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Original Articles

The temporal and spatial changes of the ecological environment quality of the urban agglomeration on the northern slope of Tianshan Mountain and the influencing factors

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ABSTRACT

In the present study, the urban agglomeration on the northern slope of Tianshan Mountain (UANST) in Xinjiang was taken as the research object. Principal component analysis, coefficient of variation and analytic hierarchy process were used to analyse the indicators based on RS and GIS technology methods. Dimensionality reduction analysis was conducted and the ecological environment quality index (EQI) was calculated, so as to ultimately obtain the spatial distribution characteristics of the ecological environment quality in the area from 2000 to 2018. The use of GIS mapping technology could reflect the changes in the ecological environment of the urban agglomeration over time on the map, dynamic monitoring and quantitative evaluation could be conducted on the ecological environment of the urban agglomeration on the northern slope of the Tianshan Mountains, and the ecological environment over different years could be analysed, including the differences in environmental quality and the reasons for the changes. The results reveal that: in terms of spatial distribution characteristics, the ecological environment quality in Tianshan Mountains had a certain polarization in the spatial distribution; according to the time change pattern, the overall ecological environment quality exhibited a trend of improvement in the past 19 years; in respect of the stability analysis, over 97% of the regional ecological environment quality stability was between weak and medium variation; according to the spatial cluster analysis, the ecological environment quality of the urban agglomeration on the northern slope of the Tianshan Mountains was gathered in high and low values; the coexistence of modes presents a largely “fractured” distribution; and the degree of influence of land use type was relatively high from the perspective of influencing factors.

1. Introduction

With the introduction of the “One Belt, One Road” initiative and the construction of the Silk Road Economic Belt, the ecological and environmental issues of the urban agglomeration on the northern slope of the Tianshan Mountains have received significant attention in academic circles. The urban agglomeration on the northern slope of the Tianshan Mountains is deep inland and has a typical arid continental climate, with distinctive and fragile “Mountain-Oasis-Desert” ecosystems (Ariken et al., 2020) . As a significant component of the terrestrial ecosystem, the ecological environment is a prerequisite for human development and social progress (Yuan et al., 2021). The quality of the ecological environment reflects the quality of the ecological environment, which can be described in a quantitative way (Huan Kong, 2020) . The development of urbanization requires the support of ecological environment elements and causes profound changes to the ecological environment, potentially leading to a decline in the quality of the ecological environment (Cai et al., 2021). At present, the Tianshan Mountains is the region with the highest level of urbanization, the densest population, and the most concentrated industries in Xinjiang. In the future, the Tianshan

Abbreviations: ecological environment quality index, (EQI); the urban agglomeration on the northern slope of Tianshan Mountain, (UANST).

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Mountains will be the main area of Xinjiang's new urbanization and the strategic core area of economic development (Zibibula·Simayi et al., 2020). By accelerating the development of the urban agglomeration on the northern slope of the Tianshan Mountains, the construction of the core area of the Silk Road Economic Belt will be facilitated, the national economic security and national defense security will be ensured, social stability and long-term stability in Xinjiang will be established, and the integration and development of military and civilian areas and regional coordination will be promoted. As such, development thereof is of considerable strategic significance (Yan et al., 2020).

In recent years, research on regional ecological environment quality has become an emerging topic in both domestic and foreign studies. In terms of research methods, most scholars have adopted three main methods. Firstly, the ecological index is constructed by using multi-dimensional remote sensing data; secondly, the index system is established by combining multi-dimensional statistical data with remote sensing data; and thirdly, some scholars only use remote sensing ecological indexes (Liu et al., 2021; Xu et al., 2021). Notably, however, remote sensing ecological indexes can be combined with many other methods. Multiple remote sensing data can be combined with principal component analysis (Han et al., 2020) and coupled with the coordination degree model (Ariken et al., 2020). Multiple normalisation methods combined with pixel-phenology (Xiong et al., 2021) were also used to evaluate the ecological environmental quality of the study area. The establishment of the index system is based on the characteristics of the research area and serves the research perspective. From the perspective of geology, Lu et al. (2021) selected indicators from five aspects of land, hydrology, resources, ecology and geological environment to construct an indicator system. To quantify the impact of human activities on the ecosystem, Chi et al. (2020) combined human activities with remote sensing ecological indexes and established three indicators. Chunxue (2020) comprehensively evaluated the ecological environment of the study area by integrating three types of indicators: social economy, geochemistry and landscape pattern.

