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Urban–rural human settlements in China: Objective evaluation and subjective well-being

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Human settlements have an important impact on human health, livability, and the economy, which has attracted widespread concern worldwide. Few studies have, however, paid attention to a comprehensive evaluation of urban and rural areas, as well as subjective and objective aspects. This paper evaluates four dimensions of urban–rural settlements in China, including environmental health, environmental tidiness, environmental amenity, and environmental support, from both subjective and objective perspectives. The findings are summarized as follows: (1) The quality of urban–rural human settlements in China has significantly improved over the last 20 years, and it shows a significant decreasing tendency from the southeastern coastal area to the northwestern inland area spatially. (2) The national average score of subjective estimation of human settlement is at the level of “Satisfied”, and it displays significant disparities in terms of residents’ attributes, such as occupation, age, education, and habitation. (3) The subjective evaluation and subjective well-being have a positive correlation regarding the comprehensive assessment of urban–rural human settlements, but there are significant differences in objective estimation to different sub-dimensions. Long-term follow-up investigation and evaluation should be the focus of future research. Findings provide scientific guidance for the optimization and improvement mechanism of urban–rural human settlements.

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Introduction

With the dramatic socioeconomic development around the world, some related problems in human settlements become more and more prominent (Xue et al., 2021), such as environmental pollution, ecological destruction, and insufficient living infrastructures (Shen et al., 2017). The concept of human settlements was first proposed by Doxiadis (1975), and the United Nations' Vancouver Declaration promoted it to become an independent discipline (United Nations, 1976). In general, human settlements can be divided into urban and rural human settlements (Hu and Wang, 2020). Previous studies primarily have focused on the urban dimension (Fidler et al., 2011; Xiong, 2011; Algeciras et al., 2016), since the concept of human settlements originated from the field of urban planning. However, western scholars have continuously embedded rural human settlements into urban human settlements in recent years, paying wide attention to issues like rural sustainable environment (Ciolac et al., 2019) and peri-urban settlement pattern (Kleemann et al., 2017). China, there has been at a stage of rapid industrialization and urbanization for a long time, leading to the fact that the overall human settlements are seriously threatened and there are many differences in human settlements between urban and rural areas (Yang et al., 2020; Wang et al., 2021). Therefore, it is urgent to promote urban-rural human settlements in China, which is also an important way to implement the *2030 Agenda for Sustainable Development of the United Nations* and further realize the goal of sustainable development under the new development paradigm of China.

The issues about urban-rural human settlements in China have received extensive attention from political and academic circles. In recent years, concentrating on the objective of soundness ecology and comfortable living, China has adhered to the concept of green development stressing the harmony between man and nature and has carried out a series of measures to improve the urban-rural human settlements. On one hand, the National Development and Reform Commission in China released the *Master Plan for Green Life Creation Action* in 2019 with the purpose of optimizing urban human settlements. Cities at the prefecture level or above have developed various garbage classifications and focused on the transformation of pollution control and environmental governance, contributing to the optimization of urban appearance and quality. On the other hand, in order to improve rural human settlements, the Chinese government issued multiple policies such as the *Three-year Action Plan for the Improvement of Rural Human Settlement* and the *Action Plan for Agricultural and Rural Pollution Governance*. Key tasks of rural human settlements have been gradually implemented, which have significantly improved the appearance of villages and the living conditions of rural residents. Simultaneously, some Chinese scholars have constantly avoided the previous tendency of "urbanism" when researching human settlements, carrying out relevant studies of rural human settlements (Zhao et al., 2019; Hu and Wang, 2020; Lu et al., 2020). However, with the in-depth promotion of China's new-type urbanization and rural revitalization strategy, it is urgent to achieve the goal of urban-rural integration (Liu and Zhang, 2018), while there is a lack of corresponding research on the scientific evaluation on urban-rural human settlements in China, making it difficult to solve the problems in urban-rural human settlements effectively as a whole.

Urban-rural human settlements are the organic combination of material and non-material environments in urban and rural areas, which aims for promoting human activities to coordinate with the physical environment (Wu, 2001; Cong et al., 2021). The intrinsic value of human settlements lies in pursuing the theme of "people first" and "environment first" (Tang et al., 2017), leading to comprehensive sustainable development. It is necessary to protect

the environment and meet human needs when creating suitable human settlements. Although there are abundant studies on the evaluation of human settlements from different perspectives, few of them combine both objective and subjective methods of assessment comprehensively (Wang et al., 2017). A scientific and accurate evaluation of human settlements owes not only the reflection of the physical environment (Baiocchi et al., 2015) but also the grasp of public satisfaction (Wang et al., 2021). In addition, it is very important to quantify the spatiotemporal patterns of human settlements in China during a long period from both urban and rural dimensions and identify the existing problems and potential risks. Consequently, we need to construct a comprehensive index system to evaluate the quality of urban-rural human settlements based on objective and subjective evaluations.

The rest of this paper is organized as follows. Section "Theoretical framework of the comprehensive evaluation of urban-rural human settlements" is the literature review of relevant research on urban-rural human settlements, based on which our theoretical analysis framework is proposed. Methods and data are described in the section "Methods and data". Section "Results" presents the results according to the objective evaluation and subjective well-being, and spatiotemporal patterns of urban-rural human settlements in China. The relationships between the objective and subjective evaluation of urban-rural human settlements are discussed in the section "Discussion". On the basis of our findings, the conclusion is provided in the section "Conclusions" as a feasible reference for the coordination between human activities and the physical environment, contributing to sustainable development in China.

The theoretical framework of the comprehensive evaluation of urban-rural human settlements

Human settlements generally refer to places where human beings live together, serving as a bridge between human beings and the physical environment on a geographical scale and closely related to human survival, production, life, and development (Xue et al., 2021). They are the aggregations of all material, social, organizational, spiritual, and cultural elements of human society, which cover urban, township, and rural areas (United Nations, 1976). As the basis of human survival and a prerequisite for the stable development of society (Cong et al., 2021), human settlements, as well as the problems attached to them, have attracted a lot of concerns ever since the rapid industrialization and urbanization of western countries (Tang et al., 2017; Baiocchi et al., 2015). Focusing on people-oriented planning and coordinated development of urban and rural areas, the "garden city" theory (Howard, 1989) and "the notion of area" (Geddes, 1915) have laid a theoretical foundation for the science of human settlements, i.e. Ekistics. Doxiadis, the founder of Ekistics, stressed the comprehensiveness of human settlements to conduct generalized systematic research on "elements" (people, housing, society, and nature) (Doxiadis, 1968; Zhao et al., 2019; Wu, 2001). In China, the science of human settlements was firstly proposed by Wu (2001), who defined the natural system, human system, living system, social system, and supporting system as the five crucial components of human settlements. There exist close connections and frequent interactions between these major components, forming a giant complex system and promoting the sustainable evolution of human settlements (Cong et al., 2021; Hu and Wang, 2020).

In recent years, being aware of the important role that good human settlements play in residents' life and regional development, a number of studies on the evaluation of human settlements have emerged (Ma et al., 2016; Xue et al., 2021). The comprehensive evaluation of the human environment is an

effective way to reflect the quality of the living environment for analysis and comparison, with the aim of helping policymakers to grasp the characteristics as well as problems of human settlements and providing guidance for regional planning, construction, and management (Tang et al., 2017; Cong et al., 2021). Based on abundant theories and multiple perspectives, research of this kind has revealed the status and trend of human settlements in different areas through quantitative and qualitative approaches (Michael, 2014; Zhao et al., 2019). The construction of the appraisal system is usually based on the components of human settlements, centering on elements of nature, humanity, residence or housing, society, economy, infrastructure, and so on (Yang et al., 2018; Wang and Li, 2018; Cong et al., 2021). Authoritative index systems like UN SDGs, the *Evaluation Index System of the China Human Settlements Award*, and the Rockefeller Foundation's Index System for human settlements in resilient cities provide guidelines for the indicator selection of assessment (Xue et al., 2021; Cong et al., 2021; Tang et al., 2017). As for the research methods, typical techniques for weighting like the entropy method (Li et al., 2014; Tian et al., 2014), analytic hierarchy process (AHP) (Wang et al., 2021; Xu et al., 2015), principal component analysis (PCA) (Zhang et al., 2019) and other mathematical models like structural equation model (SEM) (Zhao et al., 2019), are frequently applied in the evaluation of human settlements.

