



Evaluation of Natural Suitability of Human Settlements Environment in Hangzhou Based on GIS

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Abstract— Taking Hangzhou City as the study area, Geographic Information System (GIS) technology was used, selecting natural factors such as terrain, vegetation, climate, and hydrology for analysis. On the basis of evaluating the suitability of a single factor of human settlements, a Human Settlements Environment Index (HEI) is constructed to explore the natural suitability characteristics and spatial differences of human settlements in Hangzhou. The research results indicate that the natural suitability index of the human settlement environment in Hangzhou is between 0.06 and 0.93, with the overall pattern being the highest in the central region and gradually decreasing towards the northeast and southwest. The distribution area of more suitable areas is the widest, accounting for 26.55% of the province's area. The land area of highly suitable areas accounts for 22.69%, while the area of generally suitable areas accounts for 20.69%. The area of critical suitable areas and unsuitable areas is relatively low, accounting for 13.10% and 16.97%, respectively. Especially for the urban area of Hangzhou, low terrain undulation and flat terrain are its advantageous natural conditions, but its vegetation cover, climate, and hydrological conditions are inferior to other research areas except for the urban area. Therefore, based on the comprehensive analysis, its HEI is lower than the surrounding areas.

Keywords— *Geographic Information System (GIS), Hangzhou City, Human Settlements Environment Index (HEI), Relief Degree of Land Surface (RLDS), Natural Suitability.*

I. INTRODUCTION

Since the 20th century, productivity in various countries has developed rapidly, and some developed countries have entered the stage of modern urbanization. With reform and opening up, China has been in a state of rapid development, with rapid growth in Gross Domestic Product (GDP) and urban population. Currently, it is rapidly advancing with a posture of catching up with and

surpassing the urbanization processes of developed countries in Europe and America. The advancement of urbanization has led to the rapid modernization of people's lives, gradually improving their living standards, and overall promoting an increase in people's survival and well-being. However, there are also many problems with its development process. Both developed and developing countries face similar challenges in the field of human

settlements, such as land resources being encroached upon by extensive urban expansion, overcrowding in some cities, excessive consumption of natural resources, and continuous deterioration of the ecological environment. At the same time, with the improvement of living standards and the awakening of ecological awareness, the public's demand for a living environment is becoming increasingly high.

As early as the 1950s, based on the early architects and the post-World War II urban reconstruction planning work, the Greek scholar Doxiadis first proposed the concept of human settlement science, and the human settlement environment gradually became a hot research topic [1]. Academician Wu Liangyong in China introduced it and defined it as human settlement environment science [2]. In terms of definition, the living environment is first and foremost the place where humans live and reside, and it is the base on which humans rely for survival in nature. The core of the human settlement environment is "people", and the purpose of human settlement environment construction is to meet the needs of "human settlement".

The study area of this article, Hangzhou, has been known as the "paradise on earth" in China since ancient times, but as a new first-tier city with high urbanization, it inevitably faces some living problems. This study will analyze and evaluate the natural suitability of the

human-settlements environment in Hangzhou in recent years based on GIS technology and provide scientific suggestions and data support for urban and rural pattern planning in order to improve its operational efficiency and people's happiness and health levels.

II. STYDY AREA

Hangzhou, also known as Lin'an, Qiantang, and Wulin for short, is located in the north of East China's Zhejiang Province, the southeast coast, the southern wing of the Yangtze Delta, the west end of Hangzhou Bay, the lower reaches of the Qiantang River, and the southern end of the Beijing-Hangzhou Grand Canal. It is an important central city in the Yangtze Delta and a transportation hub in southeast China, between $29^{\circ} 11' \sim 30^{\circ} 33' N$ and $118^{\circ} 21' \sim 120^{\circ} 30' E$, covering an area of 16596 km², accounting for 15.97% of the total area of the province (Figure 1). The research scope of this paper is the administrative region of Hangzhou City, which includes 10 districts, including Shangcheng District, Gongshu District, Xihu District, Binjiang District, Xiaoshan District, Yuhang District, Linping District, Qiantang District, Fuyang District, Lin'an District, Tonglu and Chun'an counties, one County-level city in charge of Jiande, Hangzhou Bay in the east, and land borders Anhui.