In terms of research scale, small and medium scale studies have been mainly conducted, while there is a scarcity of large-scale studies. The focus of existing large-scale research has been on provincial units. Ariken et al. (2021) took the Silk Road Economic Belt as the study area, which involves several provinces in China, while Elahi et al. (2020) took Punjab province of Pakistan as the study area. Medium-scale studies have also been conducted, some of which take river and lake basins as research areas (Jing et al., 2020; Wang et al., 2021; Wu et al., 2020), some take basin as the study area (Ariken et al., 2020), while others take urban agglomeration as the study area (Yang et al., 2020). Regarding small-scale studies, such studies include large cities with a population of more than 5 million (Javanbakht et al., 2021; Liu et al., 2021), small cities with a population of only several hundred thousand (Zhang, 2020), and rural areas (Elahi et al., 2021). Additionally, mining and industrial areas are also small-scale research areas of considerable interest to scholars (Han and Cao, 2021; Saedpanah and Amanollahi, 2019).

The ecological environment quality assessment facilitates quick and systematic understanding of the ecological environment of UANST. Remote sensing is a unique tool that provides complete, extensive and continuous surface information on different scales, and can be used in EEQ (Saleh et al., 2021). With the development of remote sensing monitoring and evaluation research, the importance of environmental quality evaluation has received an increasing amount of attention from scholars (Krishnan and Firoz, 2020; Mirauda and Ostoich, 2020; Huiping et al., 2021; Jie, 2021). The use of remote sensing technology for ecological environment assessment can provide timely and effective sassessment results, while also covering a wide range. Thus, remote sensing technology has been increasingly used to assess the ecological environment (Kennedy et al. 2014). Based on the medium-resolution imaging spectroradiometer (MODIS) product image set, Xinyue (2021) used the Google Earth Engine (GEE) platform combined with the digital elevation data set and statistical yearbook, so as to calculate the remote sensing ecological index (RSEI). Laura et al. (2016) selected the remote sensing environment and ecological indicators to investigate the land ecological status of Patagonia. Yujuan (2014) took the Songhua River basin as an example, and statistical methods such as RS, GIS, and analytic hierarchy process were used to quantitatively evaluate the quality of the ecological environment. However, the existing research lacks dynamic monitoring and correlation analysis of the ecological environment.

Natural factors and man-made factors restrict the change of ecological quality, and there is much interest in exploring the external driving mechanism of ecological quality. In previous studies, multiple regression analysis (Faroughi et al., 2020) has been the main analysis method adopted to show the temporal and spatial changes of ecological quality under the interaction of multiple factors (Yang et al., 2020). The geographic detector is a new statistical method used to detect spatial heterogeneity and elucidate the potential driving factors affecting geographic phenomena, in which the interaction of influencing factors is quantitively described through factor detectors and interaction detectors. Owing to the aforementioned reasons, geographic detectors were used in the present study to calculate the driving force of socio-economic factors on ecological quality.

In summary, many researchers have adopted different theories and methods to evaluate the regional ecological environment and made important contributions to the protection of the ecological environment, and the research results have certain feasibility. However, most existing studies are often limited to a single ecological factor in the evaluation of ecological environment quality, and there is a lack of comprehensive natural ecological environment evaluation of various ecological factors. Secondly, less attention has been paid to the perspective of *meso*-scale urban agglomerations. Finally, there is a lack of analysis of the relationship between EQI and socio-economic changes in different periods and a lack of driving factors. There are many types of models and methods, and the flexibility of use is relatively large, but the application of the best models and methods needs to conform to the ecological characteristics of the actual evaluation area. As such, an attempt was made to answer the following research questions in the present study: Using natural indicators representing the real ecological environmental factors of arid zone oasis cities, can an ecological environmental quality evaluation model be constructed to evaluate the ecological environmental quality of the urban agglomeration on the northern slope of the Tianshan Mountains? By analysing the Tianshan Mountains during the period of 2000–2018, does the ecological environment of the North Slope urban agglomeration have temporal and spatial changes and stability, and can spatial clustering models be established? How can the status of EQI in the process of rapid urbanization and the relationship thereof with socio-economic and ecological changes be understood? The technical roadmap of this research is shown in Fig. 1. Exploring the temporal and spatial changes and influencing factors of the ecological environment in the process of urbanization is of practical significance for realizing the sustainable development of the city, in addition to developments of the social environment and urban planning.