Despite the complexity of the human settlement system, the connotation of human settlements implies the core status of human beings, which is the fundamental driving force for the evolution of human settlements (Cong et al., 2021). Therefore, the feelings and needs of residents should not be neglected in human settlement evaluation (Wang et al., 2019; Zhang et al., 2020). Empirical studies have shown that human settlements perceived by residents may deviate from the objective environment, suggesting the intricate relationship between human settlements and people's subjective feedback on them (Gao et al., 2016; Wang and Wang, 2016; Zhou et al., 2021). The content of subjective evaluation through public participation gains increasing concern in human settlement assessment. Some scholars conducted questionnaires or field surveys to acquire public satisfaction with the quality of human settlements (Wang et al., 2021; Zhang et al., 2020), supplementing the literature from the perspective of the subjective well-being of residents. The investigation results open up space for discussions of more in-depth issues on human settlements, including the impacts of certain environmental factors on people's subjective well-being (Song et al., 2019; Ferreira et al., 2013), the difference between the actual level of settlement quality and public satisfaction (Li and Liu, 2021), and the critical problems and residents' immediate needs on human settlements, etc. Compared with the evaluation of objective physical environment, studies on the basis of subjective well-being stand for residents' demands, paying attention to the relationship between human activities and the physical environment (Smyth et al., 2008), which embodies the thought of people-oriented development. However, few studies integrate objective and subjective indicators to reach evaluation results that show both quality evaluation and public satisfaction (Lazauskaitė et al., 2015).

As for the study area, most scholars concentrate on urban or rural regions (Tian et al., 2014). Because of the prominent distinctions between these two types of territory, there seems to exist an acquiescent demarcation between studies on urban and rural human settlements, manifesting in their differences in research emphasis, spatial scales, data, and methods (Ma et al., 2016). Under the increasingly prominent "urban disease" all around the world (Wüstemann et al., 2017; Portney, 2013), most studies on urban human settlements set sustainable development as their ultimate goal and pay attention to the spatial heterogeneity and

temporal changes of human settlements, serving for spatial planning at a macro scale (Algeciras et al., 2016; Xiong, 2011; Long et al., 2020). For example, Wang et al. (2011) defined the livable integrated index from the aspects of social development, living standard, and environmental quality to compare the urban livability of Beijing and three foreign metropolises, underlining the significance for Beijing to optimize its atmospheric quality and water quality to ascend to the ranks of global cities. Cong et al. (2021) matched the detailed terms of UN SDGs with the components of human settlements in the index system to evaluate the sustainable development of urban human settlements in China's 285 prefecture-level cities. Meanwhile, rural human settlements, as an indispensable part of regional development, have also attracted more and more attention in China since the new construction in rural areas. Scholars have shown great interest in the living conditions (e.g. housing and building forms), infrastructure (e.g. water supply), and environmental health (e.g. air quality), aiming to optimize the human settlements in rural areas from the perspective of farmers (Zhu et al., 2018; Xu et al., 2015). For finding out the real demands of local people, studies on rural human settlements assessment employ field investigation more often and conduct research at a relatively micro-scale (Ma et al., 2016). For example, Wang et al. (2021) constructed an index system consisting of six dimensions that were closely related to rural circumstances to assess local dwellers' satisfaction with the rural living environment in northwest China. The empirical study demonstrated the uneven satisfaction degree across different dimensions and villages, and some targeted strategies were suggested to improve the quality of rural human settlements. Only a few scholars have broken free from the traditional dualistic perspective to integrate urban and rural settlements in their research, associating the concept of human settlements with the urban-rural background to conduct theoretical or empirical studies (Tian et al., 2014). Studies of this kind usually focused on land use (Li and Song, 2020), population migration, and the impacts of human activities on urban-rural environment (Baiocchi et al., 2015). In the context of China's urban-rural integration, it is necessary to establish a theoretical framework to evaluate the human settlements covering the entire regional structure of urban and rural areas.

In general, existing studies have developed relatively unified and mature paradigms to evaluate and analyze human settlements scientifically. However, the main limitation falls on the paucity of the overall assessment that unifies objective and subjective dimensions of indicators and covers both urban and rural areas nationwide. Besides, a majority of studies are conducted at a micro or meso scale, inspecting the human settlements within one local area or a group of typical cities mainly due to the limited data accessibility (Xue et al., 2021; Tang et al., 2017). Take the research within China as an example, the eastern and central parts of the country have received the greatest amount of attention (Zhang et al., 2014; Zhao et al., 2019), and big cities like Beijing, Shanghai, Guangzhou, Dalian also get specialized study (Tan and Li, 2013; Xue and Yang, 2020; Wu et al., 2020; Gao et al., 2016). It is necessary to lift the spatial scale of research higher to the nationwide or even worldwide level in order to reflect the macro pattern of human settlements and perform comparisons in a more expansive scope. Since the establishment of Ekistics, human settlements have been regarded as a comprehensive concept that integrates all elements and covers the whole territory. Only when human settlements are studied systematically and holistically, can the connotations and values be accurately understood and the harmony between human beings and the natural environment be really accomplished.

In this context, this paper constructs a theoretical framework for the comprehensive evaluation of urban-rural human

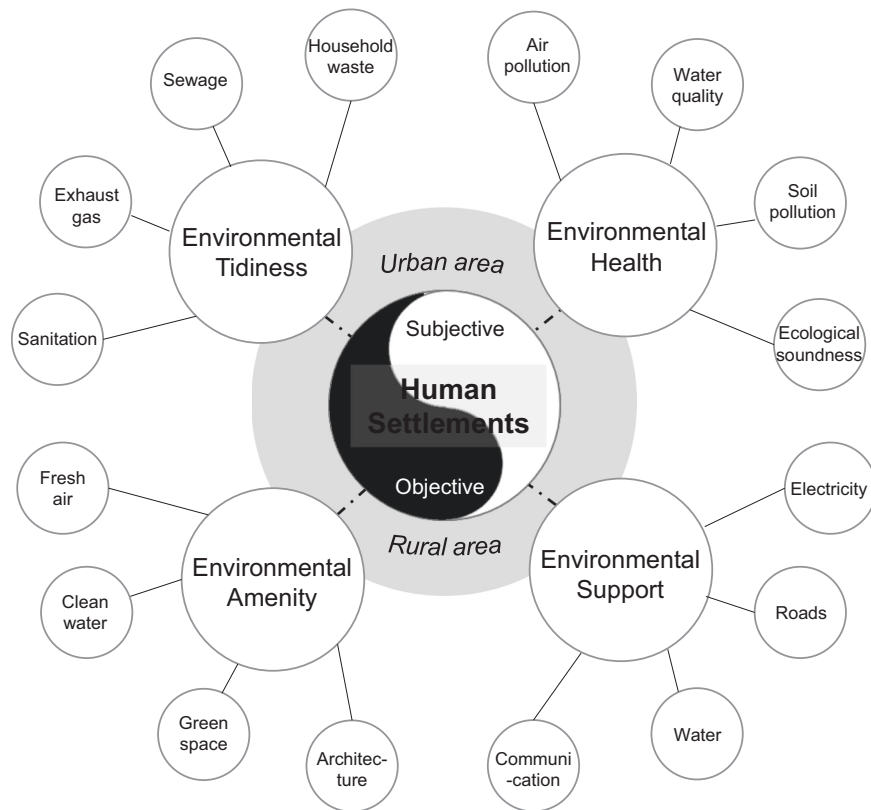


Fig. 1 Theoretical framework of the comprehensive evaluation of urban-rural human settlements. Among the four dimensions, environmental tidiness is closely related to the treatment of sewage, household waste, and exhaust gas. Environmental health is connected with the quality and pollution status of water, air, and soil. Environmental amenities puts forward demands on sufficient green space, clean water, and fresh air. Environmental support is mainly represented by the infrastructure system.

settlements in China. Compared with the urban or rural human settlements based on a microscopic or special case perspective, the urban-rural human settlements here are a more general concept based on a regional framework, so it is more suitable for a large-scale description and comparison. Based on the people-centered and goal-directed perspective, the evaluation system unifies the human settlements of urban and rural areas into four target dimensions, i.e. environmental tidiness, environmental health, environmental amenity, and environmental support (Fig. 1), which is different from the evaluation systems based on elements in previous studies. Among the four dimensions, environmental tidiness is the embodiment of urban-rural sanitation and appearance. Environmental health is the influence of natural factors on human health and ecological health. Environmental amenity refers to the physical and mental experience that people get from contact with the built environment and ecological environment. Environmental support reflects the capability to ensure the smooth operation of human society in urban-rural areas. On the basis of the four dimensions, a comprehensive evaluation is conducted from both subjective and objective aspects. As many scholars have found, the subjective well-being of the environment has an influence on residents' life satisfaction just like the objective environment does, and sometimes even plays a more direct role (Li and Liu, 2021; Li and Zhou, 2020). Therefore, indicators of both objective evaluation and subjective well-being are used to assess human settlements more rationally. The theoretical analysis framework highlights the good man-land relationship in the background of China's ecological civilization construction. As it is widely recognized, economic growth should not be achieved at the cost of deteriorating the ecological environment and consuming natural resources without constraint. By

appraising regional human settlements with the framework here, a contamination-free, resource-saving, and livable environment with sufficient space that allows residents to contact nature during daily life and a secure infrastructure system that guarantees an environment-friendly way of development is advocated.