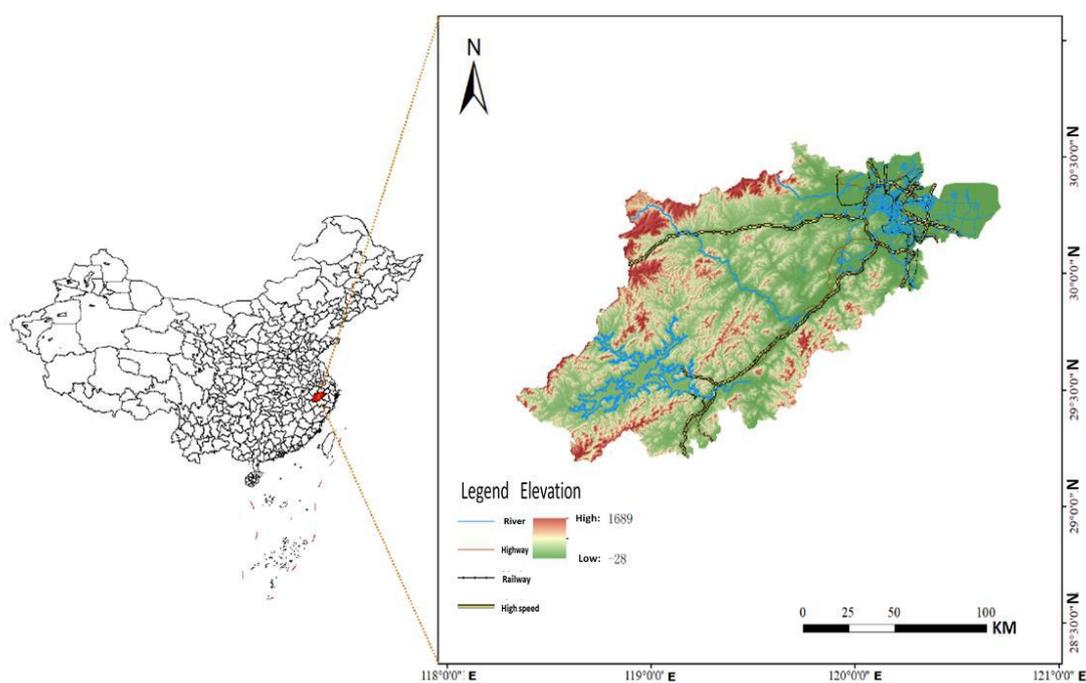


Fig.1: Geographical Location Map of Hangzhou City

2.1 Population Changes

As of 2022, the total number of permanent residents in Hangzhou has increased year by year, from 6.1605 million at the end of the 20th century to 12.376 million at the end of 2022. The urban population has increased from 2.1905 million in 1999 to 10.390 million in 2022, while the rural population has decreased from 3.970 million in 1998 to 1.986 million in 2022. The urban population has been increasing year by year, from the initial 35.60% to 83.96%, with an urbanization rate of 84.0% in the same year.

2.2 Topographic Conditions

Hangzhou is located in the south wing of the Yangtze Delta. According to its landform, it can be divided into coastal plain areas, hilly landforms, and piedmont valley areas [3]. Its topography is complex and diverse, and the terrain gradually decreases from west to east. It is

influenced by the mountain and water systems and presents beautiful scenery like a Chinese water ink painting with mountains and rivers. The western part belongs to the middle and low hilly area of northwest Zhejiang, with low mountains and valleys arranged alternately and staggered with river basins, forming three landforms: Zhongshan deep valley, low mountain hill's wide valley, and river valley plain (Figure 2). The main mountain ranges include Tianmu Mountain, Baiji Mountain, and Longmen Mountain, with the highest peak being Qingliang Peak (1781 meters above sea level) of Baiji Mountain. The eastern part is the accumulation plain of northern Zhejiang, accounting for 34.4% of the total area of the city. The terrain is low and flat, with a dense network of rivers and lakes. Hangzhou has famous water bodies such as Qiandao Lake, Qiantang River, Dongtiaoxi River, and the Beijing Hangzhou Grand Canal, which are typical of "Jiangnan Water Town" [4].