2. Study area

The urban agglomeration on the northern slope of Tianshan Mountain is located between 81°33′-93°32′ east longitude and 42°78′-45°59′ north latitude, which is at the northern foot. The spatial scope includes Urumqi and Changji, Shihezi City, Karamay City, Fukang City, Kuytun City of Yili Prefecture, Usu City, Hutubi County, Manas County and Shawan County in the Tacheng Region. The total area of the economic belt on the northern slope of the Tianshan Mountains is about 95,400 square kilometers (Fig. 2), accounting for only 5.7% of Xinjiang, with a population of 4.58 million, accounting for 23.3% of Xinjiang. The urban agglomeration on the northern slope of the Tianshan Mountains is located in a typical arid zone oasis and a desert eco-environment

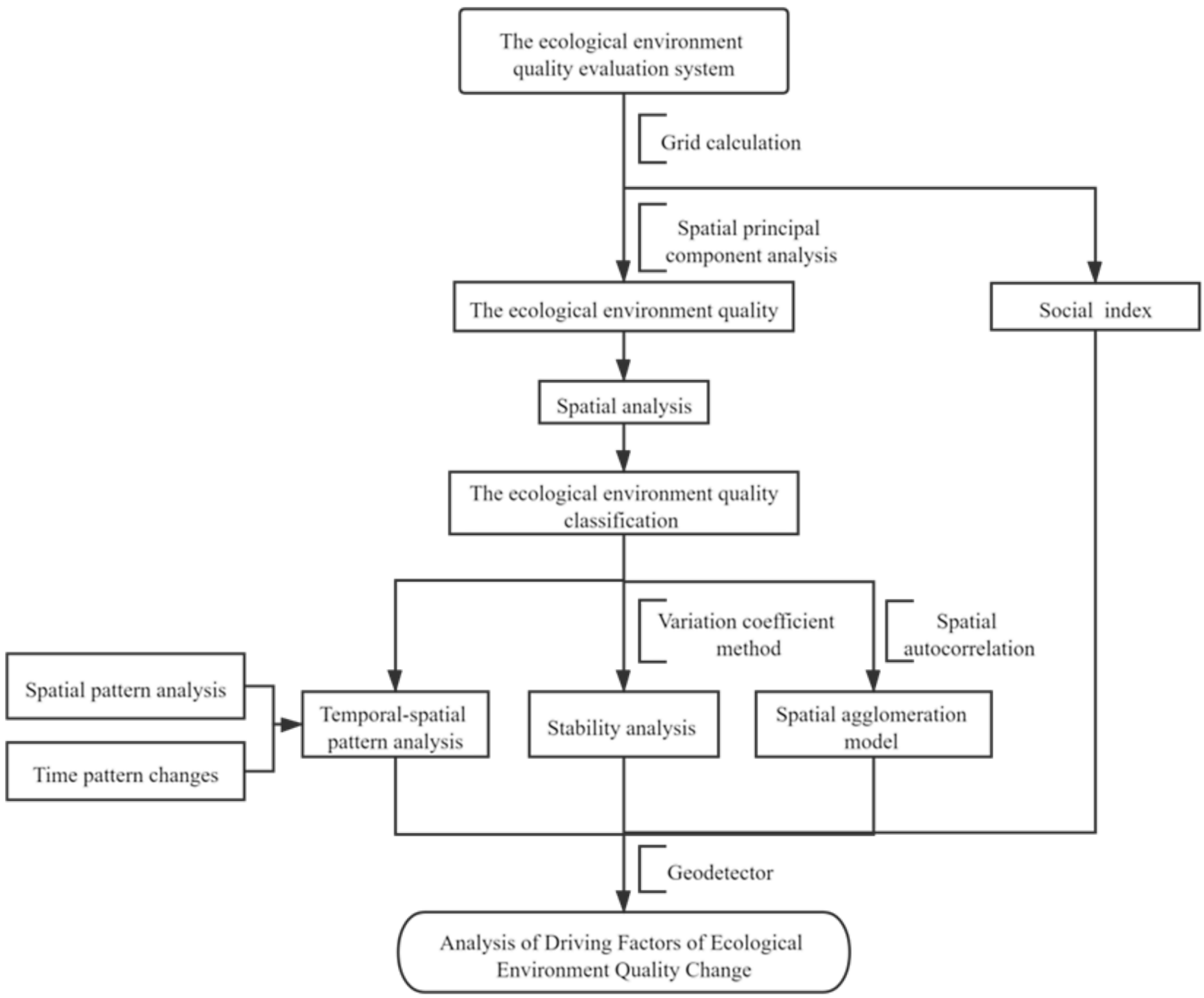

Fig. 1. Research framework and path diagram.

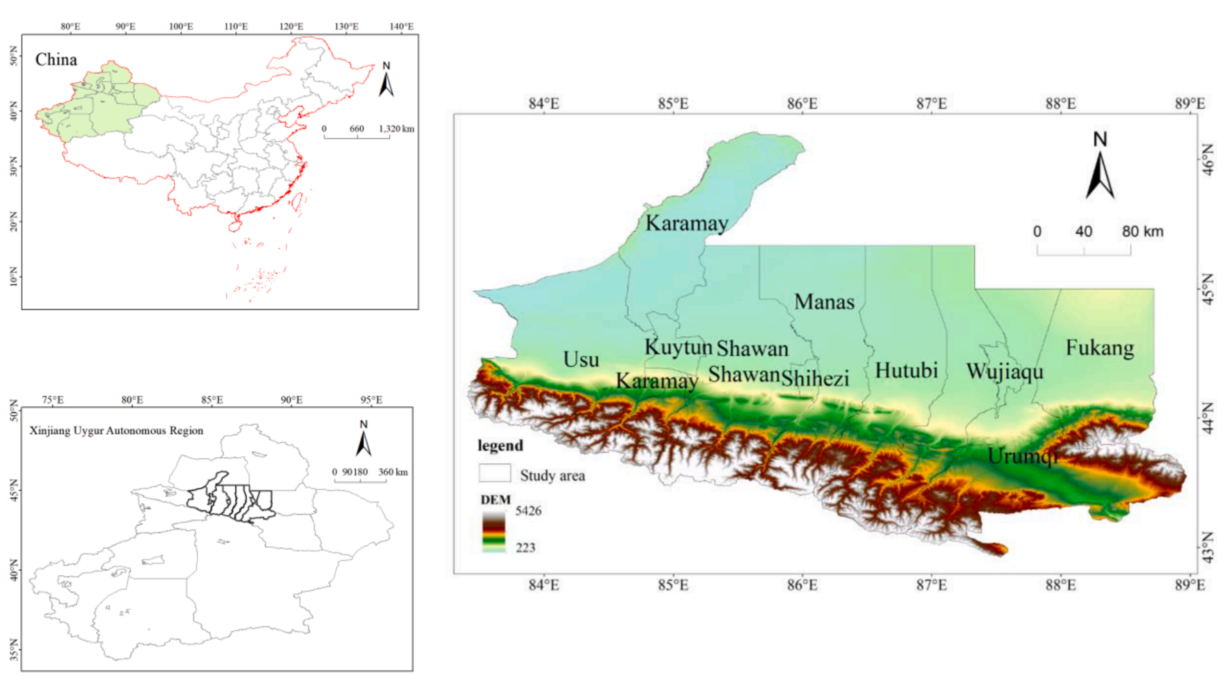

Fig. 2. Study area.

crisscross zone in Xinjiang (Zhao et al., 2021). The ecological environment is extremely fragile, and most of the natural oasis in said area has been replaced by artificial oasis. The urban agglomeration on the northern slope of the Tianshan Mountains is located in the same provincial administrative area, being the most economically developed area in Xinjiang and located in the core area of the “Silk Road Economic Belt”. Under the overall strategy of “One Belt, One Road”, the urban agglomeration on the northern slope of Tianshan has ushered in an important stage of development (Fang, 2019).