The theoretical analysis framework of human settlements here is characterized by three innovation points, (i) *Multi-dimension*: We regard public satisfaction towards the environment as a part of human settlements, including both objective and subjective indicators in the evaluation index system. (ii) *Whole-region*: We treat the urban and rural areas of each region as a whole, incorporating the performances of urban and rural areas to reflect the overall level of holistic human settlement. (iii) *Large-scale*: Our research is at a large spatiotemporal scale with the study scope covering 31 provinces, autonomous regions, and municipalities and the time period from 2000 to 2019, through which we can analyze the long-term evolution of human settlements nationwide and conduct a comparison at a macro level. The study has great significance in promoting China's integrated urban-rural development and coordinated development of regions from the aspect of human settlements.

Methods and data

Objective quality evaluation

Construction of index system. Based on the theoretical analysis framework proposed above, fully considering the characteristics of the development stage and industrial structure in China, as well as the availability of data on a national scale, we constructed a feasible index system of quality evaluation of urban-rural human settlements, aiming for coordinating the relationship between socio-economic development and eco-environmental

Table 1 Index system of quality evaluation of urban-rural human settlements and the grading standards.

Indicators	Weight	I	II	III	IV	V
C ₁ . Sewage treatment rate in urban areas (%)	0.2302	0-50	50-70	70-85	85-95	95-100
C ₂ . Harmless treatment rate of urban domestic waste (%)	0.2202	0-50	50-70	70-85	85-95	95-100
C ₃ . Greening coverage rate in urban built-up areas (%)	0.1800	0-20	20-30	30-40	40-50	50-60
C ₄ . Sanitary toilet penetration rate in rural areas (%)	0.1995	0-50	50-70	70-85	85-95	95-100
C ₅ . Per capita biomass index in rural areas (kg)	0.1700	2000-1200	1200-600	600-450	450-250	250-50

protection. The evaluation index system is composed of five indicators including sewage treatment rate in urban areas, harmless treatment rate of urban domestic waste, greening coverage rate in urban built-up areas, sanitary toilet penetration rate in rural areas, and per capita biomass index in rural areas. Among them, harmless garbage treatment and sewage treatment can reflect the performance of urban environmental governance in building a clean environment. Conditions of parkland in the neighborhood represent the livability and daintiness of the living environment, which is closely related to the welfare of urban residents (Smyth et al., 2011). The evaluation of rural human settlements focuses on farmers' living conditions. The penetration of sanitary toilets reflects the fundamental living standards of rural residents. Per capita biomass, to some extent, measures the influence of mankind on the ecology in rural areas. The lower this indicator, the higher the rural living environment.

Evaluation method

Weight setting: The upper and lower limits of indicators were determined with reference to relevant national standards, planning objectives, national action plans, and advanced levels at home and abroad, so as to define their actual value ranges. Each indicator was normalized and divided into five levels, namely, I-V. In addition, we used the 1006 samples from the *Indicator Weight Questionnaire APP of Quality Evaluation of Urban-Rural Human Settlements in China* and selected the AHP model supported by entropy technology to obtain the weights of five indicators (Table 1).

Standardization: Using the membership degree method, the standardization of five indicators was carried out in terms of their grading target values. The standardized indicators are divided into five levels of I (0-20), II (20-40), III (40-60), IV (60-80), and V (80-100), namely low, low to medium, medium, medium to high, and high, respectively. We conducted the standardization processing as follows:

Positive indicator:

$$x' = 20 \times (s - 1) + 20 \times \frac{x - x_{s,lower}}{x_{s,upper} - x_{s,lower}}, x_{s,lower} < x \leq x_{s,upper} \tag{1}$$

Negative indicator:

$$x' = 20 \times (s - 1) + 20 \times \frac{x_{s,lower} - x}{x_{s,lower} - x_{s,upper}}, x_{s,upper} < x \leq x_{s,lower} \tag{2}$$

where x and x' represent the value of each indicator before and after standardization, respectively; s is the level of each indicator. The values of I-V are 1, 2, 3, 4, and 5, respectively; $x_{s,lower}$ and $x_{s,upper}$ correspond to the lower and upper limit values of the s -level interval, and the specific grading standards of $x_{s,lower}$ and $x_{s,upper}$ are shown in Table 1. For the positive indicator, the lower limit of s -level interval is lower than the upper limit, which is contrary to that of the negative indicator. And x' in the equations is subject to the s -level interval.

Index calculating: We introduced the fuzzy membership degree function and the method of progressive weighted calculation to conduct the summation of five indicators and obtain the quality evaluation index of urban-rural human settlements (R), which can be calculated as follows:

$$R = \varphi_{c1}x_{c1} + \varphi_{c2}x_{c2} + \varphi_{c3}x_{c3} + \varphi_{c4}x_{c4} + \varphi_{c5}x_{c5} \tag{3}$$

where x_{c1} , x_{c2} , x_{c3} , x_{c4} , and x_{c5} are the relative values after standardization of sewage treatment rate in urban areas, harmless treatment rate of urban domestic waste, greening coverage rate in urban built-up areas, sanitary toilet penetration rate in rural areas and per capita biomass index in rural areas, respectively; and φ_{c1} , φ_{c2} , φ_{c3} , φ_{c4} , and φ_{c5} are their corresponding indicator weights. The grading standard of the quality evaluation index of urban-rural human settlements (R) is divided into five levels, that is, I (0-20), II (20-40), III (40-60), IV (60-80), and V (80-100).

Subjective well-being evaluation. As the main method for satisfaction surveys, the *Public Satisfaction Questionnaire APP of Quality Evaluation of Urban-Rural Human Settlements in China* was developed to distribute and collect online questionnaires. In order to make the selected sample accurately reflect public satisfaction all over China as far as possible, some requirements must be met. Firstly, the Hebei Province was chosen to do the pilot study, and we have adjusted the details according to the result. Secondly, the adjusted questionnaire has been consulted by experts and reached a consensus on the final contents of the questionnaire. Thirdly, we used an APP to send the questionnaires online in all provinces of China. The simple random sample, one of the probability sampling methods was used to reduce the select bias. Fourthly, the number of random samples in each province had to meet the prescribed requirement of covering 0.5-1‰ population in each province.

The online questionnaire contains two parts: resident attributes about personal information and satisfaction scores (0-100). The former includes the interviewees' gender, age, educational background, occupation, habitation (according to the permanent residence), etc.; the latter reflects their satisfaction with the living environment and relevant infrastructures, including the conditions of domestic waste treatment, domestic sewage treatment, parkland in the neighborhood and sanitary toilets in rural areas. Since the public is not familiar with the concept of per capita biomass, this indicator is not considered in our satisfaction questionnaire. While the other four indicators in the objective evaluation are prone to the understanding of interviewees, so we set the corresponding subjective evaluation indicators to obtain the comprehensive satisfaction index of urban-rural human settlements.

The satisfaction scores of the indicators were given by residents one by one, and the comprehensive satisfaction value of human settlements was obtained by calculating the average of each satisfaction score. Finally, the degree of public satisfaction was measured using five different levels, i.e., "highly unsatisfied (0-40)", "unsatisfied (40-60)", "average (60-75)", "satisfied (75-85)", and "highly satisfied (85-100)".

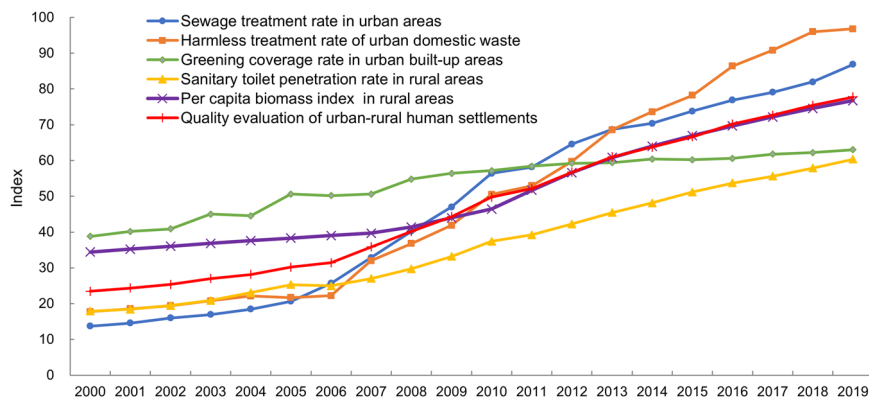


Fig. 2 Development trend of the urban-rural human settlements indexes from 2000 to 2019. Sewage treatment rate in urban areas, harmless treatment rate of urban domestic waste, greening coverage rate in urban built-up areas, sanitary toilet penetration rate in rural areas, and per capita biomass index in rural areas are shown in blue, orange, green, yellow, and purple lines, respectively. The quality evaluation of urban-rural human settlements is also shown in red line.