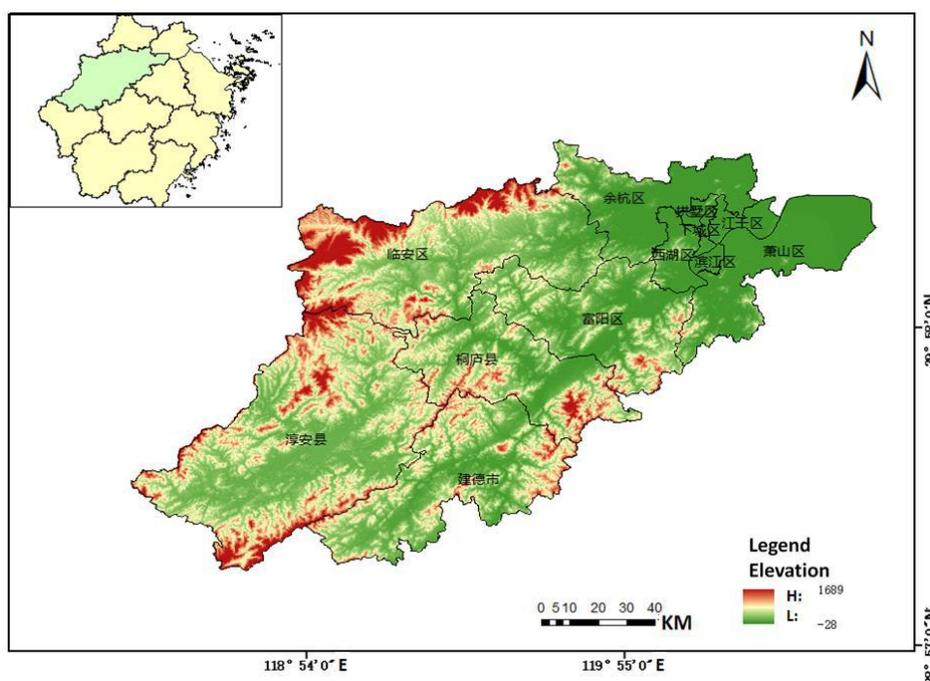


Fig.2: Topographic Overview of the Study Area

2.3 Climate Conditions

Hangzhou has a subtropical monsoon climate with four distinct seasons and abundant rainfall. The annual average temperature is 17.8 °C, the average relative humidity is 70.3%, the annual precipitation is 1454 mm, and the annual sunshine duration is 1765 hours.

Nevertheless, the summer climate is hot and humid, making it one of the new four major furnaces. On the contrary, winter is cold and dry. The spring and autumn seasons have a pleasant climate and are the golden seasons for sightseeing and tourism.

2.4 Hydrologic regime

Hangzhou has a natural environment of rivers, lakes, and mountains. In addition, the urban reservoir accounts for 8% of the total area of the city. The surface river network in the region is densely distributed. The main rivers are the Qiantang River, East Caoxi, Beijing-Hangzhou Grand Canal, Hangzhou-Shanghai Line A, Hangzhou-Shanghai Line B, Xiao-Shao Canal, and Shangtang River. Among them, the Qiantang River is the largest water system, belonging to the tidal river. The lakes mainly include West Lake, Baima Lake, Xiang Lake, Xixi National Wetland Park, etc. [5].

III. METHODOLOGY

3.1 Data Sources

The data in this study mainly includes:

(1) DEM data with a spatial resolution of 30 m, sourced from Geospatial Data Clouds (GDC) (<https://www.gscloud.cn/search>);

(2) MODIS MOD13A3 NDVI data with a spatial resolution of 1KM from 2000 to 2022;

(3) Meteorological data, sourced from the National Meteorological Information Center-China Scientific Meteorological Data Network (<http://data.cma.cn/>), including the total monthly rainfall, average monthly

temperature, relative humidity, etc. of 7 meteorological stations in the research area, with a period of 2019 to 2020;

(4) GlobeLand30 surface cover data, which divides land use types into 10 types: forest land, cultivated land, grassland, shrub land, wetland, water body, tundra, artificial surface, bare land, glacier, and permanent snow cover.