3. Data sources and research methods

3.1. Data source and preprocessing

When analysing the urban agglomeration, an indicator system was constructed for the ecological environment of the urban agglomeration on the northern slope of the Tianshan Mountains from different aspects. The required population, economy, hydrology, meteorology, soil type, NDVI data and DEM, and other parameters were also included, as shown in Table 1. The data selected in the present study were preprocessed and projected, based on ArcGIS and ENVI platform for spatial interpolation, index calculation, and others, while considering the impact of other factors on the index data. Based on the ArcGIS Geostatistical Analyst module, the Kriging interpolation method (Kriging) was used to conduct spatial interpolation to obtain various index factors that characterise the quality of the ecological environment to achieve spatial visualisation of index data. The data factor processing process is shown in Table 2.

3.2. Rationality of indicators

The results of the long-term interaction of various natural elements in the regional ecological environment is the basis for the formation of the local conditions of the regional ecological environment (Ya-shan et al., 2012). In the present study, the basic principles of comprehensiveness, scientificity, systemicity, accessibility, independence, simplicity, and others were followed (Hua and Rui, 2021). The ecological environment of the urban agglomeration on the northern slope of Tianshan Mountain were combined, and 7 indicators were selected to construct the northern slope of Tianshan Mountain, so as to form an evaluation index system of the ecological environment of urban agglomerations. Specifically, because a single indicator cannot reflect the relationship between urban agglomerations and the ecological environment, factors affecting the quality of the regional ecological environment need to be considered (Yunqing, 2020). The result of the long-term interaction of various factors of the ecological environment in the region is also the most direct manifestation of the ecological environment and functions (Gao & Sun, 2014). The urban agglomeration on the northern slope of the Tianshan Mountains is deep in the hinterland of China’s mainland. The terrain is high in the south and low in the north, being inclined from south to north. At Tianshan Mountains, there are diverse landform types, complex soil structure, sparse rainfall, uneven temporal and spatial distribution, strong spatial heterogeneity of precipitation and temperature, and lack of water resources, which constitute the unique natural conditions of the region. As such, the elevation and slope were selected to represent the topographic and landform factors; annual average precipitation, annual average temperature, and river network density were selected to represent the water and heat resources in the basin; soil type was selected to reflect the environmental conditions of the region suitable or unsuitable for vegetation growth, human survival and development, and the soil in the region was selected to represent the resource status. Vegetation coverage is an effective way to evaluate changes in regional ecological environment quality, and is also the basis for studying climate change and geographic material cycles (Peng et al., 2021).

Table 1
Data sources.

Data types	resolution	Data sources
Vegetation data	500 m	East View Cartographic
DEM	90 m	Geospatial Data Cloud
Soil Data	1 km	China Soil Dataset Based on HWSD (Science Data Center for Cold and Arid Regions)
Meteorological data		China Surface Accumulative Annual Value Data Set (National Meteorological Science Data Sharing Service Platform)
Demographic data	1 km	Google Earth Engine
Economic data		Statistical Yearbook
Road data		OpenStreetMap(OSM)

Table 2
Processing of data factors.

Target layer	Data factor	Process
Natural ecology	NDVI	Extract NDVI data directly
	Annual average rainfall	Using Kriging interpolation method to handle meteorological data
	Annual average temperature	Using Kriging interpolation method to handle meteorological data
	Slope	With the help of ArcGIS software analysis, data extraction based on DEM
	Drainage density	Obtained by using ArcGIS density analysis tool
	Soil PH	Direct extraction of soil data sets
	Soil organic carbon	Direct extraction of soil data sets
Social indicator	Land use type	The use of ArcGIS was assigned a value of 1 to 5 according to different land use types from low to high.
	Roads net density	Obtained by using the ArcGIS density analysis tool
	Population density	Directly extract population data
	Economic density	Directly extract economic data

Social ecology reflects the burden of human activities on the ecological environment in the watershed. For a long time, the economic development of the region has been relatively backward, and the regional population distribution has varied significantly. The population growth and the impact of human activities have overwhelmed the carrying capacity of the ecological environment in the watershed (Deng et al., 2015). Thus, in the present study, population density, road network density (Song et al., 2013) and land use type were selected (Liu et al., 2020) to characterise the impact of human activities on the urban agglomeration on the northern slope of the Tianshan Mountains and the pressure caused by the ecological environment. In general, the economic density represents the regional economic status, which can reflect the human ability to protect the ecology to a certain extent.

