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The Natural Suitability of Human Settlements and Their Spatial Differentiation in the Nenjiang River Basin, China

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The natural suitability of human settlements (NSHS) of the Nenjiang River Basin was carried out by evaluation indices such as terrain characteristics, vegetation, hydrology, and climate of the region. The NSHS model is built using a GIS spatial analysis platform to reveal the suitability zoning and spatial differentiation (SD) characteristics of human settlements in the study area. The results show that the NSHS index of the study area ranges from 0.31 to 0.92, with an average of 0.54, indicating that the values show a gradual increase from northwest to southeast and from mountainous and hilly areas to plains. The most suitable and generally suitable areas constitute nearly 41.81% of the basin, and the population of these terrain accounts for about 84.25% of the total population of the basin. The suitable area category covers the largest area among all other categories accounting for about 25.16%, and the population of these regions accounts for about 12.46%. The critical suitable area category accounts for 21.70% of the basin, whereas unsuitable areas account for 11.32%, constituting the smallest areas compared to other categories. It is also evident that diverse limiting factors of NSHS characterize distinct areas in the study area. For example, high NSHS index, the normalized difference vegetation index (NDVI), and water resource index (WRI) are the main limiting factors in plane areas, low NSHS index, the relief degree of land surface (RDLS) index, and temperature-humidity index (THI) are the major limiting factors in the mountainous, hilly and plateau areas.

Keywords: GIS, human settlements, natural suitability, spatial differentiation, Nenjiang River basin

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1 INTRODUCTION

The natural environment is recognized as the framework for human existence, productivity, and life. The natural suitability of human settlements (NSHS) directly influences the distribution, migration, and population density of an area under natural conditions and affects the degrees of regional and socio-economic development, living comfort, and rational utilization of resources.

Several researchers have traditionally focused on diverse aspects of human settlement environment assessment (HSEA), including HSEA with cities [(Li and Ni, 2009; Sui et al., 2013; Qing et al., 2018), etc.], HSEA with rural areas [(Li et al., 2015; Wu D. et al., 2016; Zeng et al., 2016)], etc. The mainstream evaluation methods of HSEA are mostly comprised of questionnaire surveys, structural models, analytic hierarchy processes, fuzzy comprehensive

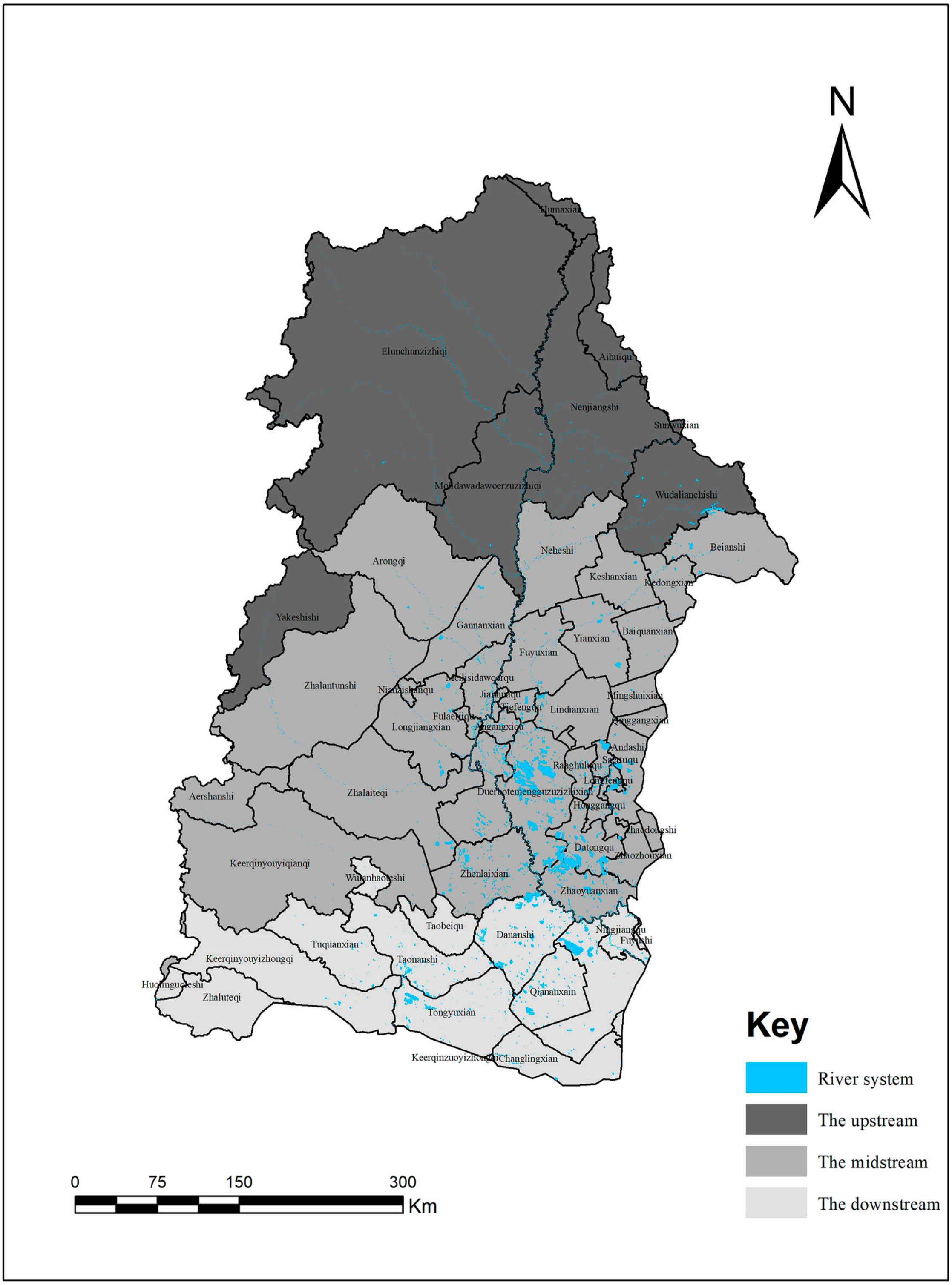

FIGURE 1 | Nenjiang river basin.