3.2 Methods

This article studies the natural suitability of human-settlements environment, mainly terrain conditions, climate conditions, hydrological conditions, and vegetation cover conditions. The operational steps and technical processes in the article are as follows (Figure 3): 1. Selecting four factors, it is namely terrain, land cover, climate, and hydrology, to construct an indicator system; 2. Using GIS technology, through vector data rasterizing, projection transformation, image clipping, and other processing, and resampling to a 250 m grid size for calculation; 3. On the basis of evaluating single factors such as terrain undulation, climate suitability, hydrological index, and vegetation status, a Hangzhou Human Settlements Environment Index (HEI) model based on GIS is constructed to quantitatively evaluate the suitability of human settlements.

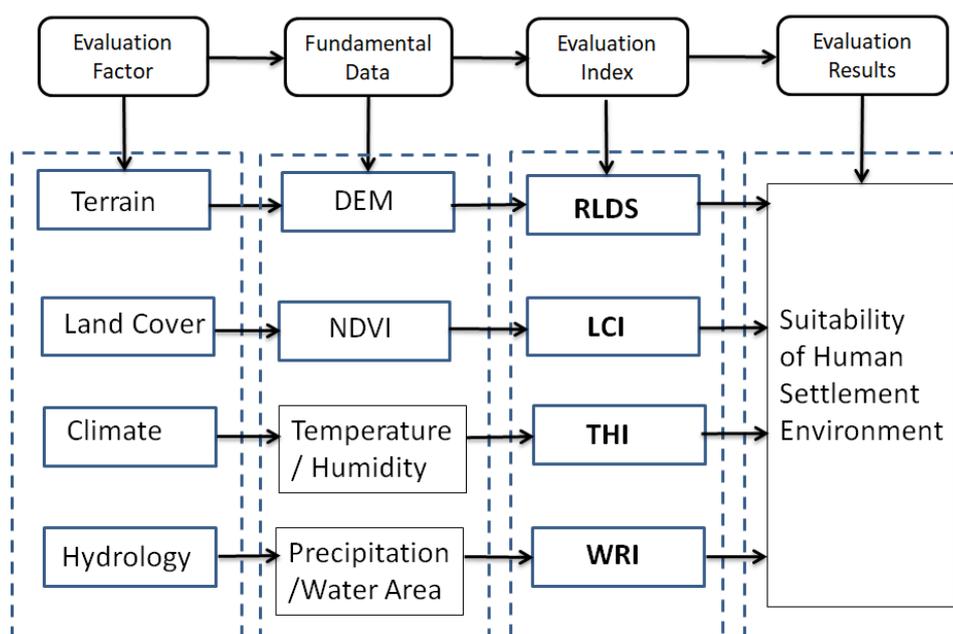


Fig.3: The Schema of the Study

3.3 Suitability Evaluation

The basic concept of suitability evaluation for human settlements is based on land suitability evaluation, which is usually used to evaluate the suitability of newly constructed land in the studied area. Its concept is generally defined as the suitability of land for a certain purpose under certain conditions and scope, that is, whether a certain land unit is to a large extent suitable for a certain utilization method. This concept extends to the suitability of human settlements and also means the suitability of environmental conditions for human settlements within the internal environment. In terms of evaluation methods, it is based on the spatial superposition of GIS, supplemented by the operational mode of spatial interaction.

There are many influencing factors that need to be considered when conducting analysis and evaluation, mainly the natural environment, economy, society, ecology, and various other environmental influencing factors. In general, suitability analysis considers ecological limiting factors, such as distance from water sources and ecologically sensitive areas, slope, elevation, etc. Thus, suitability evaluation in a narrow sense can be understood as ecological suitability evaluation. The main types of evaluations include farmland and crop suitability assessments, forest suitability assessments, grassland suitability assessments, urban construction land assessments, nature reserve assessments, as well as regional planning and environmental impact assessments. Among them, the most commonly used method is the suitability evaluation of urban construction land. This study uses the theoretical viewpoints and methods of suitability application as the basis for evaluation.

