. The evolution model of water system storage network constructed by the simulation is different from the common single rule network model, stochastic network model, small world network model or scale-free network model in complex networks, but presents a composite network model feature. Due to the influence of planar geospatial factors, its network has the characteristics of a partially random network model, with lower graph density, average clustering coefficient and eigenvector centrality than the small-world network and regular network models, and larger network diameter and average path length than the small-world network model and regular network model. And its node degree distribution is similar to the scale-free network model, with typical robustness and vulnerability; meanwhile, the network modularity value is high, the association structure is obvious, and some associations have self-similar network model characteristics. The analysis of these characteristics introduces a new field for the study of water system storage networks.

3.3 Flood safety pattern in the built-up area of Bangkok

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Based on the water storage network map of the built-up area of Bangkok (Fig.19), the attribute parameters of 581 network nodes were analyzed using complex network correlation theory. As shown in Tables 13 and 14, the green color indicates that the importance of nodes is measured by five attribute parameters such as degree, authority, hub, eigenvector centrality and triangles, and the nodes with the top ranking are selected as the key planning and construction nodes; the magenta color indicates that the important connectivity and sparsity of nodes are measured by three parameters such as Closeness Centrality, Harmonic closness centrality, Betweeness centrality, etc. The nodes with the top ranking of parameters are selected as the key planning and construction nodes; the purple and orange colors indicate that the centrality of nodes is measured by two parameters reflecting the degree of aggregation, pagerank and clustering coefficient, and the nodes with the top ranking of the parameters are selected as the key planning and construction nodes. Through the ranking statistics of 581 storage points with 11 parameters in 4 categories, 120 storage points with more than 6 parameters ranked in the top 100 were selected as the key nodes of the network (shown in Table 14), combined with 3 parameters, such as Weight, Weighted degree and Modularity, which reflect the catchment area of storage points and the structural characteristics of network associations, and Based on the full consideration of the water network and the surrounding geographic space, urban environment, road traffic and planning and construction, 25 key nodes were added, and a total of 145 key storage points were identified. By sorting out and planning these important nodes and their important connecting paths, a flood safety pattern of Bangkok built-up area with 145 key nodes and 127 important rivers as the backbone was constructed (shown in Fig.20), and the robustness and vulnerability theories in complex networks were also applied to the tolerance and resistance of the flood safety pattern.

The flood safety pattern in the built-up area of Bangkok is based on a framework of radioactive backbone cluster points, linking major associations and forming wedge-shaped open spaces penetrating into the core area of the city in combination with the water system path. In the core area, small storage points are built in combination with urban green space and open space to save land for urban development as much as possible. Large-scale storage points are built at key nodes where the surrounding land is more relaxed as the kidney of the city and used as the main storage site for urban flooding. In the absence of flooding in the upper reaches of the Chao Phraya River, when only the Bangkok area is flooded by rainfall, the core built-up area with a radius of 10 km is mainly for drainage and supplemented by storage, while the west bank and other peripheral areas are mainly for storage and supplemented by drainage. If flooding occurs in the upper reaches of the Chao Phraya River and backflow occurs in Bangkok downstream, the core built-up area is mainly drained and water is quickly transported to storage sites in peripheral areas through the backbone cluster water network to ensure maximum flood safety in the core city.

Fig.19 Map of the water storage network in the built-up area of Bangkok

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Table 13 Network node parameter ranking table