evaluation, GIS analyses, etc. (Liu and Zhang, 2014). Several domestic researchers have conducted numerous HSEAs at various levels (Xu et al., 2007; Li et al., 2010; Li et al., 2011; Min et al., 2012; Gu et al., 2015; Wu H. et al., 2016; Wang and Wang, 2019), including those conducted across different countries, regions, provinces, and cities. The earlier

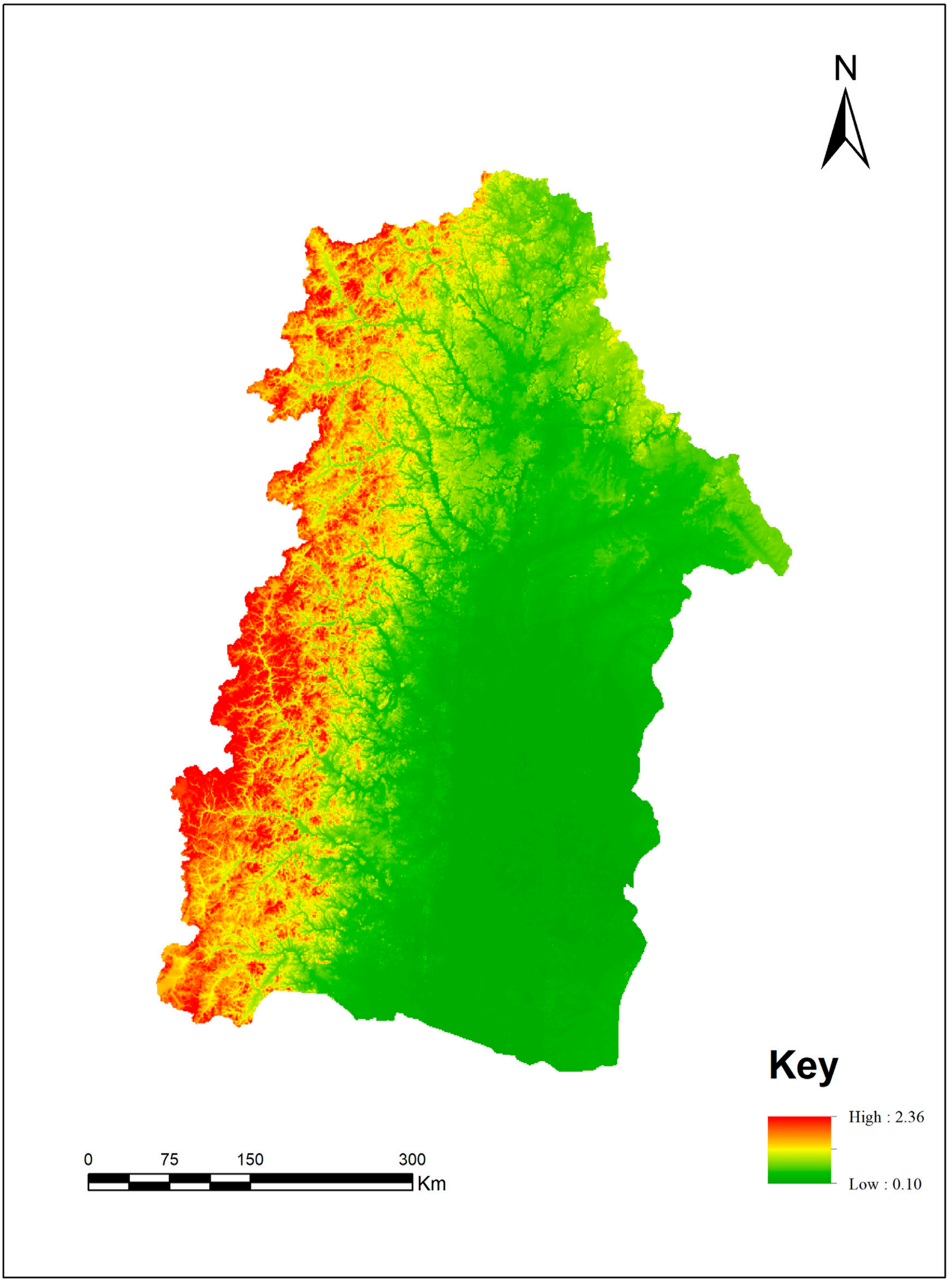

FIGURE 2 | RDLS.

research in the Nenjiang River Basin related to HSEA are unilaterally focused on climate, topography, vegetation, and hydrology (De Freitas, 1979; Wu et al., 2019; Li et al., 2020; Wang X. et al., 2020; Wang Z. et al., 2020). However, a comprehensive HSEA based on the aforementioned natural factors has not been reported so far, and hence adequate