3.3. Ecological environment quality evaluation model

Evaluation indicators often have different dimensions, positive and negative terms, and the data can vary greatly. In order to achieve comparability, testability and ease of comparison among indicators, standardization of the original data of each evaluation index is necessary before determining the weight of indicators (Zeynoddin et al., 2020).

Through the spatial principal component analysis method, under the premise of ensuring the minimum loss of data and information, multiple related indicators are transformed into a few uncorrelated comprehensive indicators by rotating the original spatial coordinate axis, which can maximise the information obtained from the original indicators (Chi et al., 2020). At the same time, weights do not need to be artificially set in the whole process of spatial principal components, and the evaluation results are objective. The calculation formula is as denoted in Eq. (1):

$$EQI = R_1X_1 + R_2X_2 + R_3X_3 + \hat{A}\cdot\hat{A}\cdot\hat{A}\cdot + R_iX_i \quad (1)$$

In the formula, R_i is the contribution rate corresponding to the i-th principal component, and X_i is the i-th principal component.

When the cumulative variance contribution rate is greater than or equal to 80%, most of the relevant information of the original data can be replaced (Wang et al., 2021). In order to obtain the natural ecological information of the urban agglomeration on the northern slope of Tianshan Mountain truly and objectively, the cumulative contribution rate of the first four principal component factors had to reach 80% (Table 3). As such, the first four principal component factors were selected for the fitting calculation.

In order to compare and analyse the differences in ecological environment quality in local areas, classification of the EQI was necessary. In the present study, the natural break point method (Jenks) was mainly used for classification (Hongbing, 2015). The classification criteria for each period should be unified, otherwise no comparative analysis can be performed (Zhang, J., 2016) . Therefore, the 2018 grading standard was adopted for 2000 to 2018. The grading standards are shown in Table 4.

3.4. The stability of ecological environment quality

The coefficient of variation was introduced to explore the stability of the ecological environment quality index. The size of the coefficient of variation reflects the degree of fluctuation of the data series. The calculation formula is as denoted in Eq. (2):

$$C = \sigma/\overline{C} \tag{2}$$

σ is the standard deviation, and the calculation formula is as denoted in Eq. (3):

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}\left(C_i - \overline{C}\right)^2}{n}} \tag{3}$$

$\overline{C}$ is the multi-year average ecological environment quality index during the study period. According to the classification of the coefficient of variation, the coefficient of variation (C) was divided into weak variation ($C < 0.1$), moderate variation ($0.1 \leq 0.1 < 1$) and strong variation ($C \geq 1$).

3.5. Spatial clustering model

In order to detect the spatial accumulation of EQI, the local index of spatial autocorrelation was used to determine whether the region had a similar spatial distribution by calculating the degree of correlation between each spatial unit and neighboring spatial units, so as to fully reflect the spatial distribution of the regional ecological environment (Isabel et al., 2021). The local indexes of spatial autocorrelation included the local Morans index (local MoransI) and local Geary index (local Getis-Ord, G_i^*) (Ulak et al., 2019). The calculation formula is as denoted in Eq. (4):

Table 4
Classification criteria of eco-environmental quality.

Class	Criteria	EQI
1	Extremely bad	< 0.425
2	Bad	0.425 ~ 0.491
3	Poor	0.491 ~ 0.556
4	Moderate	0.556 ~ 0.617
5	Better	0.617 ~ 0.675
6	Good	0.675 ~ 0.736
7	Excellent	> 0.736

$$G_i^*(d) = \frac{\sum_{i=1}^{n} W_{ij}(d) X_i}{\sum_{i=1}^{n} X_i} \tag{4}$$

Eq. (5) could be used for further comparison:

$$Z(G_i^*) = \frac{G_i^* - E(G_i^*)}{\sqrt{Var(G_i^*)}} \tag{5}$$

where W_{ij} is the spatial weight matrix, spatial adjacent is 1, and non-adjacent is 0, X_i is the observation value of area unit i; and $E(G_i^*)$ and $Var(G_i^*)$ are the expectation and variance of G_i^* , respectively. If the value of $Z(G_i^*)$ is obvious and positive, the value around the i-th area is relatively high (higher than the average), that is, the high-value gathering area (hot spot), otherwise said value refers to the low-value gathering area (cold spot).