Id（weight）	Id（degree）	Id（weighted degree）	Id(closnesscentrality)	Id(harmonicclosnesscentrality)	Id(betweennesscentrality)	Id(modularity_class)	Id(Authority)	Id(Hub)	Id(pageranks)	Id(clustering)	Id(triangles)	Id(eigencentrality)
100	17	17	17	17	17	17	394	394	17	465	394	394
17	394	447	22	471	364	470	442	442	254	572	413	413
259	413	159	23	365	365	468	413	413	447	355	442	442
98	417	394	365	22	22	378	396	396	219	566	441	396
519	396	64	471	470	471	463	369	369	135	484	440	369
535	436	219	300	468	28	464	368	368	64	145	369	368
76	442	443	14	23	52	465	367	367	394	275	368	367
164	439	544	16	14	62	466	441	441	464	437	367	441
575	367	160	7	16	532	502	440	440	519	405	396	440
173	407	495	15	576	300	5	439	439	527	454	438	439
184	448	434	534	15	306	576	436	436	155	143	439	436
25	369	135	5	7	297	325	438	438	482	406	436	417
186	368	457	6	534	299	323	417	417	225	375	405	448
133	441	396	470	353	298	471	448	448	95	332	406	438
532	404	254	468	300	519	320	407	407	25	331	404	407
358	438	572	576	5	79	354	404	404	159	466	448	404
357	440	564	538	364	308	353	405	405	443	129	407	405
310	406	430	291	394	260	292	406	406	127	381	417	406
447	405	395	353	325	80	305	366	366	544	130	384	366
16	384	180	348	6	98	501	443	443	209	522	383	443
189	519	397	325	317	252	355	395	395	495	120	382	17
552	386	527	539	323	233	2	431	431	317	525	380	395
367	378	95	354	320	81	539	437	437	457	401	386	431
482	383	566	501	539	82	120	373	373	36	521	375	437
225	447	217	317	354	366	119	389	389	189	198	571	373
306	374	545	323	312	7	377	390	390	176	226	376	389
12	376	563	292	538	8	4	388	388	20	261	374	447
443	382	63	305	292	9	534	447	447	180	568	378	390
366	450	519	328	305	20	328	414	414	434	141	17	388
246	463	559	320	291	25	538	416	416	42	392	470	414
156	380	139	312	311	535	348	424	424	279	502	468	416
139	100	438	311	348	19	291	412	412	396	274	463	424
497	464	482	2	328	46	303	370	370	306	15	465	412
187	468	429	4	2	23	121	397	397	340	324	466	384
413	571	150	303	501	29	333	434	434	217	453	502	370
6	470	458	121	4	53	117	435	435	190	569	464	386
480	375	218	355	303	169	577	408	408	102	571	450	397
185	535	496	120	121	548	118	403	403	430	422	385	383
503	173	464	119	355	114	469	419	419	215	119	16	434
191	189	250	333	120	549	319	418	418	150	379	212	435
491	482	441	117	119	232	334	445	445	535	321	213	374
254	443	249	577	333	550	3	446	446	465	99	401	376
417	366	36	118	117	39	379	364	364	358	501	15	382
262	94	197	469	577	228	472	371	371	348	441	400	380
548	485	513	319	118	193	533	444	444	243	440	23	408
518	211	269	334	469	44	322	415	415	73	369	14	403
137	364	494	28	319	144	293	430	430	160	368	210	419
236	193	450	299	334	113	473	428	428	220	367	449	418
423	385	455	364	369	76	324	573	573	134	438	189	375
215	373	435	532	368	112	1	572	572	22	404	22	571
261	22	65	8	367	164	540	372	372	252	448	211	470
96	466	439	29	373	222	537	387	387	211	407	193	468
457	465	512	27	532	77	321	386	386	63	382	519	378
568	502	209	533	448	520	541	385	385	259	380	100	463
148	98	25	301	366	78	347	449	449	513	526	446	16
240	25	181	13	413	373	304	420	420	86	442	445	22
97	16	390	472	378	291	147	391	391	572	396	414	464
394	139	225	474	463	290	44	392	392	269	439	447	23
411	491	440	463	442	58	43	457	457	282	436	416	14
203	254	388	378	439	223	46	425	425	545	446	524	385
99	215	127	537	441	94	40	574	574	395	417	390	465
291	414	391	293	440	59	25	411	411	295	470	140	466
556	140	561	357	396	97	55	398	398	559	468	389	502
207	14	560	298	436	289	39	433	433	250	376	482	15
37	445	543	464	417	235	45	409	409	76	374	173	450
198	213	189	540	407	394	49	402	402	128	464	485	364
414	390	176	465	374	137	36	500	500	139	16	373	449
175	212	243	466	404	250	54	374	374	563	212	572	6
455	127	448	502	519	485	31	384	384	455	213	484	445
153	210	524	52	438	288	35	429	429	438	416	521	5
419	524	437	379	405	211	9	450	450	245	383	141	576
288	23	270	9	406	249	42	361	361	98	413	388	446
94	389	220	3	389	413	20	360	360	94	176	424	7
514	400	190	1	472	248	19	365	365	458	395	412	400
277	449	20	290	533	47	10	400	400	165	415	573	401

doi:10.20944/preprints202201.0443.v1

485	73	465	542	464	157	37	401	401	397	400	138	325
464	259	237	352	474	287	41	383	383	450	292	520	323
309	575	245	347	384	374	47	382	382	197	142	139	471
396	532	436	373	386	100	32	380	380	72	35	491	320
276	503	384	326	465	109	50	376	376	218	23	443	354
481	455	268	327	466	518	30	375	375	249	61	526	353
147	131	387	322	502	447	18	571	571	512	14	44	519
235	412	259	324	387	225	24	575	575	429	506	127	317
256	505	404	316	390	111	56	432	432	194	523	366	292
134	326	500	366	535	200	12	410	410	391	210	176	305
20	527	208	313	388	36	11	427	427	256	6	506	312
211	102	165	321	28	282	26	426	426	264	354	6	311
131	517	535	318	447	219	21	455	455	181	244	244	365
275	416	42	310	357	534	33	421	421	206	516	527	501
334	424	383	304	377	110	48	458	458	425	449	245	355
456	138	317	147	537	74	16	423	423	355	91	43	2
353	245	445	519	8	175	22	399	399	65	305	131	539
467	126	86	374	376	215	23	393	393	476	463	172	300
265	62	134	387	299	533	14	381	381	524	388	222	120
205	520	530	535	379	188	15	497	497	564	424	517	119
83	222	256	12	383	35	6	451	451	384	412	532	377
140	474	400	528	27	259	7	17	17	383	573	215	4
509	85	529	297	29	208	28	358	358	265	138	73	534
157	55	73	360	13	369	27	362	362	341	520	535	381
223	15	405	53	540	368	29	377	377	390	385	94	328
93	40	136	51	528	367	13	482	482	452	394	332	538
287	401	348	62	449	85	8	480	480	551	386	331	348
144	377	211	377	326	353	53	479	479	342	445	381	291
425	172	386	361	301	503	51	422	422	323	414	130	303
142	573	426	461	370	575	83	456	456	62	384	525	121
200	44	102	294	382	216	60	459	459	441	378	198	371
430	43	558	536	380	242	62	452	452	4	72	72	573
174	446	39	19	360	570	52	22	22	287	490	490	333
364	388	264	358	375	131	61	471	471	85	7	7	117
471	5	161	462	571	61	76	300	300	108	49	49	577
294	46	66	473	385	95	78	7	7	338	31	31	118
327	225	452	61	361	448	66	23	23	164	528	528	469
546	306	398	541	293	146	67	520	520	496	507	507	319
258	246	282	302	542	247	82	291	291	316	132	132	334
462	6	427	476	327	133	34	485	485	388	330	330	211
163	480	265	394	3	357	64	534	534	207	71	71	193
374	457	484	481	352	209	63	353	353	177	58	58	189
340	240	128	306	322	132	79	357	357	561	44	45	387
408	175	489	10	520	246	77	348	348	361	45	54	212
243	235	194	20	461	348	65	470	470	39	54	223	213
422	134	528	475	290	562	57	468	468	327	223	200	572
292	353	72	369	347	122	81	539	539	494	200	246	210
228	157	252	368	1	234	80	325	325	114	246	175	100
412	223	371	367	443	555	467	378	378	490	175	174	457
505	93	490	18	324	482	98	463	463	415	174	242	485
217	425	182	520	316	54	102	317	317	270	242	102	535
326	200	248	389	450	517	85	527	527	313	189	455	482
432	174	94	11	313	347	144	14	14	489	22	505	532
328	471	497	356	321	561	99	576	576	27	211	126	524
527	340	476	527	318	254	101	524	524	268	193	46	520
512	228	355	524	524	377	112	538	538	107	524	55	444
513	323	432	384	527	167	111	312	312	566	390	326	415
323	71	433	386	536	281	84	328	328	505	140	5	173
71	195	238	390	310	253	70	499	499	237	389	98	140
486	555	164	388	304	515	103	478	478	40	527	395	127
32	563	568	295	147	55	113	320	320	439	139	415	139
290	506	493	370	462	75	74	292	292	21	245	292	527
280	7	123	376	482	73	115	305	305	163	43	142	455
409	86	229	383	358	384	114	496	496	18	131	35	138
483	242	40	382	400	168	59	498	498	19	172	61	491
38	487	373	380	395	346	145	311	311	278	491	523	526
48	492	275	375	473	560	95	303	303	7	222	354	94
551	325	372	571	401	554	109	121	121	560	517	516	215
301	320	279	289	9	256	122	323	323	70	532	91	528
267	39	406	526	52	255	116	5	5	474	450	305	98
337	521	4	525	457	102	110	2	2	173	482	457	141
378	507	287	523	575	63	75	4	4	43	127	36	575
459	490	257	478	485	470	104	16	16	125	457	452	428
214	141	369	351	372	468	169	6	6	351	36	323	430
192	431	574	346	371	280	108	354	354	404	150	39	484
195	132	456	169	526	356	135	15	15	387	243	233	521
332	244	35	543	573	149	69	501	501	529	76	325	425
102	72	271	60	480	64	105	355	355	378	128	515	172
1	58	403	63	518	220	107	120	120	240	458	555	451