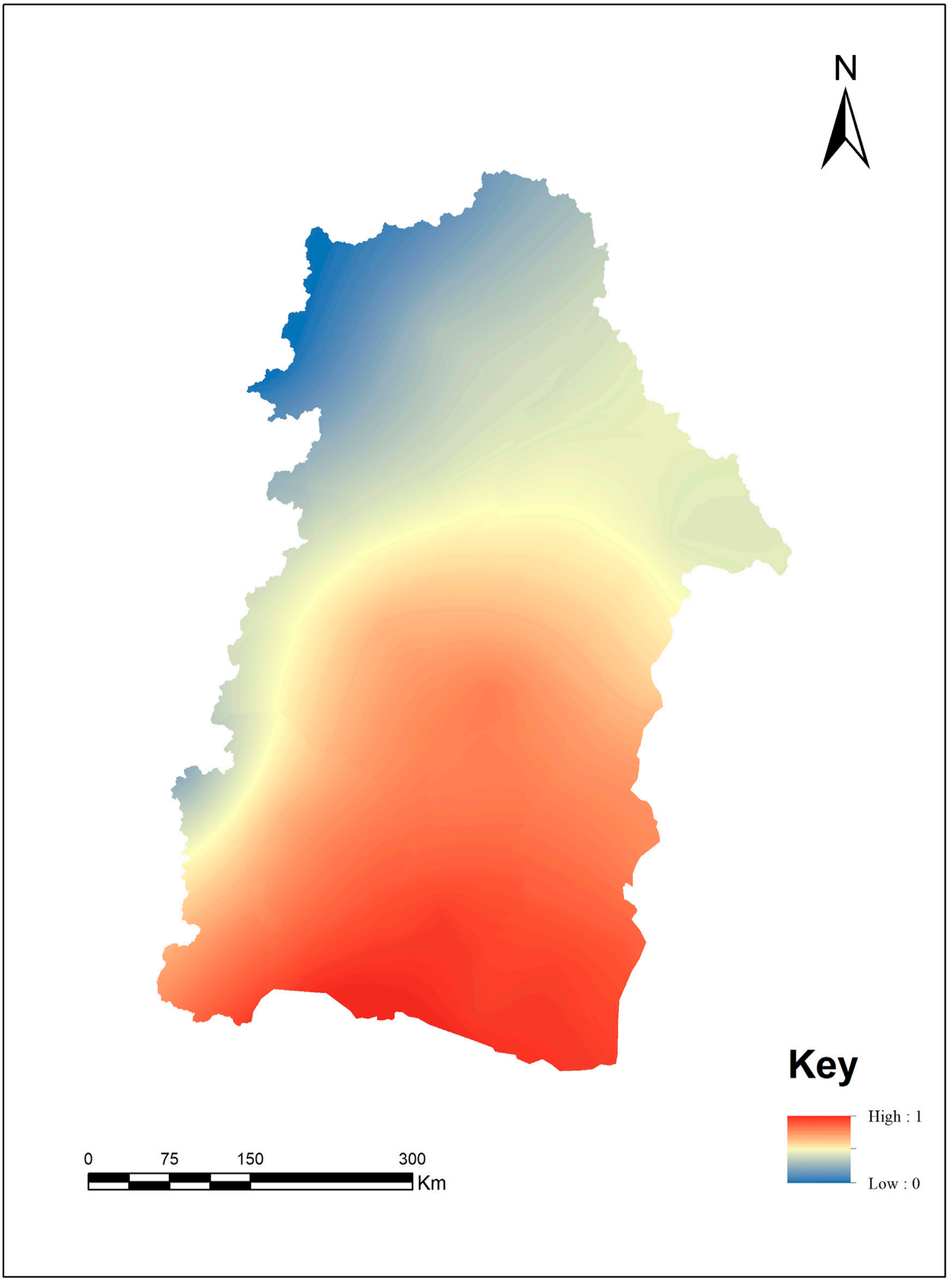

FIGURE 3 | THI.

research on NSHS evaluation of the study areas needs utmost importance. In this context, the present study builds the human settlements index (HSI) model for the Nenjiang River Basin in terms of various factors such as topography, climate, vegetation, hydrology, and soil using GIS. The study also highlights the spatial adaptability and geographical