It should be noted that the satisfaction of an objective environment within which people live, work, and recreate is a dynamically cumulative process. The subjective well-being of residents in a certain year not only manifests the feelings about the environmental status at that time point but also is influenced by the longstanding performance of environmental conditions and the evolution of living standards. Therefore, we believe that it is rational to make the investigation result of public satisfaction in 2020 the basis of subjective evaluation of human settlements for years.

Data sources. The data on sewage treatment rates in urban areas are derived from the China Urban Construction Statistical Yearbook (2000–2018) and the relevant data in 2019 provided by all provinces in China. The data on the harmless treatment rate of urban domestic waste were obtained from the China Statistical Yearbook (2000–2020). The data on the greening coverage rate in urban built-up areas are collected from the China City Statistical Yearbook (2000–2005) and the China Statistical Yearbook (2006–2019). We obtained the data on sanitary toilet penetration rate in rural areas from the China Health Statistical Yearbook (2000–2019) and the China Rural Statistical Yearbook (2000–2019). Besides, the Shu Tao's Research Group of Peking University offered the data per capita biomass index in rural areas of all prefecture-level cities from 2000 to 2020, originating from the relevant National Natural Science Foundation of China.

According to the *Public Satisfaction Questionnaire APP of Quality Evaluation of Urban-Rural Human Settlements in China*, the valid sample number of questionnaires is 55,1783 collected from 31 provinces, autonomous regions, and municipalities from July to October 2020. The demographic characteristics of the interviewees are reasonable and representative. In order to keep a balance in gender, there are 27,0373 males and 28,1410 females in the sample, accounting for 49% and 51% of the total, respectively. Taking into account their age, most of the interviewees are adults and the number of interviewees has an inverted U-shaped curve with the increase in their ages. The percentages of interviewees aging 18–30 and 30–40 are 44% and 46%, respectively, which is in line with the frequency of mobile phone use. Given their highest academic qualifications, most of the interviewees are undergraduates or junior college students (70%). And it is notable that most of them work in the fields of agriculture, forestry, animal husbandry, fishery, and water conservancy concerning their occupational structures.

Results

Objective evaluation of urban-rural human settlements. On the basis of 20 years of statistical analysis of the human settlements' indexes (Fig. 2), we find that living conditions at the national scale have significantly improved. The material living standard of Chinese urban and rural residents has been significantly improved while urbanization has accelerated. From 2000 to 2019, the average level of urban-rural human settlements increased from 23.48 to 77.43, with a total growth rate of 231.02% and an average annual growth rate of 11.55%. The change of urban-rural human settlements can be roughly divided into two stages: the period from 2000 to 2007 is a slow growth stage that remained at level II; the period from 2007 to 2019 is a relatively fast growth stage changing from level II to level IV.

Each index shows a significant increasing trend. By 2019, the average level sewage treatment rate score was 86.96, with an average annual growth rate of 26.70%. The overall level of harmless treatment rate of urban domestic waste improved steadily, with an average annual growth rate of 22.23%. The overall level of greening coverage rate in urban built-up areas and sanitary toilet penetration rate in rural areas volatility also increased. In 2000, the average level of per capita biomass index was 34.42, while it was 76.73 in 2019. It indicated that in the past 20 years, with the increase of the country's emphasis on the human settlements environment and the gradual implementation of relevant policies, the national urban and rural human settlements environment improvement actions have achieved remarkable achievements.

The statistical value of each index of human settlements environment in 2000, 2010, and 2019 are shown in Fig. 3. The urban sewage treatment rate in all provinces continued to increase, which was higher than 60% only in Shanghai, Jiangsu, and Xinjiang in 2000, and exceeded 92% in 2019. In terms of the harmless treatment rate of urban domestic waste, only Jiangsu, Qinghai, Shandong, and Zhejiang were higher than 80% in 2000, but 17 provinces including Gansu scored 100% in 2019. Heilongjiang, Jilin, Qinghai, and Tibet were relatively backward in Sewage treatment and harmless treatment of urban domestic waste. These areas had a low coverage rate of environmental sanitation facilities, and the domestic garbage and sewage were not treated in time in these areas, which resulted in a low level of environmental sanitation conditions.

In terms of greening coverage rate in urban built-up areas, the index range of each province was between 12.1–46.2% in 2000, 25.4–55.1% in 2010, 35.2–48.5% in 2019, and Qinghai, Gansu, Heilongjiang had always been at the bottom. In 2018, the government carried out a large-scale renovation of toilet facilities,

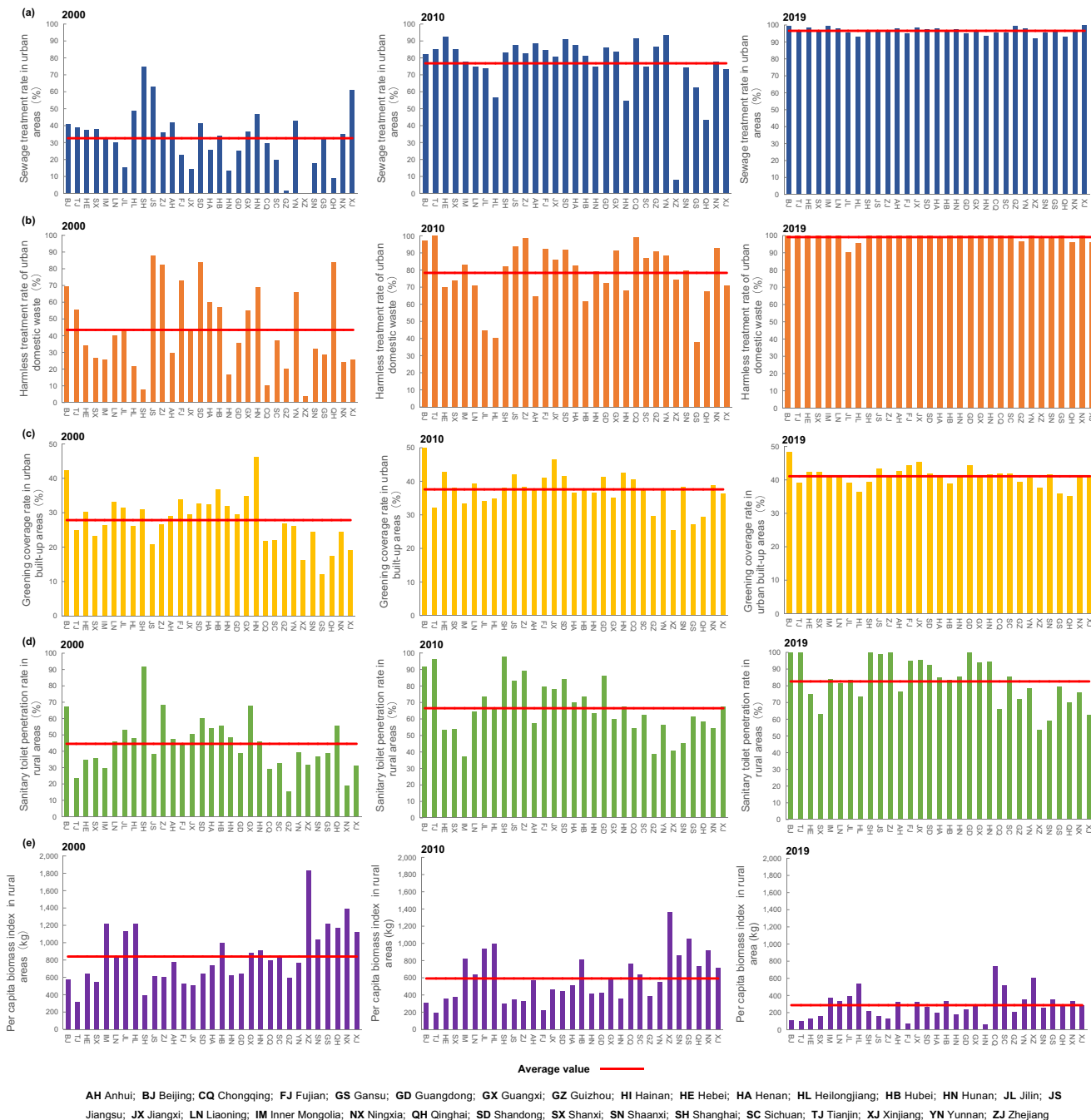


Fig. 3 Spatial distribution of each indicator of human settlements among 31 regions in 2000, 2010, and 2019. **a–e** Displayed the five indicators. **a** Sewage treatment rate in urban areas. **b** Harmless treatment rate of urban domestic waste. **c** Greening coverage rate in urban built-up areas. **d** Sanitary toilet penetration in rural areas. **e** Per capita biomass index in rural areas.

and toilet hygiene was significantly improved, making the rate of 11 provinces over 90% in 2019. However, Tibet, Shanxi, Shaanxi, and Xinjiang were still at a low level, it may be that some villagers appeared to be not accustomed to flushing toilets, resulting in low utilization after the renovation (Wang et al., 2021). The Rural per capita biomass of 9 provinces exceeded 1000 kg/person in 2000, but only Tibet and Gansu exceeded 1000 kg/person in 2010. On the whole, the uneven distribution of indicators of urban and rural human settlements had narrowed, but the regional difference in rural biomass per capita had widened.