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458	472	548	372	541	472	106	119	119	208	397	504	73
386	54	446	518	476	539	136	333	333	350	391	488	44
279	526	531	330	481	201	179	117	117	548	476	92	126
574	452	431	332	525	24	68	577	577	484	564	93	222
226	171	340	331	523	439	154	118	118	201	452	195	503
555	330	442	460	424	474	94	469	469	145	323	451	43
421	36	526	329	298	177	131	319	319	283	361	320	326
155	550	366	315	414	71	132	334	334	386	39	492	3
468	219	562	314	445	556	130	484	484	49	114	576	574
341	488	425	371	478	345	134	521	521	123	489	487	505
569	572	166	79	412	325	128	453	453	440	19	171	372
517	31	505	25	479	134	150	359	359	260	560	234	379
196	49	37	522	416	431	149	454	454	233	70	480	517
239	515	382	548	452	573	125	483	483	168	173	62	420
407	576	215	76	574	139	129	363	363	31	125	85	46
416	429	399	21	431	712	90	28	28	543	350	40	175
500	233	240	547	446	442	181	52	52	357	233	474	176
448	451	151	452	356	27	133	62	62	364	168	503	525
563	92	230	477	455	195	180	532	532	435	360	377	474
406	528	316	531	12	443	151	306	306	360	299	364	174
506	234	575	529	522	30	146	297	297	530	166	355	480
7	504	358	448	484	86	89	299	299	400	325	566	131
410	9	551	296	521	178	182	298	298	275	371	145	391
424	495	498	308	451	461	183	519	519	528	426	275	472
418	317	389	453	53	189	153	79	79	299	96	437	40
542	45	428	482	51	340	152	308	308	292	103	454	506
557	484	247	362	475	218	215	260	260	136	509	143	200
14	176	43	449	62	66	73	80	80	60	115	129	523
360	461	474	309	460	279	222	98	98	8	423	522	223
544	76	454	480	548	18	175	252	252	288	420	120	533
359	164	125	24	572	480	174	233	233	550	485	226	92
81	358	327	83	434	31	200	81	81	507	541	261	322
86	357	295	442	397	203	223	82	82	248	214	568	58
145	156	19	479	294	173	58	8	8	166	170	392	245
194	497	145	441	547	230	71	9	9	314	570	274	25
8	262	98	440	391	309	228	20	20	142	515	324	102
178	518	283	413	19	269	72	25	25	132	555	453	392
242	137	573	439	453	378	195	535	535	325	373	569	490
545	423	323	396	435	516	86	19	19	126	144	422	71
206	96	253	407	408	424	91	46	46	46	90	119	452
376	97	155	436	392	32	214	29	29	66	311	379	225
351	556	131	404	403	65	168	53	53	417	111	321	55
516	198	153	417	330	238	166	169	169	448	504	99	39
382	481	306	438	529	108	88	548	548	461	101	501	518
158	20	485	405	437	563	167	114	114	371	488	150	507
335	509	550	406	531	574	87	549	549	140	540	243	45
182	144	470	485	351	128	123	232	232	426	84	76	254
479	142	503	359	297	51	165	550	550	436	262	128	132
108	430	341	385	332	349	881	39	39	169	10	458	242
571	327	108	484	331	103	227	228	228	35	92	397	293
487	163	451	521	419	138	173	193	193	96	93	391	228
454	243	292	450	418	463	127	44	44	103	356	476	504
177	292	233	114	346	174	172	144	144	437	322	564	72
476	551	368	400	456	21	126	113	113	509	553	361	142
492	301	168	401	289	49	176	76	76	182	301	114	488
336	214	7	67	543	204	92	112	112	23	499	489	244
450	332	107	26	477	336	171	164	164	500	195	19	462
138	458	380	64	302	56	198	222	222	470	481	560	171
325	279	444	36	61	43	93	77	77	55	421	70	234
245	421	260	35	329	171	170	78	78	405	451	125	492
260	155	177	395	362	140	124	290	290	410	349	350	198
352	341	525	456	381	72	216	58	58	216	149	168	487
126	500	288	307	10	158	177	223	223	503	533	360	93
62	542	523	544	315	326	202	94	94	382	320	299	49
274	360	378	349	314	93	197	59	59	77	537	166	473
89	516	488	350	503	390	196	97	97	115	300	371	360
266	479	49	530	20	96	199	289	289	253	479	426	233
263	177	342	260	499	283	148	235	235	427	492	96	324
103	476	76	80	18	317	201	137	137	167	113	103	1
282	103	570	451	530	26	217	250	250	403	539	509	411
415	282	367	30	515	262	236	288	288	238	576	115	499
320	415	499	32	25	414	157	211	211	153	312	423	85
107	331	235	447	444	196	137	249	249	29	78	420	429
241	170	385	391	306	42	97	248	248	87	487	541	246
68	124	522	392	11	60	156	47	47	330	511	214	36
39	168	557	575	399	107	96	157	157	328	171	170	361
460	395	201	77	516	491	155	287	287	339	124	570	195
521	269	22	288	359	148	187	100	100	131	370	144	54
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doi:10.20944/preprints202201.0443.v1