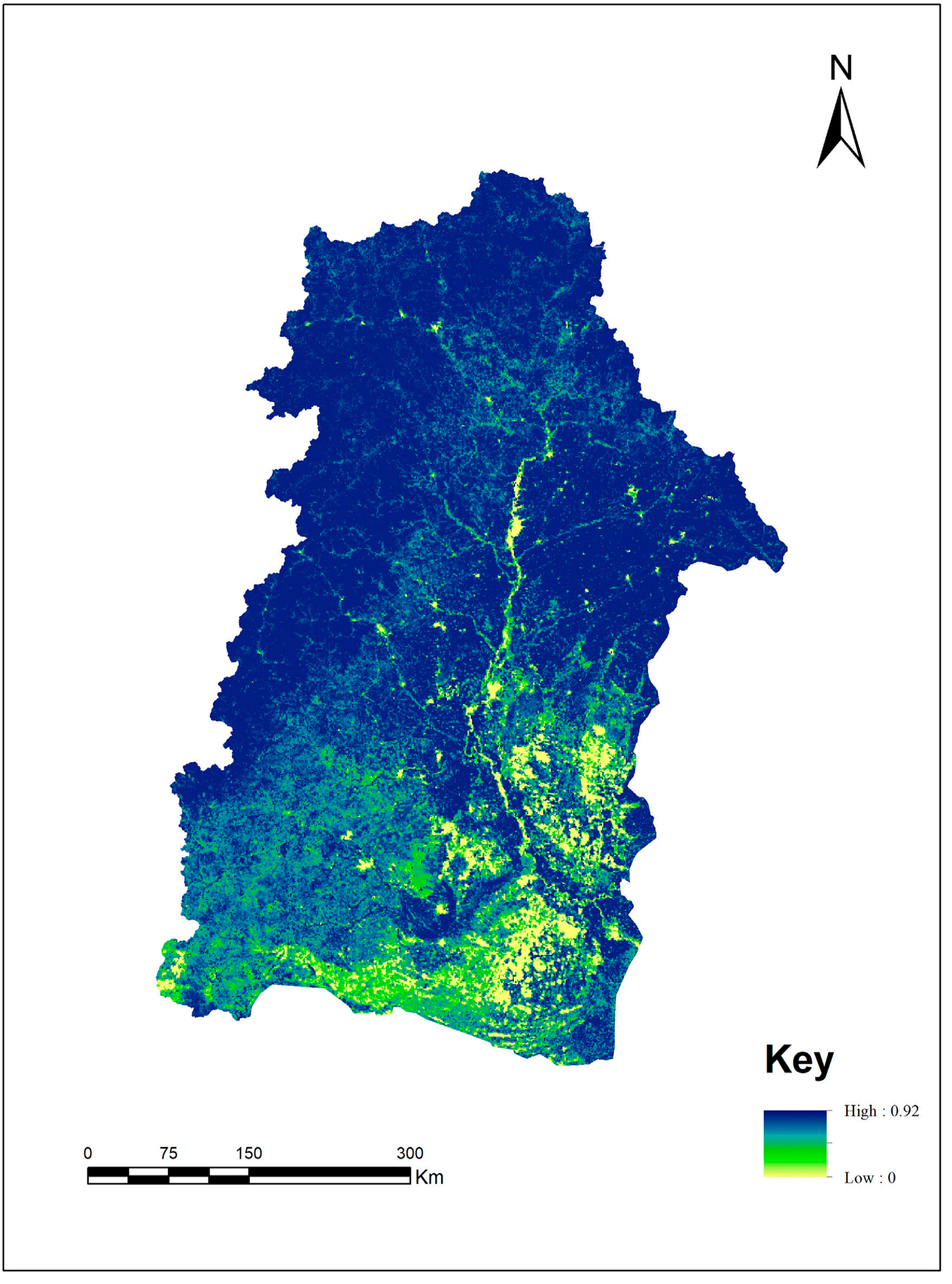

FIGURE 4 | NDVI.

distribution features of human settlements in the study area. It provides a scientific basis and decision-making reference for population distribution planning, resources efficiency and rationality, environmental protection, and improvement of NSHS. The present paper evaluates the adequacy of natural conditions and living environment in the Nenjiang River

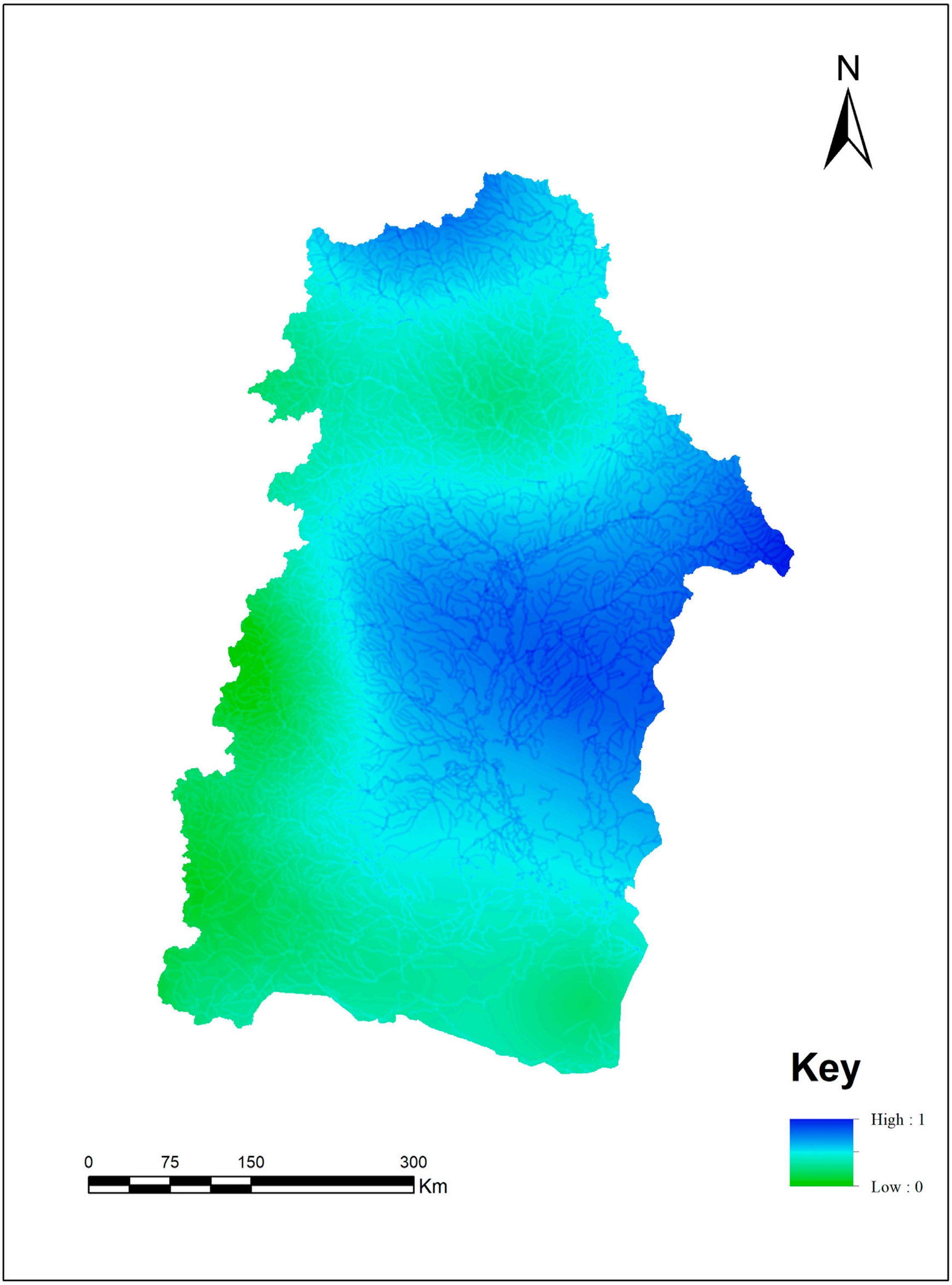

FIGURE 5 | WRI.