In addition, based on the convenience and limitations of obtaining research data, this study is based on the combination of water, soil, light, and heat conditions and selects four basic factors of terrain, land cover, climate, and hydrology as evaluation indicators, which are also the most basic indicators of environmental evaluation. The natural constituent factors of the living environment are the natural ecological environment foundation for local population development, economic and social development. Using the Human-Settlements Environment Index (HEI) model [6], quantitative research is conducted

on the spatial regularity and natural suitability of human settlements through the evaluation and analysis of individual indicators of natural constituent elements and the spatial correlation of population density.

To develop a reasonable suitability evaluation, it is first necessary to establish a model, collect and organize various factors that affect the target, and calculate them with weights to obtain data and images within the evaluation range. Then, a hierarchical classification is carried out, dividing the research area into areas that are unsuitable, critical suitable, generally suitable, more suitable, highly suitable. Then, using data information such as the occupied area, location, and shape of these areas, the matching degree of the current construction land is analyzed, existing problems and solutions are analyzed, and scientific suggestions are finally proposed [7].

3.4 Data Processing and Evaluation

3.4.1 Suitability Evaluation of Topography (SET)

Terrain is an important component of the natural geographical environment and plays a fundamental role in the formation, development, and evolution of regional geographical environments. Relief Degree of Land Surface (RLDS) refers to the maximum elevation difference within a certain distance from the ground [8], which is essentially an extension of the concept of slope. The formula for calculating the terrain relief index is:

$$RLDS = ALT / 1000 + \{ [\text{Max}(H) - \text{Min}(H)] \cdot [1 - P(A)/A] \} / 500 \dots (1)$$

In the formula, RLDS represents the terrain undulation index; ALT is the Height above mean sea level in a certain area (m); Max (H) and Min (H) are the highest and lowest elevations (m) within a certain area. All three parameters were calculated from DEM data using ArcMap neighborhood statistics, where A represents the total area of the region and P (A) is the flat area within the area.

3.4.2 Temperature-Humidity Index (THI)

Climate suitability is an important reference factor for people's survival and site selection. The quality of regional climate affects people's living experiences, and climate suitability evaluation has become an important component of human settlement environment evaluation. This article selects the temperature and humidity index as the indicator

for evaluating the climate suitability of human settlements, and the formula is:

$$THI = 1.8t - 0.55(1-f) (1.8t - 26) \quad (2)$$

In the formula, THI is the temperature and humidity index; T is the monthly average temperature (°C); F is the relative humidity (%), and this article uses the monthly average data of 7 meteorological stations in the study area for operation.

3.4.3 Hydrological Index (HI)

Hydrological conditions not only have an impact on terrain and topography but also have a significant impact on transportation, socio-economic development, and human habitation. Based on the scale of the study area and the availability of data acquisition, this article refers to the "hydrological index" (including precipitation and water area) proposed by relevant studies as the evaluation index [9-11]. The calculation formula for the hydrological index is:

$$WRI = \alpha P + \beta Wa \quad (3)$$

In the formula: WRI is the hydrological index; P and Wa are normalized annual precipitation and normalized water area, respectively; α and β are the weights of the ratio of annual precipitation to water area.

3.4.4 Vegetation Index (VI)

Plants are unique among the life materials that fix carbon, release oxygen, improve the environment, and form different seasonal landscapes. They are the lifeline of cities and the most important carriers for the sustainable development of human settlements. They are of great significance for improving the quality of human settlements. The formula is:

$$LCI = NDVI \times LTi \quad (4)$$

In the formula, LCI is the land cover index; NDVI is the Normalized Difference Vegetation Index; LTi is the weight of each land use in the study area; and i is the weight of each land use type. The weight values of each land use type are determined based on the vegetation cover index and the characteristics of the land use type in the study area.