562	130	328	336	458	504	206	518	518	296	542	311	500
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308	61	407	113	60	104	207	111	111	247	234	101	28
445	311	401	34	349	150	184	200	200	420	112	540	515
507	539	417	345	295	425	185	36	36	558	137	84	130
208	387	140	515	425	527	209	282	282	485	52	262	235
331	78	507	516	486	452	231	219	219	454	480	10	259
522	216	71	39	350	50	221	110	110	541	536	356	330
170	420	509	443	483	127	220	74	74	143	156	322	86
124	19	461	66	79	358	178	175	175	556	293	553	27
168	113	375	454	76	542	712	215	215	285	518	301	357
520	112	142	457	63	181	203	533	533	329	100	499	522
490	2	8	57	500	229	251	188	188	214	102	481	164
33	232	62	549	549	126	193	35	35	303	455	421	327
141	3	492	33	430	341	189	259	259	456	505	349	398
88	434	376	31	544	67	212	208	208	170	126	149	91
395	300	258	65	398	449	213	85	85	372	46	533	29
269	66	463	252	428	407	210	503	503	16	55	537	13
289	297	132	55	420	14	100	216	216	235	326	300	144
143	111	278	455	46	83	140	242	242	345	5	479	226
95	525	351	546	36	450	139	570	570	59	443	113	461
130	536	364	112	345	156	138	131	131	37	215	539	540
436	523	471	115	21	170	141	61	61	81	73	312	555
34	350	350	499	415	495	142	95	95	411	366	78	495
146	181	126	37	44	87	164	146	146	61	447	511	240
90	426	87	483	517	576	226	247	247	257	98	124	536
61	554	473	363	546	258	158	133	133	277	62	370	35
559	128	173	81	35	124	143	209	209	445	85	97	537
307	101	58	44	24	115	194	132	132	570	40	542	458
28	428	333	431	411	524	190	246	246	366	474	554	433
311	499	381	545	288	106	163	562	562	531	503	112	542
539	52	149	424	296	105	162	122	122	271	377	137	516
251	115	477	503	309	293	159	234	234	515	535	52	99
431	305	32	414	498	538	160	555	555	555	94	536	299
132	397	555	412	114	389	191	54	54	373	519	156	479
57	125	325	416	488	488	192	517	517	187	495	293	550
387	322	31	233	308	417	161	347	347	463	317	518	158
78	84	167	397	504	155	246	561	561	71	563	495	243
47	42	556	434	39	163	219	254	254	104	429	317	489
213	511	361	435	83	404	232	167	167	557	425	563	134
216	35	206	408	497	361	248	281	281	471	550	429	209
538	356	216	403	55	339	247	253	253	105	471	425	301
183	209	504	437	215	70	188	515	515	380	228	550	332
237	564	370	486	433	135	208	55	55	144	157	471	331
420	361	44	419	228	159	230	75	75	58	431	228	101
19	91	374	418	487	197	218	73	73	90	9	157	8
319	67	357	56	31	284	250	168	168	151	472	431	9
113	537	360	399	43	278	238	346	346	109	353	9	128
193	299	466	573	233	564	249	560	560	228	259	472	42
529	478	478	78	409	268	204	554	554	416	575	353	409
112	109	329	574	67	312	211	256	256	32	364	259	170
188	150	521	54	393	263	245	255	255	311	254	575	321
244	349	549	49	222	360	225	102	102	562	25	254	511
72	541	468	467	511	328	242	63	63	116	17	25	214
227	560	313	445	64	445	244	280	280	493	219	219	157
324	59	143	40	80	245	240	356	356	69	135	135	399
255	553	541	446	30	499	243	149	149	478	64	64	563
222	64	85	572	98	180	224	64	64	881	155	155	143
427	149	546	85	550	497	257	220	220	111	225	225	453
30	531	483	46	58	92	239	472	472	121	95	95	509
129	293	481	111	49	455	229	201	201	284	159	159	481
2	489	415	341	363	237	237	24	24	369	544	544	426
390	370	538	228	26	386	241	474	474	333	209	209	52
474	570	41	116	200	221	254	177	177	157	20	20	61
85	391	449	82	545	478	234	71	71	504	180	180	112
58	166	18	393	336	500	235	556	556	101	434	434	486
232	312	377	287	32	240	259	345	345	538	42	42	150
4	371	423	340	491	151	262	134	134	526	279	279	476
3	540	303	517	40	457	269	139	139	406	306	306	20
434	381	104	43	341	543	253	712	712	294	340	340	149
472	533	392	444	54	116	256	27	27	498	217	217	541
577	70	21	514	402	13	255	195	195	508	190	190	194
249	114	284	45	34	187	275	30	30	375	430	430	352
300	248	144	234	50	396	274	86	86	205	358	358	340
383	10	188	458	514	40	261	178	178	477	348	348	306
54	354	27	84	77	881	258	461	461	298	160	160	111
82	231	122	550	113	451	263	189	189	44	220	220	553
565	186	207	222	223	557	270	340	340	229	134	134	219
51	133	59	122	260	412	268	218	218	497	252	252	423