Basin, China. This study helps to rejuvenate the northeast by providing a theoretical foundation for rational population distribution planning, efficient and rational utilization of resources, regional natural environmental protection, rational social infrastructure construction, and improvement of NSHS.

2 MATERIALS AND RESEARCH METHODS

2.1 Overview of the Study Area

This region is located at 119°15′–127°40′E and 44°26′–51°37′N. Originating from the south foot of Yilehuli Mountain in Greater Khingan Mountains, the river flows through Nenjiang, Erlunchun, Nehe, and other counties (cities and banners) from north to south. It merges with the main stream of Songhua River at Sancha estuary, with a total length of 1,370 km and a drainage area of 297,000 km^2. The region is in the northern edge of East Asian monsoon region, with the semi-humid continental climate of cold temperate zone. It has long and cold winter, short and rainy summer, with the annual average temperature of 1°–4°. Its historical minimum temperature is −39.5°C, while the maximum temperature is 40.1°C. The region's main geomorphic types include plateaus, mountains, hills, and plains. It covers Hailar City, Ulanhot City, Huolingol City, and Tongliao City in Inner Mongolia Autonomous Region, Heihe City, Qiqihar City, Daqing City, Suihua City, and Harbin City in Heilongjiang Province, Baicheng City and Fuyu City in Jilin Province. The region can be divided into three sections on the basis of the natural characteristics: the upstream, the midstream and the downstream, as shown in **Figure 1**.

2.2 Data Source and Processing

2.2.1 Data Sources

The remote sensing data and images of the study area, including 30 m × 30 m DEM, were generated using the topographic map from the China Geospatial data Cloud of the Chinese Academy of Sciences. The meteorological data such as temperature, humidity, and precipitation in the basin from the basic observation data of 16 meteorological stations as part of the China Meteorological data Network. The vegetation data of the area from July to September 2015 were collected from the remote sensing data captured by Landsat 8. The demographic population data in 2017 was collected from the economic and social statistical yearbook for the study area.

2.2.2 Data Preprocessing

A uniform projection coordinate system was established by projecting and transforming the remote sensing and DEM data. Further, relief features such as slope, elevation variation, average altitude, and other relevant data were extracted from the DEM. The normalized difference vegetation index (NDVI) and modified normalized difference water index (MNDWI) of the basin were extracted using ENVI software. A comprehensive evaluation of the natural factor data precipitation, temperature, and humidity in the basin was carried out by generating their index data layers through density calculation and kriging interpolation using the spatial analysis tool of the ArcGIS software. Further, the HSEA model was built to develop the NSHS index map and to examine the SD characteristics of the study area.

2.3 Research Methods

2.3.1 RDLS

The land surface is the foundation for human existence and development, and hence, the human activities of an area are significantly influenced by the topographic variations and geomorphic features. The relief degree of the land surface (RDLS) of the study area has been calculated based on Feng et al. (2008), and the following equation is used for the calculation.

$$RDLS = ALT/1000 + \{[Max(H) - Min(H)] \times [1 - P(A)/A]\} \times /500$$

Where: *Max(H)* and *Min(H)* represent the highest and the lowest altitudes respectively in the study area; *A* is the total area, and *P(A)* is the area of flat land. The RDLS is computed using the unique topography and landform of the basin as the basis of this study, with a 1 km × 1 km grid as the fundamental evaluation unit (*A* is 1 km^2). The calculation results of RDLS are shown in **Figure 2**.

2.3.2 THI

Climate patterns have a significant impact on human activity. Tome's discomfort index, commonly known as the temperature-humidity index (THI), measures the degree of humidity in the absence of wind. The following equation is used for the calculation of THI.

$$THI = T - 0.55 \times (1 - f)(T - 58)$$
$$T = 1.8t + 32$$
$$K = -(10\sqrt{v} + 10.45 - v)(33 - t) + 8.55S$$

Where *THI* represents the temperature-humidity index, *K* represents the wind efficiency index, *t, and T* represent the monthly averages of temperatures in °C and °F respectively, *f* represents the monthly average relative humidity of air (%), *v* represents the average wind speed (m/s) at the height of 10 m above the ground, and *S* represents the sunshine hours (h/d). The calculation results of THI are shown in **Figure 3**.

2.3.3 NDVI

The height of vegetation cover is considered as one of the essential indices for determining the living environment and is used to evaluate ecological conditions of human production and life. The normalized difference vegetation index (NDVI) is the standard way to represent the vegetation index (Wei et al., 2012). The following equation is used to calculate the NDVI.

$$\mathrm{NDVI} = (\mathrm{NIR} - \mathrm{R})(\mathrm{NIR} + \mathrm{R})$$

Where *NIR* and *R* are the reflectances of the near-infrared and red bands, respectively. The estimated values of NDVI are in **Figure 4**.

2.3.4 WRI

The quality of hydrological conditions is particularly significant to the NSHS in the basin since water resources are essential natural resources for survival and development. One of the most often used indices for assessing the regional hydrological conditions is the water resource index (WRI) (Wei et al., 2012). The equation used for the calculation of WRI is as follows.

$$WRI = \alpha P + \beta WPM$$

Where *WRI* is the water resource index, *P* is normalized precipitation; *WPM* is the normalized water production modulus, and α and β are the weight values of precipitation and water production modulus, respectively. The estimated values of WRI for the basin are shown in **Figure 5**.