3.4.5 Evaluating the Suitability of HEI

Based on the availability of the information in this

article, the formula is:

$$HEI = \alpha \times NR DLS + \beta \times NLCI + \gamma \times NTHI + \delta \times NWRI \quad (5)$$

In the formula, HEI represents the human-settlement environment index, ranging from 0 to 100, while NR DLS, NLCI, NTHI, and NWRI represent the standardized terrain relief, land cover index, temperature humidity index, and hydrological index, respectively. The weights corresponding to the four types of indices are determined as follows: α 、 β 、 γ 、 δ . Referring to the research results of Feng Zhiming [10] and others, the correlation coefficients between the natural single factor indices and population density are determined as follows: 0.305, 0.245, 0.295, and 0.155.

IV. ANALYSIS AND RESULTS

4.1 Terrain Conditions Impact on Human-Settlement Environment

There are various types of landforms in Hangzhou, with high terrain in the west and low terrain in the east. The western, central, and southern regions belong to the middle and low mountains and hills of western Zhejiang, while the northeastern region is the northern Zhejiang plain. The mountainous and hilly area of the city accounts for 65.6%, and the plain accounts for 26.4%. The topographic relief index increases from the northeast to the southwest on the whole. The area with the largest topographic relief is located in Lin'an District in the northwest, Chun'an and Tonglu County in the southeast. The highest altitude area in this area is more than 1000 meters, and the residential suitability is general. The area with the smallest terrain fluctuation is distributed in the northeast of Hangzhou City, mainly consisting of river network plains and coastal plains. The terrain is flat, with low elevation and high residential suitability (Figure 4).

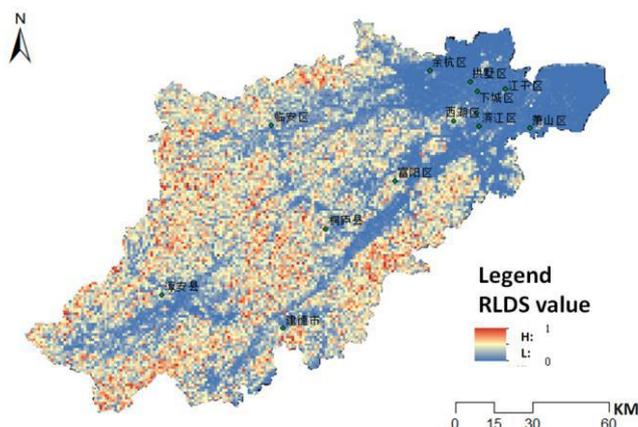


Fig.4: Spatial Pattern of RLDS in Hangzhou

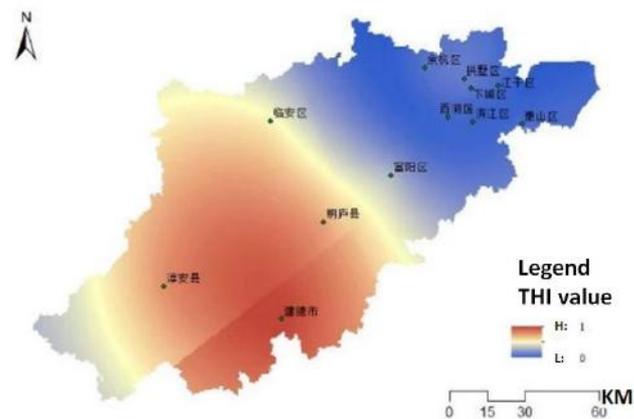


Fig.5: Spatial pattern of THI in Hangzhou

4.2 Climate Conditions Impact on Human-Settlement Environment

Hangzhou spans the southern and northern heat zones, and its climate characteristics have obvious regional characteristics. Influenced by the East Asian monsoon, mountains, and water bodies, it has formed a climate characterized by light, heat, and water in the same season and good coordination. The four seasons are distinct, with sufficient sunlight. The annual average temperature is 16.2 °C, the summer average temperature is 28.6 °C, the winter average temperature is 3.8 °C, the frost-free period is 230 to 260 days, and the average relative humidity is between 74% and 85%.