3.6. Geodetector

Geodetector is a new statistical method proposed by (Wang and Xu, 2017) to detect spatial differentiation and reveal the driving factors thereof.

3.6.1. Factor detection

In the present study, a factor detector was used to analyse the causes of the ecological environment quality of the urban agglomeration on the northern slope of the Tianshan Mountains. The factor detector can detect whether a factor was the cause of the spatial and temporal distribution pattern of the ecological environment quality and to what extent said factor can explain the space of the ecological environment quality. Among them: the q value represents the degree of influence of the independent variable X on the dependent variable Y, the greater the value, the greater the degree of influence; the p value is used to explain the degree of interpretation of the influence of the independent variable X on the dependent variable Y, the greater the value, the degree of explanation The smaller. The available q value measurement is denoted in Eq.(6):

$$q = 1 - \frac{\sum_{h=1}^{L} N_h \sigma_h^2}{N\sigma^2} \tag{6}$$

Table 3
Results of spatial principal component analysis.

Principal component	Eigenvalue			Rate of contribution (%)			Cumulative contribution rate (%)		
	2000	2010	2018	2000	2010	2018	2000	2010	2018
1	2.65	2.65	2.39	33.08	33.10	29.93	33.08	33.10	29.93
2	1.79	1.55	2.06	22.34	19.36	25.69	55.42	52.45	55.62
3	1.46	1.06	1.55	18.27	16.25	19.42	73.69	65.70	75.04
4	0.97	1.03	0.83	12.17	12.91	10.36	85.86	81.61	85.40
5	0.55	0.72	0.57	6.92	9.01	7.14	92.77	90.61	92.54
6	0.41	0.58	0.44	5.19	7.30	5.51	97.96	97.92	98.05
7	0.16	0.41	0.16	2.04	5.08	1.95	100.00	100.00	100.00

1: NDVI; 2: Annual average rainfall; 3: Annual average temperature; 4: Slope; 5: Drainage density; 6: Soil PH; 7: Soil organic carbon.

3.6.2. Interaction detection

An interaction detector is mainly used to identify the interaction between different factors, that is, to evaluate whether the two factors will increase or decrease the explanatory power of EQI or whether the influence of such factors on EQI is independent of each other. The classification of related interaction types is shown in Table 5.

4. Results and discussion

4.1. Spatial distribution characteristics of ecological environmental quality

According to the spatial distribution characteristics of the ecological environment of the urban agglomeration on the northern slope of the Tianshan Mountains, the natural fault method was used to classify the EQI value (Yaming, 2018) , which was divided into 5 grades: extremely bad, poor, moderate, good, and excellent. Statistics of the spatial distribution map are shown in Fig. 3.

The spatial distribution of the ecological environment quality of the urban agglomeration on the northern slope of Tianshan Mountain was analysed, and an observation can be made from Fig. 3 that in 2000, 2010 and 2018, the environmental quality distribution of the urban agglomeration on the northern slope of Tianshan Mountain showed certain regularity. The ecological environment quality of the Po city group had significant spatial differences, exhibiting a northwest-southeast distribution, and the improvement in the east was more obvious than that in the west.

(1) The areas with extremely bad and bad ecological environments were mainly distributed in the northern foothills of the Tianshan Mountains. In the deserts, Gobi, alpine plateaus and other areas with less human activity interference that were closer to urban built-up areas, the disturbance to the ecological environment quality by human activities was greater, and the type of change also became more complex.

(2) The quality of the ecological environment was better in the moderate-level belt area running through the south of Fukang City, the moderate area of Urumqi City, the moderate area of Changji City, the moderate area of Hutubi County, the north-central area of Manas County, the north-central area of Shawan County, and Usu City. In the northeast areas of Kuytun City, Shihezi City, and Wujiaqu City, the population density in plain areas and some desert areas was relatively high, vegetation coverage was low, and there was greater human disturbance. Meanwhile, some areas were affected by salinisation and desertification.