2.3.5 HEI Model

$$HEI = \boldsymbol{\alpha}\times NRDLS + \boldsymbol{\beta}\times NTHI + \boldsymbol{\gamma}\times NWRI + \boldsymbol{\delta}\times NLCI$$

Where *HEI*, *NRDLS*, *NTHI*, *NWRI*, and *NLCI* represent human settlements environment index, normalized relief degree of the land surface, normalized temperature-humidity index, normalized water resource index, and normalized land-cover index. The symbols α, β, γ, and δ represent the weights of *NRDLS*, *NTHI*, *NWRI*, and *NLCI*, *respectively*. The maximum, minimum, and optimum values corresponding to each index in standardization procedures are based on the research findings reported by Feng et al. (2008), Wei et al. (2012), and Li and Zheng (2018). The correlation between these four indices and the grid layer of population density was examined using the spatial analysis tool of ArcGIS. The correlation coefficients were subsequently inverted and normalized using SPSS statistical software. The weights of NSHS evaluation indices in the basin, α, β, γ, and δ were estimated as 0.387, 0.153, 0.275, and 0.185, respectively. Based on the NSHS values, the study area has been divided into five categories: most suitable, generally suitable, suitable, critical suitable, and unsuitable areas. The SD and regional characteristics of these categories were analyzed based on the results of earlier research on the human settlements index model (Ma et al., 2007; Hao and Ren, 2009; Wei et al., 2012; Li and Zheng, 2018).

3 RESULTS AND ANALYSIS

3.1 NSHS Evaluation in Nenjiang River Basin

The results of the calculations (**Figure 3**) demonstrate that the NSHS indices of the Nenjiang River Basin vary from 0.3 to 0.92, with an average of 0.54. The relative suitability progressively improves from northwest to southeast and from mountainous and hilly areas towards plains. The north of Songnen and Liaohe Plains, with flat topography, excellent hydrothermal conditions, convenient transportation, a high level of economic development, and large population density, is characterized by high NSHS indices. The area falling under the suitable category of NSHS indices occupies most part of the basin, accounting for 25.16% of the total area of the basin. The details of different categories of NSHS indices of the basin are discussed in the following subheads.

1) Most suitable area: The areas under the most suitable category are characterized by NSHS indices from 0.68 to 0.90, covering an estimated land area of 56,161.05 km^2, accounting for 19.35% of the basin area. The settlements of the area are mainly concentrated in the Songnen Plain and the northern parts of Liaohe plain with a population of 3,563,250, which is 61.54% of the total population of the basin and the population density of 63 people/km^2. These areas mark the economic powerhouse of the Nenjiang River Basin due to ideal natural conditions. However, the shortage of water resources and severe deterioration of vegetation in the area limits the NSHS in terms of population and natural conditions.
2) Generally suitable area: The NSHS indices of the generally suitable category of areas range from 0.59 to 0.69, covering a land area of 65,188.41 km^2, which account for about 22.46% of the basin area. These zones are mainly focused in the southeastern parts of the Greater Khingan Mountains and nearby areas with a population of 1,315,187, which is 22.71% of the total population of the basin, and a population density of 20 people/km^2. Agricultural production lands mainly dominate these areas where the topography is flat.
3) Suitable areas: The NSHS indices of the suitable category of land range from 0.47 to 0.59, covering a land area of 73,028.45 km^2, which is about 25.16% of the basin area. The category is mainly distributed in the Greater Khingan Mountains areas, where the population is 721,493, which accounts for 12.46% of the total population of the basin, with a population density of 10 people/km^2. These areas are described as agricultural lands with modest residual mountains and hills.
4) Critical suitable area: The NSHS indices of the critical suitable area category ranges from 0.36 to 0.47, occupying nearly 62,969.82 km^2 of land area, which accounts for 21.70% of the basin area. This zone covers the northwestern parts of the Greater Khingan Mountains, where the population is 150,359, which is 2.60% of the total population of the basin, with a population density of 2 persons/km^2. This zone is characterized by larger RDLS with poor human settlements and is unsuitable for living due to its relatively sparse population.
5) Unsuitable areas: The NSHS indices of the unsuitable category of the basin range from 0.13 to 0.36, covering a land area of 32,864.03 km^2, accounting for about 11.32% of the basin area. This zone is occupied in the eastern part of Hulunbuir plateau, where the population is 40,211, which is nearly 0.69% of the total population of the basin and the population density is 1 person/km^2. The area is characterized by steep slopes with low THI and poor environment and hence unsuitable for living.

3.2 Single-Factor Analysis of NSHS in the Study Area

The superimposition of each evaluation factor and the NSHS using the spatial analysis tool in ArcGIS indicates that the dominant limiting factors of human settlements vary spatially with greater spatial differentiation.

1) RDLS factor analysis: The NSHS of the study area is essentially associated with RDLS in space, with a significant negative correlation, indicating lower values of RDLS for better NSHS and vice versa. RDLS has a significant impact on the population distribution of an area. A lesser percentage of the population occupy steep and hilly areas, while most of the population lives in plane lands.
2) NDVI factor analysis: The NDVI index directly impacts the perception of people on NSHS, and there is a positive

TABLE 1 | The grading standards of biometeorology suitability assessment.