From the spatial distribution of the THI in Hangzhou, the overall trend shows an increasing trend from the northeast to the southwest (Figure 5). The areas with a lower THI are distributed in the central urban areas of Hangzhou, such as Yuhang, Binjiang, and Xiaoshan. Because the northeast is mostly plain, the terrain is flat, the terrain is open to the north, and the precipitation is relatively low. The thermal conditions are slightly worse than those in the lake area, and the suitability for living is relatively low. The higher areas are distributed in Chun'an County, Tonglu County, and Jiande. Because the Qiandao Lake District, Meicheng Liangjiang Plain, and Shouchang Basin in the southwest are surrounded by mountains on all sides, with water regulation in the middle, they are the areas with more precipitation, the best heat conditions, the longest frost-free period, and the best wintering conditions in Hangzhou, with higher residential suitability.

4.3 Hydrological Conditions Impact on Human-Settlement Environment

Hangzhou has a subtropical monsoon climate. In summer, it is often controlled by the Western Pacific Horse Latitudes. In winter, it is affected by the Siberian cold air mass. The climate is mild and humid, with an average annual rainfall of 1435 mm and abundant rainfall. The overall hydrologic index of Hangzhou is obviously higher in the southwest than in the northeast (Figure 6). The hydrologic index in the urban area of Hangzhou is the lowest, and the valley plain and basin in the middle are between the north and the south. The climate is suitable, and the precipitation is moderate. Chun'an County and Jiande in the southwest of the city, where Qiandao Lake District is located, have the highest index and high residential suitability.

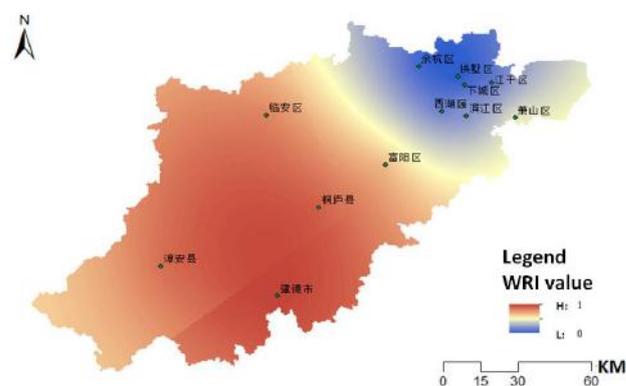


Fig.6: Spatial Pattern of Hydrological Index in Hangzhou

4.4 Vegetation Index Impact on Human-Settlement Environment

As a famous "forest city" in China, Hangzhou has a forest area of 16.89 million mu, a forest stock of 67.9 million cubic meters, and a forest cover of 66.85%. The vegetation index of the city shows a characteristic of being high in the southwest and low in the northeast, especially the lowest in the urban area (Figure 7). In fact, under the green development policy of the Hangzhou Municipal Government, the urban greening rate in the urban area is not low compared with other provincial capitals or economically developed cities, but compared with other regions in the study area, the urban area is highly developed and still expanding due to urbanization, has less vegetation coverage than other regions such as Lin'an District and Chun'an County, and the ecological environment is fragile.

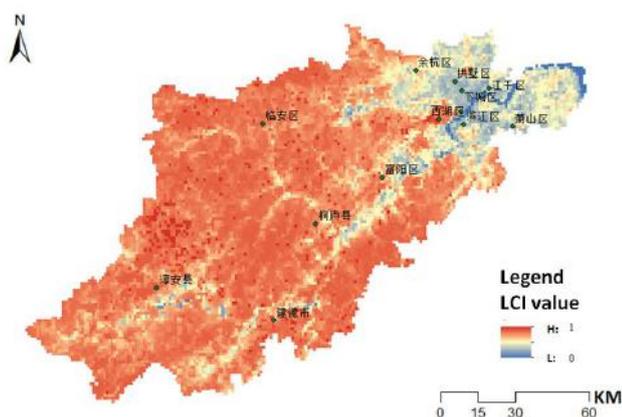


Fig.7: Spatial Pattern of Vegetation Index in Hangzhou

4.5 The Spatial Pattern of the Suitability of Human-Settlement Environment

The urban area of Hangzhou, which is located in the northeast of the study area, has advantages only in terms of topography, while areas such as Chun'an, Jiande, and Tonglu County, which are located in the southwest and middle of the study area, have better hydrothermal conditions and vegetation coverage than the urban area of Hangzhou, which does not coincide with the spatial distribution of population in Hangzhou.