The spatial trends map of the urban–rural human settlements’ quality values from 2000–2009 and 2010–2019 in 31 provinces, autonomous regions, and municipalities are shown in Fig. 4. We

extracted data at two temporal points in 2009 and 2019, and used ArcGIS Natural Breaks to classify the quality level of human settlements of 31 regions into five levels: low level (0–20), low to medium level (20–40), medium level (40–60), medium to the high level (60–80), and high level (80–100). The urban–rural human settlements quality values across the country have gradually increased over the last 20 years. The number of provinces and cities with low indexes (20–40) decreased from 10 in 2009 to 0 in 2019. All provinces except Tibet belonged to the “medium to high level (60–80)” and “high level (80–100)” in 2019.

As seen in Fig. 4, from 2000 to 2019, the spatial difference in the development level of the urban–rural human settlements quality values in China was relatively obvious, showing a significant

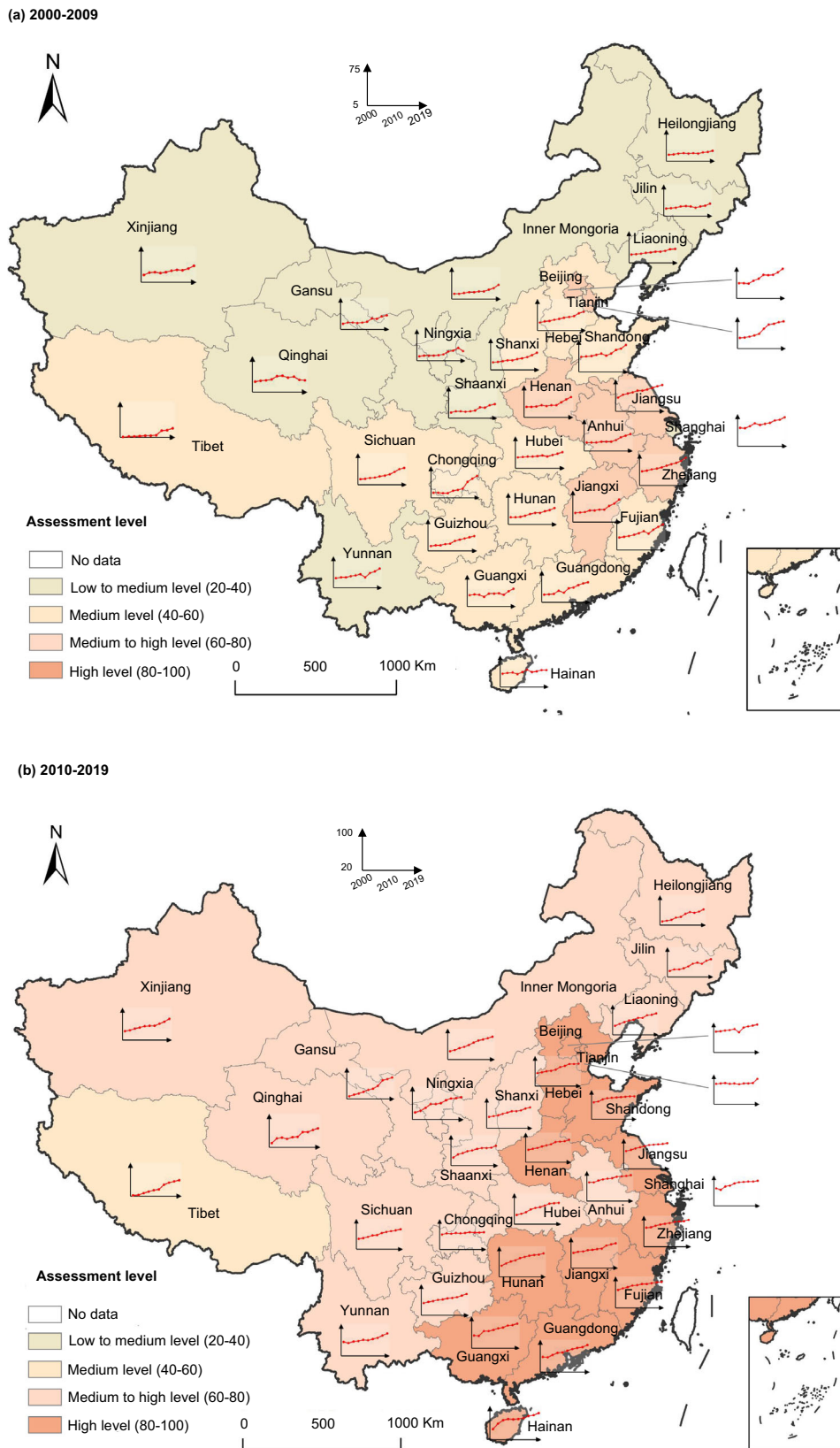


Fig. 4 Urban-rural human settlements quality values across space and its time trend in 31 regions. a Trends of human settlements' quality values from 2000 to 2009; **b** Trends of human settlements' quality values from 2010 to 2019.

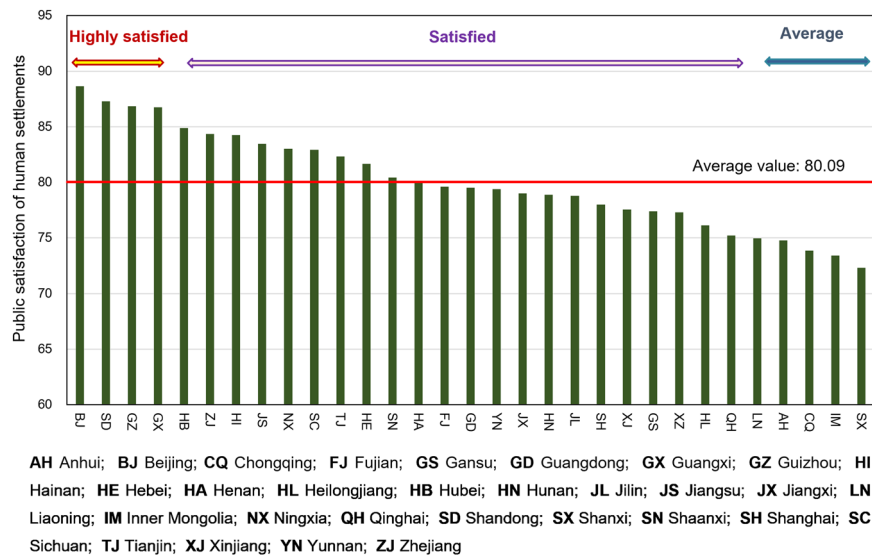


Fig. 5 Public satisfaction with urban-rural human settlements in 2020. The results of 31 regions are arranged in descending order. The national average value of public satisfaction with human settlements was also plotted in red line.

decreasing tendency from the southeastern coastal area to the northwestern inland area. The urban-rural human settlements quality values in some provinces, such as Qinghai and Ningxia, fluctuated obviously, showing an increase followed by a decline in 2000–2009 and a fluctuating rising trend in 2010–2019. The rate of increase varied unevenly across space, with a slight advantage in western China while the growth rate in eastern coastal provinces, such as Beijing, Tianjin, Shandong, Shanghai, Jiangsu, Zhejiang, Fujian, etc., tended to be flat. The growth rate in northeast China, such as Heilongjiang, Jilin, and Liaoning, in the latter decade was significantly faster than that in the previous decade. The values in Hebei, Henan, Hubei, Hunan, Chongqing, Shanxi, Xinjiang, Ningxia, Inner Mongolia, and Gansu Provinces showed significant increases from 2000 to 2019 where great attention has been paid to improving the living environment quality.

In general, the provinces with high human settlements quality values were located in the east and gradually expanded from the Yangtze River Delta to the entire eastern coastal area. As leaders in China’s economic development and industrial upgrading, the eastern provinces stepped into the process of industrialization and urbanization early, with a complete infrastructure system for environmental maintenance and governance. In recent years, advanced institutions and technologies further provided conditions for the construction of “smart cities” in these provinces, helping to continuously update and improve the regional living environment from urban management, public utilities, and other aspects. The provinces with the lowest quality values were mainly located in northwest and northeast China with severe climatic conditions and fragile ecological environments. Natural conditions fundamentally determined the suitability of living in urban and rural areas, restricting the construction of urban hardware facilities and the creation of blue-green spaces. With the continuous advancement of national strategies such as Northeast Revitalization and Western Development, the quality of human settlements in these areas has improved rapidly in the past decade. However, due to the relatively backward economic level, the infrastructure systems in these areas for drainage and solid waste recycling have not been perfected or have been aging, and the urban environment needs to be improved urgently.