THI		K		Grade
Range	Degree of sensation	Range	Degree of sensation	
<40	Extremely cold, extremely uncomfortable	<−1,200	Severe cold, extremely uncomfortable	e
40–45	Cold, uncomfortable	−1,200~−1,000	Cold, uncomfortable	d
45–55	Slightly cold, rather uncomfortable	−1,000~−800	Cold and icy, rather uncomfortable	c
55–60	Clear and cool, comfortable	−800~−600	Clear and cool, comfortable	b
60–65	Cool, very comfortable	−600~−300	Cool, very comfortable	A
65–70	Warm, comfortable	−300~−200	Warm, comfortable	B
70–75	Slightly heat, rather comfortable	−200~−50	Warmly heat, rather comfortable	C
75–80	Muggy, uncomfortable	−50–80	Hot, uncomfortable	D
>80	Extremely muggy, extremely uncomfortable	>80	Scorching hot, extremely uncomfortable	E

correlation between these two factors. However, the correlation is generally lower in densely populated areas with higher NSHS, while it is higher in sparsely populated mountainous and hilly areas, especially between NVDI and RDLS factors. This is one of the most important elements affecting the NSHS on the plain.

3) THI factor analysis: The THI indices of the Nenjiang River Basin rises substantially from northwest to southeast and from areas with higher altitudes to low altitudes, and the values are shown in **Table 1**. Based on the spatial variations in THI, the basin has been divided into three categories with THI values < 40, 40–45, and 45–55. Extreme areas are also distributed in the basin, especially in the northwestern parts, accounting for 36.3% of the basin area. Hence, THI can be considered as one of the important factors affecting the NSHS values. It is also observed that the THI indices are negatively correlated with RDLS.
4) WRI Factor analysis. The WRI and NSHS indices of the Nenjiang River basin are positively correlated with a correlation coefficient of 0.1848. The overall WRI index of the basin increases in the east and decreases towards the west along the Nenjiang River. This is one of the major challenges that limit the improvement in NSHS in the plain to a certain extent.

4 DISCUSSION

The present study investigates the suitability zoning and spatial differentiation (SD) characteristics for human settlements in the Nenjiang River Basin using NSHS as an evaluation index by considering the terrain features, climate, vegetation, and hydrology. The NSHS model of the area was built using the GIS spatial analysis platform. The Nenjiang River is a tributary of Songhua River and serves various purposes, including water conservation, soil and water conservation, economic development, and human survival. Hence, understanding the NSHS and SD of the basin offers both theoretical and practical relevance.

It may be used to provide theoretical and empirical justification for a follow-up ecological compensatory mechanism to analyze the NSHS of the basin using a quantitative approach. The most suitable areas are often economically established, with significant environmental carrying capacities, whereas the unsuitable areas are often economically underdeveloped, with limited environmental carrying capacities. As a result, it is necessary to establish a reasonable and appropriate upstream-midstream-downstream ecological compensation mechanism must be established and the ecological compensation priority and compensation criteria of each basin section must be calculated. The goal of the present study is to use the ecological compensation mechanism to limit human activities in unsuitable areas and develop a green industry. Furthermore, the selection of indices and weighting procedures involved in the study need to be discussed further in view of the complex social and natural environment of the study area. Asa consequence of long term and historical effects, certain phenomena in the study area are incongruous with the research conclusion in the present study, which needs detailed investigations in the future. At the same time since the natural foundation, social foundation, and ecological background involved in human settlements make a complex system to accurately express the suitability of human settlements, the selection of indicators and determination of parameters of the model still need to be deeply investigated.

5 CONCLUSION

1) The NSHS values gradually decrease from southeast to northwest and from plain to mountainous and hilly areas. The most suitable category covers nearly 56,161.05 km^2 of area, which accounts for 19.35% of basin area, whereas the generally suitable category covers an area of 65,188.41 km^2, which accounts for 22.46% of the basin areas. The suitable category areas cover 73,028.45 km^2 of land, accounting for about 25.16% of basin area, while the critically suitable areas cover 62,969.82 km^2 of land, accounting for about 21.70% of the basin area. Further, the unsuitable areas cover nearly 32,864.03 km^2 of land, accounting for 11.32% of the basin area.
2) The major limiting factors of NSHS vary spatially, with high NSHS THI index and WRI index values in plane areas. The limiting factors in the mountainous and hilly areas include low NSHS and RDLS indices. The NDVI index has a negligible effect on the SD of NSHS in the study area.
3) The SDs of NSHS in the study area are highly correlated with RDLS values, which greatly affect the population distribution of the basin. The majority of the population is occupied in the northern parts of Songnen and Liaohe plains.
4) With the help of GIS platform, the calculation, statistics, and analysis methods of GIS are used to determine the influencing

factors of human settlement suitability in Nenjiang River Basin. Based on grid data and spatial patterns, which can better quantitatively reflect the regional differences in the basin, it can guide the rational distribution and flow of population, and is of great significance to promote the coordinated development of population, resources and environment. It is a research method worthy of reference and utilization.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

YZ and JZ contributed to conception and design of the study. YZ organized the database, performed the statistical analysis. YZ wrote the first draft of the manuscript, wrote sections of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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REFERENCES

De Freitas, C. R. (1979). Human Climates of Northern China. *Atmos. Environ.* 13, 71–77. doi:10.1016/0004-6981(79)90246-4

Feng, Z., Tang, Y., Yang, Y., and Zhang, D. (2008). The Establishment and Application of China's Human Settlement Index Model Based on GIS. *Acta Geogr. Sin.* 63, 1327–1336. doi:10.3321/j.issn:0375-5444.2008.12.010

Gu, Y., Yang, J., Feng, X., Li, C., and Li, X. (2015). Research on the Spatial Differentiation of Human Settlement Suitability in Typical Tourist Cities in China. *Geogr. Sci.* 35, 410–418. doi:10.13249/j.cnki.sgs.2015.04.004