The suitability analysis results of this study show that the human settlement suitability in Hangzhou is dominated by comparative more suitable and high suitable (Figure 8),

which respectively account for 26.55% and 22.69% of the total area and are distributed in the northeast of Chun'an County, the southwest of Lin'an District, Jiande City, and the south of Tonglu County. Some of the landforms in these areas are low mountains, hills, river valleys, and basins. Although the topographic relief index is higher than that of the urban area of Hangzhou, the overall terrain does not constitute a limiting factor that destroys the livability of the area. And because the Qiandao Lake area, Meicheng Liangjiang Plain, and Shouchang Basin in the southwest are surrounded by mountains on four sides and there is water regulation in the middle, this area is an area with more precipitation, the best heat conditions, the longest frost-free period, and superior wintering conditions in Hangzhou, thereby having a higher suitability for living.

The generally suitable areas account for 20.69% of the total area and are mainly distributed in the central part of Hangzhou, namely the east of Lin'an District, the southwest of Chun'an County, and the south of Fuyang District. The valley plains and basins in the central part are between the north and the south. The climate is suitable, the precipitation is moderate, and the habitability is general. The proportion of critical suitable and unsuitable areas is relatively low, at 13.10% and 16.97%, respectively. The overall distribution of Hangzhou urban area is in these two areas, which is caused by the special geographical location and highly developed urbanization of Hangzhou urban area. It is worth noting that although the natural suitability of the human settlement environment in Hangzhou is inconsistent with the current population distribution, the overall human settlement suitability of the city cannot be ignored, which is the particularity of this study area.

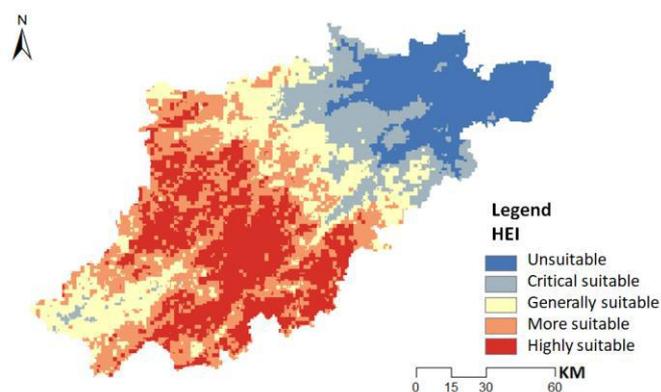


Fig.8: Spatial Pattern of Suitability Index

V. CONCLUSION

The human-settlement environment is the foundation of human survival and development; the surface space is closely related to human activities and is the base of human survival in nature; and it is the main place for humans to use and transform nature [12-13]. The evaluation of the natural suitability of human settlements is an important foundation and component of the functional zoning of population development in China at present. This paper constructs a comprehensive HEI model from four aspects of topography, climate, hydrology, and vegetation, analyzes the suitability of Hangzhou's human settlements environment with the help of the GIS Spatial analysis function, and provides the basis and support for the coordinated development and scientific planning of the human settlements environment construction in this area. The results of the analysis show that:

(1) The overall suitability of the living environment in Hangzhou is good, with low terrain undulation, good water and heat conditions, and high vegetation coverage. It is a famous forest city and a livable city.

(2) The current spatial pattern of population distribution in Hangzhou is inconsistent with the suitability of the living environment in the area because this study is based on natural factors. However, the geographical location and developed urbanization of the Hangzhou urban area make it inferior to other research areas in terms of water, heat, and vegetation, resulting in relatively unsuitable living conditions.

(3) Hangzhou has the widest distribution area of more suitable areas, accounting for 26.55% of the city's area, followed by highly suitable areas, accounting for 22.69% of the city's area, generally suitable areas, accounting for 20.69%, critical suitable areas, and unsuitable areas, accounting for 13.10% and 16.97%, respectively. The study results may be due to the inaccuracy of DEM accuracy, the incompleteness of meteorological data, and the existence of personal equations, the subjectivity of evaluation method selection may affect the quality of research results. Next, data acquisition and processing methods should be further optimized to ensure scientific results.

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