Subjective evaluation of urban-rural human settlements. The results of public satisfaction with urban-rural human settlements in 2020 are shown in Fig. 5. The national average value of public

satisfaction with human settlements was 80.09. There were 12 regions whose scores are higher than the national average. On the whole, the satisfaction degree of residents in south China was higher than that in north China. The top four provinces with the highest indexes were at the assessment level of “highly satisfied”, including Beijing, Shandong, Guizhou, and Guangxi with scores of 88.64, 87.29, 86.83, 86.74, respectively; the provinces with the lowest indexes were Shanxi, Inner Mongolia, Chongqing, Anhui, and Liaoning, with the value level at “average”. In contrast to the objective evaluation, subjective well-being showed no obvious downward trend from East to West spatially.

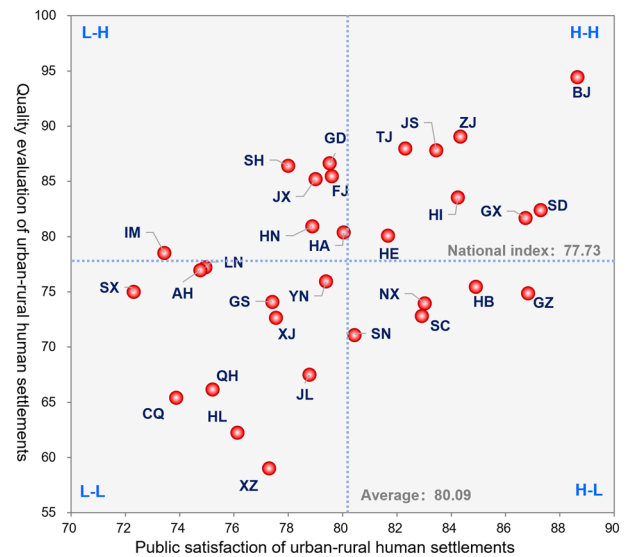
Residents’ attributes are vital factors affecting their subjective well-being in urban and rural human settlements (Fig. 6). Through the analysis of their attributes of 551,783 questionnaires, it was found that men are generally more satisfied with their living environment than women. The “satisfied” and “highly satisfied” samples were mainly concentrated in the youth group under 18 years old, and the samples who were at the level of “average” or “unsatisfied” with their living environment were mainly the old people over 70 years old. In the sample group with a master’s degree or above, the satisfaction evaluation showed obvious differentiation. The proportion of unemployed people and manufacturing workers who were unsatisfied with the human settlements were relatively high. 63.25% of the urban samples were “highly satisfied”, and that was 65.13% of the rural samples. It is worth noting that the satisfaction degree of human settlements in rural areas was similar to that of urban residents, indicating that with the implementation of “Rural Revitalization” strategy and the “Beautiful Countryside” project in recent years, the improvement of living environment in rural areas has achieved remarkable results.

Discussion

To better assess the quality of human settlements in different regions, regional differences were explored based on a comparison between subjective and objective evaluation results. The national average score of public satisfaction on urban-rural human settlements is 80.09, and the national average assessed value of urban-rural human settlements is 77.73. According to the average values of the two, China can be divided into four types correspondingly. Five diagrams of the urban-rural human settlements’ quality evaluation and public satisfaction



Fig. 6 Residents' attributes of satisfaction with human settlements. **a-d** Displayed the results by different attributes. **a** Occupation, **b** Age, **c** Education background, and **d** Habitation.



AH Anhui; BJ Beijing; CQ Chongqing; FJ Fujian; GS Gansu; GD Guangdong; GX Guangxi; GZ Guizhou; HI Hainan; HE Hebei; HA Henan; HL Heilongjiang; HB Hubei; HN Hunan; JL Jilin; JS Jiangsu; JX Jiangxi; LN Liaoning; IM Inner Mongolia; NX Ningxia; QH Qinghai; SD Shandong; SX Shanxi; SN Shaanxi; SH Shanghai; SC Sichuan; TJ Tianjin; XJ Xinjiang; YN Yunnan; ZJ Zhejiang

Fig. 7 The relationship between quality evaluation and public satisfaction of urban-rural human settlements in China. It is divided into four quadrants with the medians of quality evaluation and public satisfaction of urban-rural human settlements, namely, H-H, H-L, L-H, and L-L.

relationships appear below (Figs. 7 and 8). As a whole, the objective and subjective evaluations of urban-rural human settlements had a positive correlation (Fig. 7). More than half of the provinces dropped in H-H or L-L type, and the scores of remaining provinces whose types were H-L and L-H were close to the average values, with only a few provinces having a large gap between objective and subjective estimations, such as Guizhou and Inner Mongolia.

Regions with “H-H” levels, including Beijing, Jiangsu, Zhejiang, and Shandong, were the most international metropolises with the most developed economy, the densest population, and the highest consumption capacity in China. In these areas, most of the rural areas were close to the city and have a good economic foundation. The lifestyle of rural residents in those areas was close to that of urban residents. Backward regions with “L-L” levels included Xinjiang, Gansu, Qinghai, Henan, Heilongjiang, Chongqing, Shanxi, Yunnan, and Tibet. These regions were economically backward and lack power in infrastructure construction. Public satisfaction was higher than objective evaluation in Guizhou, Hubei, Sichuan, and Ningxia, which was in contrast to Shanghai, Jiangxi, Guangdong, and Hunan.

However, the quality evaluation and public satisfaction of each indicator were uneven, and there are significant differences between the four sub-dimensions (Fig. 8). The harmless treatment rate of urban domestic waste had basically reached a level close to 100%, and the lowest Jilin was also above 90%, but the public satisfaction was obviously divided, with a difference of nearly 20 points between the highest Beijing and the lowest Inner Mongolia, and objective and subjective