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473	12	540	498	234	383	272	66	66	376	63	63	76
534	187	129	97	45	436	271	279	279	377	513	513	84
80	548	281	42	340	320	264	18	18	110	86	86	316
66	261	46	167	495	551	267	31	31	332	269	269	570
79	568	105	98	252	294	265	203	203	488	282	282	190
297	148	508	232	37	166	266	173	173	362	545	545	19
212	411	510	47	66	420	273	230	230	549	295	295	554
111	203	881	96	307	408	290	309	309	106	559	559	163
402	99	506	398	429	231	282	269	269	540	250	250	224
347	291	339	110	232	202	279	516	516	473	165	165	70
525	207	210	488	506	376	281	32	32	280	197	197	137
536	37	272	215	42	487	287	65	65	565	218	218	168
453	288	170	487	175	292	280	238	238	468	249	249	478
523	514	56	504	100	305	283	108	108	510	512	512	103
197	277	60	430	73	428	278	563	563	281	194	194	356
127	309	491	425	112	352	289	128	128	82	256	256	166
55	256	130	428	47	84	288	51	51	575	264	264	232
56	275	221	41	81	547	284	349	349	30	181	181	421
350	456	296	58	57	186	277	103	103	202	206	206	125
15	265	479	511	115	441	285	138	138	84	65	65	313
13	205	121	95	85	440	335	174	174	309	265	265	113
229	83	88	420	33	257	276	21	21	262	341	341	97
29	287	314	415	193	537	286	49	49	331	551	551	349
342	294	244	411	505	434	300	204	204	10	342	342	10
201	546	172	433	71	460	233	336	336	374	4	4	262
526	258	393	409	82	272	299	56	56	424	287	287	156
40	462	413	402	65	479	301	43	43	230	108	108	402
401	408	90	200	426	514	306	171	171	297	338	338	129
181	422	228	500	423	400	297	140	140	92	164	164	88
268	217	106	137	287	162	336	72	72	172	496	496	548
558	432	542	223	94	496	252	158	158	80	316	316	269
398	328	120	168	507	34	298	326	326	466	207	207	358
433	512	262	144	127	481	309	93	93	398	177	177	96
426	513	280	497	459	498	294	96	96	93	561	561	341
385	486	285	70	195	430	308	283	283	14	327	327	547
452	32	330	75	144	486	296	26	26	258	494	494	551
442	290	569	491	59	172	260	262	262	356	270	270	78
210	280	267	109	78	528	295	196	196	322	313	313	350
372	409	183	342	421	89	307	42	42	553	27	27	162
554	267	539	506	174	57	302	60	60	506	268	268	454
171	1	487	513	167	12	317	107	107	407	107	107	74
494	574	553	59	496	267	312	491	491	100	237	237	531
530	226	520	102	72	311	311	148	148	389	21	21	115
377	569	193	282	173	303	316	125	125	301	163	163	124
128	196	114	507	211	121	313	504	504	41	18	18	497
247	239	83	339	489	301	318	183	183	499	278	278	253
74	410	236	344	102	391	310	104	104	195	351	351	37
881	557	345	250	111	403	315	150	150	481	387	387	90
172	544	67	216	56	362	314	50	50	45	529	529	114
50	81	100	253	427	458	326	127	127	421	240	240	560
101	145	92	100	168	45	330	542	542	451	208	208	347
348	194	55	495	86	507	327	181	181	523	548	548	290
75	8	202	570	93	509	332	229	229	399	201	201	530
257	178	533	555	432	214	331	126	126	221	283	283	564
330	545	70	48	490	101	329	341	341	129	123	123	297
36	206	424	459	216	342	364	67	67	349	260	260	231
343	351	511	157	509	338	365	83	83	381	543	543	216
428	158	30	551	235	69	360	156	156	210	357	357	159
493	182	534	164	555	136	361	170	170	130	435	435	256
470	108	472	195	492	160	357	495	495	352	530	530	255
499	454	515	146	189	565	352	87	87	522	136	136	556
524	336	75	73	164	285	340	258	258	442	60	60	59
52	260	93	71	138	217	356	124	124	286	8	8	41
115	352	203	101	513	277	349	115	115	149	288	288	529
369	274	712	175	410	323	358	106	106	120	248	248	66
305	89	294	99	570	316	341	105	105	432	314	314	67
295	266	109	72	41	327	350	293	293	533	66	66	456
373	263	322	166	116	313	351	488	488	11	461	461	82
162	107	410	214	74	264	345	155	155	412	169	169	47
550	460	537	155	92	5	339	163	163	56	182	182	145
27	321	61	156	122	91	362	339	339	534	500	500	177
397	562	416	489	214	295	346	70	70	326	410	410	95
508	561	57	505	91	182	342	135	135	203	216	216	318
105	308	354	429	95	387	338	159	159	57	77	77	248
125	208	23	509	84	544	344	197	197	186	253	253	181
219	522	171	427	126	492	359	284	284	525	427	427	109
379	88	77	426	139	397	363	278	278	433	167	167	282
488	289	81	423	75	444	343	564	564	574	403	403	329
573	143	356	512	551	243	337	268	268	308	238	238	275