Hao, H., and Ren, Z. (2009). Evaluation of the Natural Suitability of Human Settlements in Shaanxi Province Based on Raster Data. *Acta Geogr. Sin* 64, 498–506. doi:10.11821/xb200904012

Li, B., and Zheng, S. (2018). Evaluation of Human Settlement Environment Suitability and Spatial Differentiation in Fenhe River Basin. *Arid Land Resourc. Environ.* 32, 87–92. doi:10.13448/j.cnki.jalre.2018.240

Li, H., Yang, W., and Li, F. (2020). Analysis of Temporal and Spatial Distribution of Precipitation Characteristics in Nenjiang River Basin. *J. Northwest. Univ. Nat. Sci. Ed.* 50, 427–437. doi:10.16152/j.cnki.xdxbzr.2020-03-013

Li, P., Chen, C., and Chen, J. (2015). Research on the Evolution and Influencing Factors of the Multi-Functional Spatio-Temporal Pattern of Rural Areas: Taking Jiangsu Province as an Example. *Geogr. Sci.* 35, 845–851. doi:10.13249/j.cnki.sgs.2015.07.006

Li, X., and Ni, Y. (2009). Evaluation of the Coordinated Development of Urbanization and Urban Human Settlements in My Country's Excellent Livable Cities in the Past Ten Years. *Arid Land Resourc. Environ.* 23, 8–14. doi:10.13448/j.cnki.jalre.2009.03.025

Li, Y., Liu, C., Zhang, H., and Gao, X. (2011). Evaluation on the Human Settlements Environment Suitability in the Three Gorges Reservoir Area of Chongqing Based on RS and GIS. *J. Geogr. Sci.* 21, 346–358. doi:10.1007/s11442-011-0849-2

Li, Y., Liu, S., and Li, X. (2010). GIS-based Evaluation of Human Settlements in the Nujiang Canyon — Taking Lushui County as an Example. *Adv. Geogr. Sci.* 29, 572–578. doi:10.11820/dlkxjz.2010.05.009

Liu, J., and Zhang, W. (2014). A Review of Research on Human Settlement Environment Evaluation Methods. *Urban Dev. Res.* 21, 46–52. doi:10.1007/s11356-014-2843-6

Ma, L., Sun, G., Li, F., and Wang, B. (2007). Evaluation of Tourism Climate Comfortableness in Shanxi Province. *Resourc. Sci.* 29, 40–44. doi:10.3321/j.issn:1007-7588.2007.06.006

Min, J., Liu, C., and Li, Y. (2012). Nature Suitability for Human Settlement Based on GIS Technology. *Resourc. Environ. Yangtze River Basin* 21, 1006–1012.

Qing, F., Xia, X., and Jiang, Z. (2018). Evaluation of Human Settlement Environment Suitability in Xindu District of Chengdu Based on RS and GIS. *J. Qiqihar Univ. (Nat. Sci. Ed.* 34, 7689–7780. doi:10.3969/j.issn.1007-984X.2018.02.015

Sui, Y., Shi, J., Cui, L., and Liang, P. (2013). Comprehensive Evaluation of the Ecological Quality of Urban Human Settlements in Shanghai. *Resourc. Environ. Yangtze River Basin* 22, 965–971.

Wang, X., Liu, H., and Lu, J. (2020). *Analysis on the Characteristics of Wetland Changes in the Nenjiang River Basin*. China Soil Water Conserv, 59–62.

Wang, Z., Li, Y., Luo, J., Liu, F., Wang, Y., and Li, H. (2020). The Evolution of the Spatial and Temporal Pattern of Habitat Quality in the Nenjiang River Basin Based on the InVEST Model. *Environ. Ecol.* 2, 19–26.

Wang, X., and Wang, C. (2019). Natural Suitability Analysis of Human Settlement Environment in Liaoning Province Based on GIS Spatial Analysis Modeling. *For. Sci. Technol. Inform.* 51, 133–136.

Wei, W., Shi, P., Feng, H., and Wang, X. (2012). Suitability Assessment of Human Settlements in Arid Inland River Basins — Taking Shiyang River Basin as an Example. *J. Nat. Resourc.* 27, 1940–1950. doi:10.1007/s11442-013-1013-y

Wu, D., Li, Y., and Li, S. (2016). The Characteristics of Spatial Distribution and Human Settlement Suitability of Residential Areas in the Hexi Small Watershed of Miyun County under the Influence of Natural Factors. *J. China Agr. Univ.* 21, 129–136. doi:10.11841/j.issn.1007-4333.2016.04.17

Wu, H., Wang, X., Shahid, S., and Ye, M. (2016). Changing Characteristics of the Water Consumption Structure in Nanjing City, Southern China. *Water* 8, 314. doi:10.3390/w8080314

Wu, Y., Zhang, G., Qi, P., Rousseau, A. N., Hu, B., Song, Z., et al. (2019). Simulation Efficiency Evaluation of Watershed Hydrological Model Coupled with Wetland Module. *Adv. Water Sci.* 30, 326–336. doi:10.14042/j.cnki.32.1309.2019.03.003

Xu, C., Liu, M., Zhang, C., An, S., Yu, W., and Chen, J. M. (2007). The Spatiotemporal Dynamics of Rapid Urban Growth in the Nanjing Metropolitan Region of China. *Landscape Ecol.* 22, 925–937. doi:10.1007/s10980-007-9079-5

Zeng, J., Yang, Q., Liu, Y., Zhao, C., and Li, B. (2016). The Evolution and Influence Mechanism of the Rural Human Settlement Environment in the National Key Ecological Function Zone: Taking Lichuan City, Hubei Province as an Example. *Hum. Geogr.* 31, 81–88. doi:10.13959/j.issn.1003-2398.2016.01.011

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.