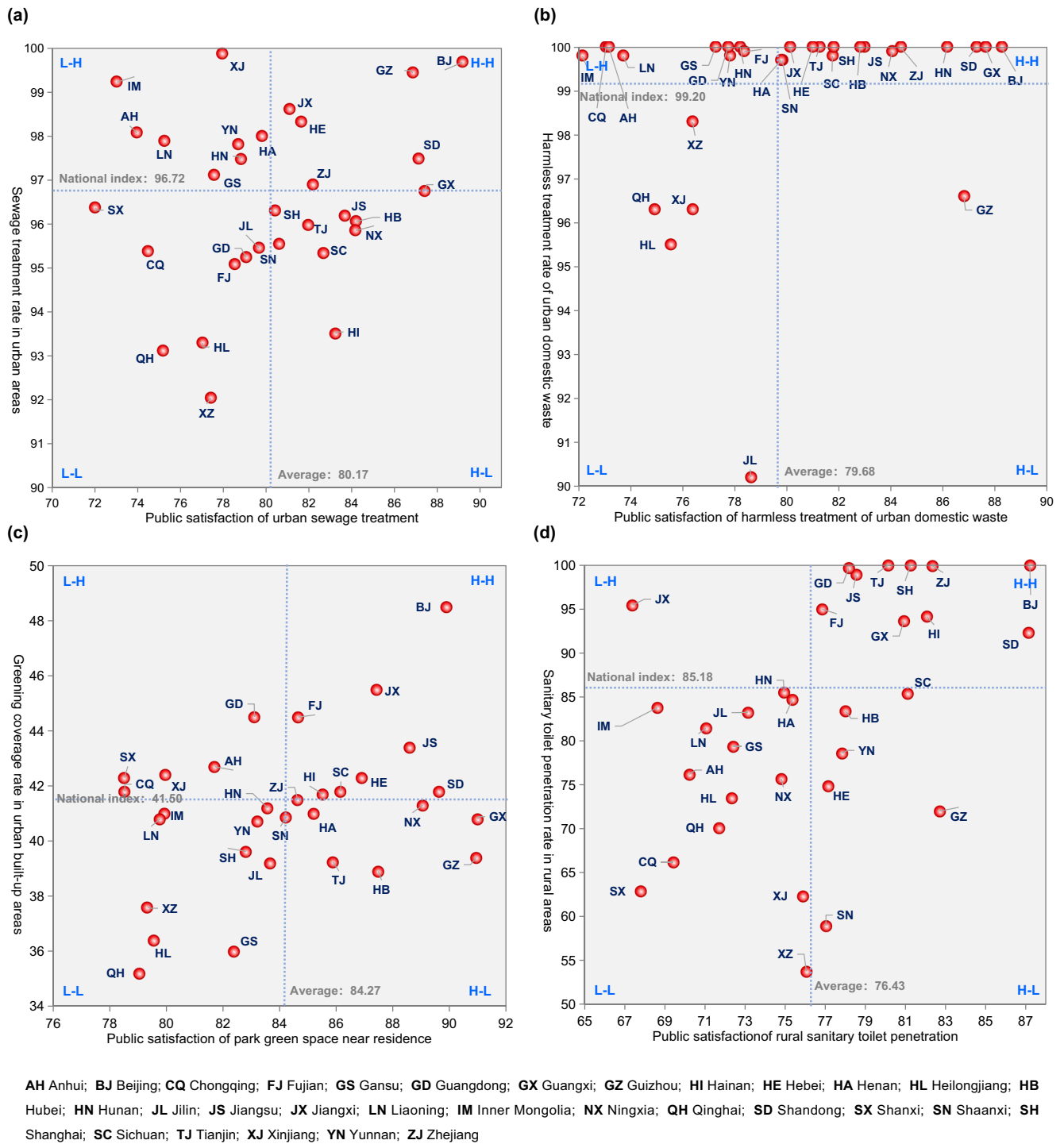


Fig. 8 Type of relationship between quality evaluation and public satisfaction of each indicator of human settlements. **a-e** Displayed the four indicators. **a** Urban sewage treatment. **b** Harmless treatment of urban domestic waste. **c** Urban greening coverage. **d** Rural sanitary toilet penetration.

evaluations were relatively low mainly in the western and northeastern regions. The correlation between the subjective and objective evaluation of sewage treatment rate was relatively weak, for example, the objective evaluation value of Inner Mongolia, Anhui, and Liaoning was higher than the national average but their public satisfaction was in the lower reaches. Heilongjiang, Jilin, Qinghai, and Tibet all belonged to L-L in terms of sewage treatment and harmless treatment of urban domestic waste.

The consistency of the subjective and objective evaluation results of urban greening and sanitary toilet penetration was relatively strong, with more than 20 regions belonging to H-H or L-L, and only a few provinces had a large gap between the subjective and objective evaluations. Environmental improvement and infrastructure construction in residential areas were closely related to daily lives, and the subjective well-being in the physical environment was relatively accurate. It could be noted that the national average score of public satisfaction with rural sanitary

toilet penetration was 76.43, which was relatively low compared with the other three dimensions, indicating a low level of infrastructure construction in most areas of rural China.

Overall, it should be noted that public satisfaction is affected by a variety of factors (Ferreira et al., 2013). Due to the differences in resources, environmental conditions and economic development stages, residents in the different regions have different perception dimensions and degrees of the environment, which has been proved by some studies (Ma et al., 2015; Quiroz et al., 2021; Xu et al., 2022). For example, the residents of the arid areas in the northwest are more sensitive to the urban water environment and greening environment; the residents of the poor mountainous areas in the southwest have a clearer understanding of the regional infrastructure construction and the improvement of the economic level; the residents of the old industrial bases in the northeast have more urgent demands for urban renewal and renovation of city features. Therefore, it is of great importance to improve the living environment according to local conditions, enhance the status of residents' participation in urban planning and construction, meet the requirements of residents to the greatest extent, and improve their satisfaction and happiness basically.

Conclusions

Human settlements have long been a significant subject in which people seek to build more sustainable and pleasant living environments for themselves. The quality of urban and rural human settlements can be reflected by the multi-dimensional and reasonable evaluation. Human beings are the intrinsic determinant of human settlements since the direct purpose of human settlements development is to meet people's increasing needs (Wang et al., 2017). Therefore, besides objective quality evaluation, the subjective well-being of residents is also integrated into our framework. Aiming to achieve the effective aggregation and optimization of production factors, the estimation results in Chinese 31 provinces, autonomous regions, and municipalities have been discussed. The main findings are as follows:

- (1) The quality of Chinese urban and rural human settlements has shown a strong upward trend over the last 20 years, though some living indicators show short-term fluctuations. The quality of urban and rural human settlements in China shows regional differences in national dimensions and sub-dimensions. In general, it is characterized by high quality in the East and South and low in the West and North, which has connections with the level of regional economic development, but the uneven distribution has narrowed in the last decades. The trend of the objective index varies unevenly across space, and many provinces in central and western regions with low assessment values experienced faster growth rates.
- (2) The national average score of public satisfaction on human settlement is 80.09 which is on the level of "Satisfied". In contrast to the objective evaluation, the subjective evaluation shows no obvious spatial distribution. Residents' attributes including age, education, and occupation, are vital factors affecting their subjective well-being in human settlements, so it is necessary to motivate public participation, by considering the opinions of different groups. There is no significant difference in satisfaction between urban and rural residents, which may indicate that the implementation of the strategic plan of "Poverty alleviation" and "Rural revitalization" in China has greatly contributed to the narrowing gap between urban and rural areas. In the long run, more efforts should be put into technology advancement, public participation incentives, and the subsequent maintenance of projects.
- (3) According to the national average of objective and subjective estimations, 31 regions in China can be divided into four types: H-H, H-L, L-H, and L-L. Combining the characteristics of comprehensive and sub-dimensions, the gap between these two indexes shows obvious regional differences. As a whole, there exists a positive correlation between environmental quality and public satisfaction in urban-rural human settlements. The consistency of the subjective and objective estimations of urban greening and sanitary toilet penetration is relatively stronger than that of harmless treatment of urban domestic waste and sewage treatment. There are significant differences in objective estimation to different sub-dimensions.

Using the convenience of accessible online questionnaires in the information age, this study offers a new perspective on the study of urban human settlements. Due to China having a vast territory and a large population, the public satisfaction and main demands on human settlements vary from region to region in different geographic environments and socioeconomic development stages. Our results are helpful for adjusting measures to local conditions and promoting continuous improvement, thus providing a reference for policymakers to fully consider the needs of residents in the top-level design, so that national policies can better benefit the people's livelihood. However, limited by the availability of indicators, the indicator system in this paper has deficiencies in reflecting the comprehensive conditions and needs of residents of human settlements. How to perfect the index system of quality evaluation in urban-rural human settlements will be the focus of further research to delimit the regional types more reasonably, so as to help managers carry out the improvement work accurately.

Data availability

The datasets generated during and/or analyzed during the current study are available from the author on reasonable request.

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References

- Algeciras JAR, Coch H, Perez GDLP (2016) Human thermal comfort conditions and urban planning in hot-humid climates-The case of Cuba. *Int J Biometeorol* 60:1151–1164
- Baiocchi G, Creutzig F, Minx J, Pichler PP (2015) A spatial typology of human settlements and their CO₂ emissions in England. *Glob Environ Change* 34:13–21
- Ciolac R, Adamov T, Iancu T, Popescu G, Lile R, Rujescu C, Marin D (2019) Agritourism—a sustainable development factor for improving the 'health' of rural settlements. Case study Apuseni Mountains area. *Sustainability* 11(5):1467
- Cong X, Li X, Gong Y (2021) Spatiotemporal evolution and driving forces of sustainable development of urban human settlements in China for SDGs. *Land* 10:993
- Doxiadis CA (1968) *Ekistics: an introduction to the science of human settlements*. Hutchinson, London
- Doxiadis CA (1975) *Action for human settlements*. Athens Publishing Center, Athens
- Ferreira S, Akay A, Brereton F, Cuñado J, Martinsson P, Moro M, Ningal TF (2013) Life satisfaction and air quality in Europe. *Ecol Econ* 88:1–10
- Fidler D, Olson R, Bezold C (2011) Evaluating a long-term livable communities' strategy in the US. *Futures* 43(7):690–696
- Gao J, Zhang Y, Li X (2016) Basic characteristics and spatial patterns of pseudo-settlements—taking Dalian as an example. *Int J Environ Res Public Health* 13(1):145