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322	34	480	432	140	511	394	263	263	191	153	153	274
712	146	332	421	253	165	396	245	245	133	29	29	261
368	559	101	135	131	476	395	180	180	320	87	87	32
22	28	214	188	254	190	373	92	92	368	328	328	34
285	57	255	410	97	296	389	237	237	122	339	339	122
496	47	299	133	132	224	390	221	221	385	296	296	427
510	538	195	74	250	2	388	240	240	67	83	83	167
84	183	460	138	166	536	384	151	151	367	247	247	64
264	237	274	490	512	456	370	543	543	537	558	558	63
253	529	16	193	210	90	386	116	116	431	556	556	258
441	188	420	492	212	10	397	13	13	300	285	285	310
77	324	411	108	213	206	383	187	187	6	329	329	155
160	255	246	235	467	464	374	40	40	491	303	303	336
199	427	349	249	99	37	376	881	881	479	456	456	257
375	30	82	496	101	540	382	557	557	492	372	372	202
44	129	277	201	225	558	380	551	551	113	235	235	247
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314	249	331	69	110	423	571	166	166	2	59	59	279
42	82	402	132	282	411	385	231	231	401	37	37	496
572	565	169	93	96	385	449	202	202	539	81	81	498
23	51	532	208	141	421	400	487	487	521	411	411	432
31	473	187	139	88	212	401	352	352	310	257	257	239
69	534	326	140	158	213	381	84	84	446	277	277	569
152	80	320	141	494	438	371	547	547	193	531	531	133
404	79	266	254	339	531	387	186	186	148	271	271	79
49	347	204	343	109	416	372	257	257	9	187	187	493
333	453	308	145	201	409	391	537	537	3	104	104	549
511	197	29	174	137	11	392	460	460	428	557	557	87
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35	229	552	281	177	513	393	162	162	198	109	109	252
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515	342	198	283	130	506	414	481	481	188	562	562	221
501	201	163	158	196	244	416	486	486	75	116	116	477
278	268	178	127	202	205	424	172	172	289	493	493	197
356	558	110	508	249	489	412	528	528	89	69	69	298
355	398	141	338	344	194	415	89	89	161	478	478	494
209	433	261	194	157	382	428	57	57	312	881	881	196
218	372	111	173	48	380	430	12	12	354	121	121	123
380	494	115	494	128	433	425	267	267	79	284	284	514
238	530	133	165	133	541	420	301	301	472	333	333	199
18	247	89	88	493	271	411	45	45	337	538	538	422
60	74	148	219	134	494	429	507	507	78	294	294	77
363	881	138	142	248	395	409	509	509	53	498	498	116
393	50	347	554	170	4	426	214	214	712	508	508	180
564	348	412	562	165	399	423	101	101	573	205	205	151
345	75	157	143	103	210	421	342	342	413	477	477	110
346	257	263	553	146	462	427	338	338	487	298	298	304
365	493	289	94	554	530	422	69	69	244	229	229	147
179	295	502	187	242	545	410	136	136	226	497	497	188
389	162	80	552	194	512	413	160	160	184	110	110	309
123	27	45	87	219	446	442	565	565	272	362	362	294
344	105	297	211	422	41	369	285	285	212	549	549	18
135	379	24	131	87	529	368	217	217	222	106	106	148
180	712	309	179	176	477	367	277	277	511	473	473	187
444	285	337	493	123	388	441	316	316	483	280	280	559
304	496	475	162	142	16	440	327	327	276	565	565	208
122	264	117	177	553	398	439	313	313	516	510	510	201
120	253	311	248	162	493	436	264	264	552	281	281	230
361	77	298	209	149	473	417	91	91	290	82	82	75
576	160	234	107	171	429	448	295	295	409	30	30	351
221	314	362	189	256	559	438	182	182	171	202	202	345
91	69	74	202	255	490	407	544	544	26	309	309	229
24	498	116	130	562	370	404	492	492	261	230	230	308
67	110	231	227	190	270	405	243	243	567	297	297	65
429	501	577	210	150	88	406	511	511	124	80	80	218
537	278	6	212	145	6	366	165	165	138	398	398	24
299	355	124	213	143	350	443	476	476	178	258	258	220
437	218	554	186	129	523	437	190	190	50	41	41	410
159	238	486	184	508	239	447	296	296	370	399	399	339
296	18	576	185	198	553	434	224	224	347	221	221	512
230	60	9	104	156	426	435	536	536	568	352	352	543
478	345	291	92	240	432	408	90	90	444	286	286	165
204	346	10	510	188	266	403	10	10	141	432	432	562
302	365	84	422	245	410	419	206	206	54	11	11	56
233	123	34	136	208	265	418	464	464	24	56	56	57
286	135	3	126	135	354	445	37	37	185	534	534	178
451	180	54	170	246	322	446	540	540	267	203	203	250
165	444	353	256	125	315	573	558	558	223	57	57	12

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109	122	241	255	247	372	572	505	505	353	186	186	11
252	120	571	230	148	176	444	212	212	200	433	433	53
150	221	2	123	108	330	575	213	213	291	574	574	51
41	24	222	190	510	314	574	531	531	414	308	308	104
250	437	453	225	224	427	500	11	11	517	191	191	561
21	159	212	68	281	207	433	123	123	520	133	133	263
92	296	290	159	155	371	402	351	351	74	122	122	186
316	230	536	258	283	435	432	513	513	546	67	67	566
349	204	514	163	259	142	450	546	546	460	231	231	568
541	165	312	275	230	3	457	506	506	97	2	2	270
560	252	5	274	244	415	455	244	244	255	310	310	268
547	41	174	218	220	526	451	205	205	542	148	148	169
11	250	232	881	552	329	474	489	489	392	3	3	146
43	21	205	273	238	1	452	194	194	554	428	428	89
303	316	79	172	221	15	462	541	541	234	88	88	182
161	547	91	128	199	501	461	271	271	449	188	188	362
400	11	158	229	124	355	458	494	494	302	75	75	238
475	303	421	280	227	120	479	210	210	12	289	289	296
104	104	518	284	163	119	453	462	462	213	89	89	249
528	543	14	149	258	333	481	530	530	532	161	161	557
543	87	118	134	881	117	476	545	545	112	79	79	83
59	119	300	176	338	577	478	512	512	137	337	337	281
438	338	226	129	343	118	454	41	41	246	53	53	183
553	477	516	220	159	469	456	529	529	336	712	712	108
87	549	223	150	556	319	460	477	477	52	184	184	287
119	566	213	198	104	334	477	493	493	34	272	272	280
64	224	69	238	90	405	475	473	473	179	483	483	283
338	272	324	337	243	406	459	559	559	475	276	276	135
477	220	200	199	229	465	485	490	490	263	552	552	315
549	399	517	556	275	466	482	270	270	502	290	290	546
449	151	175	106	274	502	520	88	88	480	409	409	346
234	284	414	561	218	379	491	350	350	13	26	26	278
566	136	409	148	69	375	484	523	523	266	567	567	314
440	65	276	105	231	571	521	239	239	175	178	178	237
224	121	304	247	179	324	503	553	553	174	50	50	81
272	106	567	206	178	321	505	266	266	393	347	347	69
149	270	196	221	273	318	506	265	265	274	444	444	260
220	362	162	224	226	310	490	322	322	117	24	24	289
399	435	224	242	89	304	507	315	315	536	185	185	272
446	169	310	171	187	147	504	176	176	15	267	267	513
151	63	242	89	561	401	488	330	330	183	291	291	881
504	315	26	226	151	525	492	314	314	514	74	74	26
469	392	462	205	107	522	487	207	207	324	546	546	80
284	26	78	154	180	484	499	142	142	196	460	460	342
531	283	113	204	712	521	495	3	3	91	255	255	558
136	271	344	712	239	475	489	526	526	577	302	302	204
154	403	53	125	257	572	511	329	329	156	12	12	295
9	298	11	259	241	453	509	1	1	344	336	336	21
65	339	50	240	203	392	486	465	465	158	34	34	206
293	281	119	237	237	437	497	466	466	51	179	179	60
489	116	184	124	186	332	496	502	502	304	475	475	712
567	202	179	231	280	331	498	379	379	486	263	263	271
370	167	408	241	105	419	493	324	324	402	13	13	203
121	313	186	246	204	418	483	321	321	224	266	266	544
106	53	191	178	136	302	494	318	318	241	393	393	565
388	329	318	90	106	381	508	310	310	453	117	117	105
570	190	52	272	181	359	510	304	304	47	183	183	264
391	184	336	160	153	454	517	147	147	346	514	514	205
166	310	185	191	152	483	515	525	525	118	196	196	288
495	552	47	192	197	393	516	522	522	293	577	577	267
312	185	346	151	284	363	514	475	475	408	344	344	107
270	191	239	180	560	402	512	332	332	315	158	158	545
362	236	315	245	269	307	513	331	331	236	51	51	207
371	153	547	239	182	33	519	302	302	307	304	304	33
435	419	419	279	183	459	532	307	307	569	486	486	106
540	276	293	285	272	467	524	33	33	462	402	402	265
5	147	51	244	557	99	527	467	467	571	224	224	266
169	334	343	203	184	141	526	99	99	518	241	241	284
63	467	15	153	185	130	528	141	141	343	47	47	475
315	483	112	152	262	344	525	130	130	1	346	346	273
392	48	301	557	337	48	480	344	344	422	118	118	160
466	337	147	560	206	422	523	48	48	232	408	408	217
384	459	459	565	160	145	518	145	145	204	315	315	338
317	192	33	207	565	143	522	143	143	119	236	236	136
26	418	154	243	261	129	531	129	129	239	307	307	277
283	359	307	257	279	508	530	508	508	318	462	462	285
271	335	305	183	563	198	529	198	198	147	343	343	241
403	241	99	197	68	510	542	510	510	68	1	1	508
298	68	379	269	191	552	547	552	552	242	232	232	48

339	33	418	262	192	199	543	199	199	419	204	204	153
281	307	321	261	205	227	546	227	227	379	239	239	152
439	251	97	181	251	343	544	343	343	146	318	318	393
381	319	1	182	271	275	545	275	275	321	147	147	344
533	227	146	251	285	274	535	274	274	162	68	68	307
45	577	365	271	558	179	555	179	179	99	419	419	179
46	402	137	161	154	273	536	273	273	305	146	146	459
465	343	422	278	569	226	550	226	226	418	162	162	227
484	508	12	335	217	241	563	241	241	192	418	418	302
116	510	13	286	270	153	553	153	153	335	192	192	510
202	199	156	563	268	152	570	152	152	365	335	335	191
176	152	335	558	207	184	554	184	184	33	365	365	192
318	333	302	569	263	185	548	185	185	547	33	33	552
502	363	273	567	278	337	551	337	337	227	547	547	359
118	393	152	217	559	261	560	261	261	251	227	227	251
167	179	501	270	564	68	564	68	68	501	251	251	467
70	344	251	268	567	191	556	191	191	363	363	363	184
114	304	68	263	161	192	569	192	192	154	154	154	185
117	302	227	277	335	251	549	251	251	28	28	28	335
313	286	467	559	286	154	559	154	154	152	152	152	363
53	161	469	564	267	569	562	569	569	48	48	48	68
73	475	359	236	264	567	561	567	567	459	459	459	343
248	469	192	267	236	161	566	161	161	359	359	359	567
329	154	319	264	277	335	568	335	335	273	273	273	161
10	567	28	276	566	286	557	286	286	199	199	199	236
190	318	334	566	568	236	558	236	236	469	469	469	337
273	118	363	568	266	566	565	566	566	319	319	319	276
461	117	199	266	265	568	552	568	568	334	334	334	154
354	273	48	265	276	276	567	276	276	467	467	467	286
231	38	38	38	38	38	38	38	38	38	38	38	38
0	0	0	0	0	0	0	0	0	0	0	0	0