- Gao M, Ahern J, Koshland CP (2016) Perceived built environment and health-related quality of life in four types of neighborhoods in Xi'an, China. *Health Place* 39:110–115
- Geddes P (1915) *Cities in evolution: an introduction to the town planning movement and the study of civicism*. Howard Ferug, New York
- Howard E (1989) *To-Morrow: a peaceful path to real reform*. Swan Sonnenschein, London
- Hu Q, Wang C (2020) Quality evaluation and division of regional types of rural human settlements in China. *Habitat Int* 105:102278
- Kleemann J, Inkoorn JN, Thiel M, Shankar S, Lautenbach S, Furst C (2017) Peri-urban land use pattern and its relation to land use planning in Ghana, West Africa. *Landscape Urban Plan* 165:280–294
- Lazauskaitė D, Burinskienė M, Podvezko V (2015) Subjectively and objectively integrated assessment of the quality indices of the suburban residential environment. *Int J Strat Prop Manag* 19(3):297–308
- Li F, Zhou T (2020) Effects of objective and subjective environmental pollution on well-being in urban china: a structural equation model approach. *Soc Sci Med* 249:112859
- Liu, C. F., & Zhang, Z. Y (2018) From town-country integration to urban-rural integration: new thinking on the relationship between urban and rural areas. *Sci Geol Sin* 38(10):1624–1633 (In Chinese)
- Li H, Song W (2020) Evolution of rural settlements in the Tongzhou District of Beijing under the new-type urbanization policies. *Habitat Int* 101:102198
- Li S, Wei H, Ni X, Gu Y, Li C (2014) Evaluation of urban human settlement quality in Ningxia based on AHP and the entropy method. *Chin J Appl Ecol* 25(9):2700–2708. (In Chinese)
- Li X, Liu H (2021) The influence of subjective and objective characteristics of urban human settlements on residents' life satisfaction in China. *Land* 10:1400
- Lu M, Wei L, Ge D, Sun D, Zhang Z, Lu Y (2020) Spatial optimization of rural settlements based on the perspective of appropriateness-domination: a case of Xinyi City. *Habitat Int* 98:102148
- Long Y, Han H, Lai S, Jia Z, Li W, Hsu W (2020) Evaluation of urban planning implementation from spatial dimension: an analytical framework for Chinese cities and case study of Beijing. *Habitat Int* 101:102197
- Ma R, Wang M, Zhang W, Yu J, Wang Y, Ren L (2015) Residents' perceptions of the impact on urban human settlements from petrochemical industry cluster in port area: case study of Zhenhai district. *Geogr Res* 34(4):729–739
- Ma R, Wang T, Zhang W, Yu J, Wang D, Chen L, Jiang Y, Feng G (2016) Overview and progress of Chinese geographical human settlements research. *J Geogr Sci* 26(8):1159–1175
- Michael LF (2014) Review of urban sustainability indicators assessment—case study between Asian countries. *Habitat Int* 44(2014):491–500
- Portney KE (2013) *Taking sustainable cities seriously: economic development, the environment, and quality of life in American cities*. MIT Press, Cambridge
- Quiroz NF, Walls R, Cicione A (2021) Residents' perceptions of the impact on urban human settlements from petrochemical industry cluster in port area: case study of Zhenhai district. *Fire* 4(3):39
- Shen L, Shuai C, Jiao L, Tan Y, Song X (2017) Dynamic sustainability performance during urbanization process between BRICS countries. *Habitat Int* 60:19–33
- Smyth R, Mishra V, Qian X (2008) The environment and well-being in urban china. *Ecol Econ* 68(1-2):547–555
- Smyth R, Nielsen I, Zhai Q, Liu T, Liu Y, Tang C, Wang Z, Wang Z, Zhang J (2011) A study of the impact of environmental surroundings on personal well-being in urban china using a multi-item well-being indicator. *Popul Environ* 32(4):353–375
- Song Y, Li M, Zhang M, Sun X (2019) Study on the impact of air pollution control on urban residents' happiness from microscopic perspective. *J Clean Prod* 229:1307–1318
- Tan M, Li X (2013) The changing settlements in rural areas under urban pressure in China: patterns, driving forces and policy implications. *Landsc Urban Plan* 120:170–177
- Tang L, Ruth M, He Q, Mirzaee S (2017) Comprehensive evaluation of trends in human settlements quality changes and spatial differentiation characteristics of 35 Chinese major cities. *Habitat Int* 70:81–90
- Tian S, Li X, Yang J, Zhang C, Zhang Y (2014) Initial study on triaxiality of human settlements—in the case of 10 districts (counties) of Dalian. *Sustainability* 6:7276–7291
- Vancouver Declaration on Human Settlements, 1976. (1976). *Ekistics*. 42(252):262–266. <http://www.jstor.org/stable/43620457>
- Wang F, Wang D (2016) Place, geographical context and subjective wellbeing: state of art and future directions. In: Wang D, He S (eds.) *Mobility, sociability and well-being of urban living*. Springer, Berlin, pp. 189–230
- Wang J, Su M, Chen B, Chen S, Liang C (2011) A comparative study of Beijing and three global cities: a perspective on urban livability. *Front Earth Sci* 5(3):323–329
- Wang M, Li X (2018) Urban human settlement environment suitability assessment—a case study of four districts in Dalian city. *J Hum Settl West China* 33(4):48–53
- Wang P, Qin X, Li Y (2021) Satisfaction evaluation of rural human settlements in northwest China: method and application. *Land* 10:813
- Wang Y, Jin C, Lu M, Lu Y (2017) Assessing the suitability of regional human settlements environment from a different preferences perspective: a case study of Zhejiang province, China. *Habitat Int* 7:1–12
- Wang Y, Zhu Y, Yu M (2019) Evaluation and determinants of satisfaction with rural livability in China's less-developed eastern areas: a case study of Xianju County in Zhejiang Province. *Ecol Indic* 104:711–722
- Wu F, Liu Y, Zeng Y, Yan H, Zhang Y, Li L (2020) Evaluation of the human settlements environment of public housing community: a case study of Guangzhou. *Sustainability* 12(18):1–17
- Wu L (2001) *Introduction to Sciences of human settlements*. China Architecture & Building Press, Beijing, (In Chinese)
- Wüstemann H, Kalisch D, Kolbe J (2017) Access to urban green space and environmental inequalities in Germany. *Landsc Urban Plan* 164:124–131
- Xiong X (2011) Uncertainty evaluation of the coordinated development of urban human settlements environment and economy in Changsha city. *J Geogr Sci* 21:1123–1137
- Xu J, Feng P, Yang P (2015) Research of development strategy on China's rural drinking water supply based on SWOT-TOPSIS method combined with AHP-Entropy: a case in Hebei Province. *Environ Earth Sci* 75:58
- Xu J, Zhang W, Chen L (2022) Impact of urban population density on perception of human settlements in Hangzhou. *Sci Geogr Sin* 42(2):208–218
- Xue Q, Yang X (2020) Evaluation of the suitability of human settlement environment in Shanghai city based on fuzzy cluster analysis. *Therm Sci* 24(4):2543–2551
- Xue Q, Yang X, Wu F (2021) A two-stage system analysis of real and pseudo urban human settlements in China. *J Clean Prod* 293:126272
- Yang J, Wang Y, Xiu C, Xiao X, Xia J, Jin C (2020) Optimizing local climate zones to mitigate urban heat island effect in human settlements. *J Clean Prod* 275:123767
- Yang Q, Chen J, Li B, Zhu Y (2018) Evolution and driving force detection of urban human settlement environment at urban agglomeration in the middle reaches of the Yangtze River. *Sci Geogr Sin* 38(2):195–205
- Zhang Q, Gao T, Liu X, Zheng Y (2020) Exploring the influencing factors of public environmental satisfaction based on socially aware computing. *J Clean Prod* 266:121774
- Zhang Y, Hou K, Chang Y, Li X (2019) Assessment of human settlements and associated influential factors in Weihe River Plain. *Indoor Built Environ* 28:1162–1170
- Zhang Z, Xiao R, Shortridge A, Wu J (2014) Spatial point pattern analysis of human settlements and geographical associations in eastern coastal China—a case study. *Int J Environ Res Public Health* 11(3):2818–2833
- Zhao X, Sun H, Chen B, Xia X, Li P (2019) China's rural human settlements: qualitative evaluation, quantitative analysis and policy implications. *Ecol Indic* 105:398–405
- Zhou K, Tan J, Watanabe K (2021) How does perceived residential environment quality influence life satisfaction? Evidence from urban China. *J Community Psychol* 49:2454–2471
- Zhu Y, Fan X, Wang C, Sang GCJ (2018) Analysis of heat transfer and thermal environment in a rural residential building for addressing energy poverty. *Appl Sci-Basel* 8:2077

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Author contributions

Conceptualization: CF and HM; methodology: CB, ZW, GL, and SS; writing—original draft preparation: CF, HM, CB, and YF; writing—review and editing: CF and HM; funding acquisition: CF.

Competing interests

The authors declare no competing interests.

Ethical approval

The data used in this study was obtained from the Public Satisfaction Questionnaire APP for the Quality Evaluation of Urban–Rural Human Settlements in China. The procedures used in the study followed the ethical principles of research formulated by the government. The contents of the questionnaire were all multiple-choice questions with clear instructions and did not involve ethical issues. The Author is respected for the autonomy, privacy, and dignity of all participants involved in the survey, and the datasets contain no personal identities for the participants with their informed consent. All contents of the questionnaire were communicated in advance to the survey participants, who assisted the authors in completing the questionnaire activities out of social responsibility and total voluntariness.

Informed consent

By clarifying the information about the researchers, objectives, data uses, and the voluntary attribute of participation at the beginning of the questionnaire interface, informed consent was obtained from all participants. No identifying information was collected during the survey, and there are no ethical issues with science and technology.

Additional information

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