Table 14　Statistics of 120 important node parameters

degree、authority、hub、eigenvector centrality、triangles			Closeness Centrality、Harmonic closness centrality、Betweeness centrality					clustering coefficient		pagerank	
17	448	386	519	14	323	52	82	525	375	36	464
394	369	378	468	23	7	299	534	381	466	219	189
413	368	383	470	532	325	312	80	275	465	155	482
417	441	447	364	62	320	354	79	145	401	95	25
396	404	382	22	15	576	291	348	454	521	209	254
436	438	380	98	5	233	81	501	522	484	64	127
442	440	571	16	306	317	260	365	143	572	544	527
439	406	443	389	6	539	308	252	129	332	135	225
367	405	366	431	353	300	28	298	355	331	159	457
407	384	373	395	471	297	538	437	120	130	566	495

Fig.20 Flood safety pattern in the built-up area of Bangkok

4.Discussion

4.1 Dynamic security pattern on the horizontal

The urban flood safety pattern in Bangkok is a changing dynamic pattern, and this dynamic is reflected in both temporal and spatial dimensions. Temporal dynamics means that the safety pattern can be adjusted and optimized at any time in response to climate change, urban development and changes in government decisions, and is a dynamic safety pattern that can be chosen and defended. Spatially dynamic refers to the topological evolution of the geographic landscape layout of the security pattern guided by complex network theory. Urban development and flooding pattern is a process of mutual influence and mutual choice, both of them play each other in time and space, constantly adjust and promote each other, and finally form a dynamic balance of security, stability and development. At the same time, the urban flood safety pattern is an open system in a broad sense, allowing various factors that affect and interfere with the structure and function of the water network to participate in the superposition, such as water transport traffic, water markets, water body landscape, water ecological communities, etc., and through the horizontal game integration with various factors, finally forming an urban water network safety pattern based on urban flood safety.

4.2 Hierarchical security pattern in the vertical

The flood safety pattern in the built-up area of Bangkok is vertically divided into three levels: macro, meso and micro. The analysis and study of the current situation of the water system and the storage network model in the built-up area of Bangkok using complex network theory identifies the key nodes and important paths, and constructs the flood safety pattern at the macro level by combining the current conditions and the characteristics of urban development. Through the network model analysis construction, the Bangkok water system storage network model has an obvious association structure, and the area covered by the association is analyzed twice by using the self-similarity feature to establish a mesoscopic scale regional-association level safety pattern. Combining with the characteristics of urban neighborhoods and geographic landscape environment, the micro-scale landscape design of the storage point-water system is carried out, so that it not only has the practical function of urban flood storage, but also can be integrated with the urban landscape and landscape, creating a landscape leisure pattern for citizens' leisure activities and gathering and communication.

4.3 Problems

The theoretical analysis and research related to complex networks mainly focus on virtual networks, although there are also some physical space networks that have been studied using some of the attributes of complex networks, but in general, a more mature research method has not been formed. The active exploration in this paper has analyzed and processed a large amount of data on the basis of no case to follow, and although certain theoretical methods have been formed and some results have been achieved, there are inevitably imperfections and lack of depth, and further in-depth research is needed.

The implementation of the land privatization policy in Bangkok and the construction of a flood safety pattern in the built-up area of Bangkok will require the Bangkok Metropolitan Administration to reserve and purchase land at key nodes in the safety pattern in advance and to plan and control them. At the same time, the construction of the safety pattern is not only a technical and engineering solution, but also involves political, economic, social and cultural aspects of the city, which will be a long and complicated process given the current construction and development of Bangkok city.

5.Conclusions

The implementation of the land privatization policy in Bangkok and the construction of a flood safety pattern in the built-up area of Bangkok will require the Bangkok Metropolitan Administration to reserve and purchase land at key nodes in the safety pattern in advance and to plan and control them. At the same time, the construction of the safety pattern is not only a technical and engineering solution, but also involves political, economic, social and

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cultural aspects of the city, which will be a long and complicated process given the current construction and development of Bangkok city.

Author Contributions: Conceptualization, Zhou Yingying and Li Shuaibo; methodology, Zhou Yingying; software, Li Shuaibo; validation, Li Shuaibo and Zhou Yingying ; formal analysis, Li Shuaibo; investigation, Zhou Yingying; resources, Zhou Yingying; data curation,Li Shuaibo and Zhou Yingying; writing—original draft preparation, Zhou Yingying; writing—review and editing, Li Shuaibo; visualization, Li Shuaibo; supervision, Zhou Yingying. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Not applicable.

Acknowledgements: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

Availability of data and materials: The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Ｒeferences

Albert R, B. A. (2002). Statistical mechanics of complex networks. Review of Modern Physics , pp. 74(1):47-97.

Ben-Naim, E. (2004). Complex Networks. Springer .

exclusive secrets, bangkok's next 7 potential investment golden places! (2019, 1 24). Retrieved from sohu: https://www.sohu.com/a/291113405_117348

HAN Ruidan, Z. L. (2017). Urban expansion and its ecological environmental effects in Bangkok, Thailand. Acta Ecologica Sinica , pp. 37(19): 6322-6334.

J.M ENewman. (2003). The structure and function of complex networks. SIAM Review, pp 45;167-256.
J.M ENewman. (2003). The structure and function of complex networks. SIAM Review, pp 45;167-256.
Newman. (2003). The structure and function of complex networks. SIAM Review , pp. 45;167-256.

Newman, B. W. (2006). The Structure and Dynamics of Networks. Princeton University Press.

Noble, N. E. (2009, 159 (10)). The clustering coefficient of a scale-free random graph . Discrete Applied Mathematics , pp. 953–965.

S.Boccaletti. (2006). Complex Networks: Structure and dynamics. Physics Reports , pp. 424 (2006) 175-308.

Watts D J, S. S. (1998). Collective dynamics of 'small-world' networks. Nature , p. 393(6684):440.