(3) The low-value areas and the high-value areas were alternately distributed, particularly the northern and northeastern parts of the area close to the Gurbantunggut Desert. The water source was relatively scarce, the evaporation was strong, and most of the inland rivers had short flow and small flow. In the industrial and agricultural water supply areas along the route, insufficient water sources for plant growth were not conducive to vegetation growth and led to lower ecological environment quality. However, with the implementation of policies and ecological projects such as “returning farmland to forest” and “returning farmland to grass” and other projects, the quality of the ecological environment gradually improved.

Table 5
Interaction type classification of interaction detector.

Judgments based	Interaction
$q(X1 \cap X2) < \mathrm{Min}(q(X1), q(X2))$	Nonlinear enhancement
$\mathrm{Min}(q(X1), q(X2)) < q(X1 \cap X2) < \mathrm{Max}(q(X1), q(X2))$	Single factor nonlinearity attenuation
$q(X1 \cap X2) > \mathrm{Max}(q(X1), q(X2))$	Two-factor enhancement
$q(X1 \cap X2) = q(X1) + q(X2)$	Independent
$q(X1 \cap X2) > q(X1) + q(X2)$	Nonlinear enhancement

In general, the quality of the ecological environment has gradually improved, with high-value areas gradually expanding, while low-value areas have gradually shrunk.

4.2. Spatio-temporal evolution pattern of ecological environmental quality

The results of the statistical analysis of the different levels of ecological environment quality indexes in the study area reveal that from 2000 to 2018, the study area with low ecological environment quality index generally exhibited a decreasing trend, and the area of moderate-low, moderate and moderate-high ecological environment quality index exhibited a gradually decreasing trend. At the same time, the area with high ecological environment quality index generally increased (Table 6).

Among the study areas: (1) the extremely bad and poor areas decreased (the area accounted for 53.93% in 2000, 34.2% in 2010, and 20.27% in 2018); (2) the moderate areas increased (in 2000, the proportion of the total area of medium grade was 14.84% in 2010, 15.26% in 2010, and 15.09% in 2018); (3) the good and excellent areas increased significantly (the total area accounted for 27.23% in 2000, 50.52% in 2010 and 64.65% in 2018). In general, the proportion of high ecological environment quality index exhibited a gradually increasing trend, reflecting the trend of obvious improvement in the ecological environment quality of the urban agglomeration on the northern slope of the Tianshan Mountains from 2000 to 2018.

The ecological environment quality index on the northern slope of the Tianshan Mountains has also exhibited an increasing trend owing to the implementation of the aforementioned policies and projects (Fig. 4 and Table 6). In order to obtain the changes in the ecological environment quality of the urban agglomeration on the northern slope of the Tianshan Mountains from 2000 to 2018, the two phases of the ecological environment quality classification maps in 2018 and 2000 were subtracted, where a negative value represents the deterioration of the ecological environment quality, and a value of 0 represents that the quality of the ecological environment has not changed significantly, while a positive value means that the quality of the ecological environment has improved. The specific performance is as follows: (1) the proportion of areas with better ecological environment quality (29.44% in 2010 and 47.94% in 2018) is greater than that of the deteriorating areas (28.2% in 2010 and 38.45% in 2018). The environmental quality exhibited a positive development trend; (2) the areas with no significant changes in the ecological environment quality index account for about the total area of the region (42.36% in 2010 and 13.61% in 2018), mostly in the eastern, southern and northeastern parts of the region; and (3) the areas where the eco-environmental quality index increased were mainly in the central and western parts of the central and northern parts of the region, which were roughly distributed in the north of the regional farming area in the form of two east–west horizontal axes with the degraded ecological environment. Around the ring-shaped eco-environmental quality improvement area, extremely degraded areas were distributed sporadically, exhibiting that human activities had a positive impact on the improvement of regional ecological environment quality to a certain extent.

4.3. Analysis of stability of ecological environment quality grade changes

After removing outliers and statistical analysis (Fig. 5), that the following findings were made: (1) over 96% of the region’s ecological environment quality stability was between the variation of weak and moderate, the regional ecological environment quality was relatively stable, weakly variable regions were mainly distributed in the study area, and the moderately variable regions were mainly distributed in the central and northern regions of the study area; (2) the strong variable regions accounted for a considerably small proportion and were mainly scattered in high-altitude areas in the south of the region, which were far

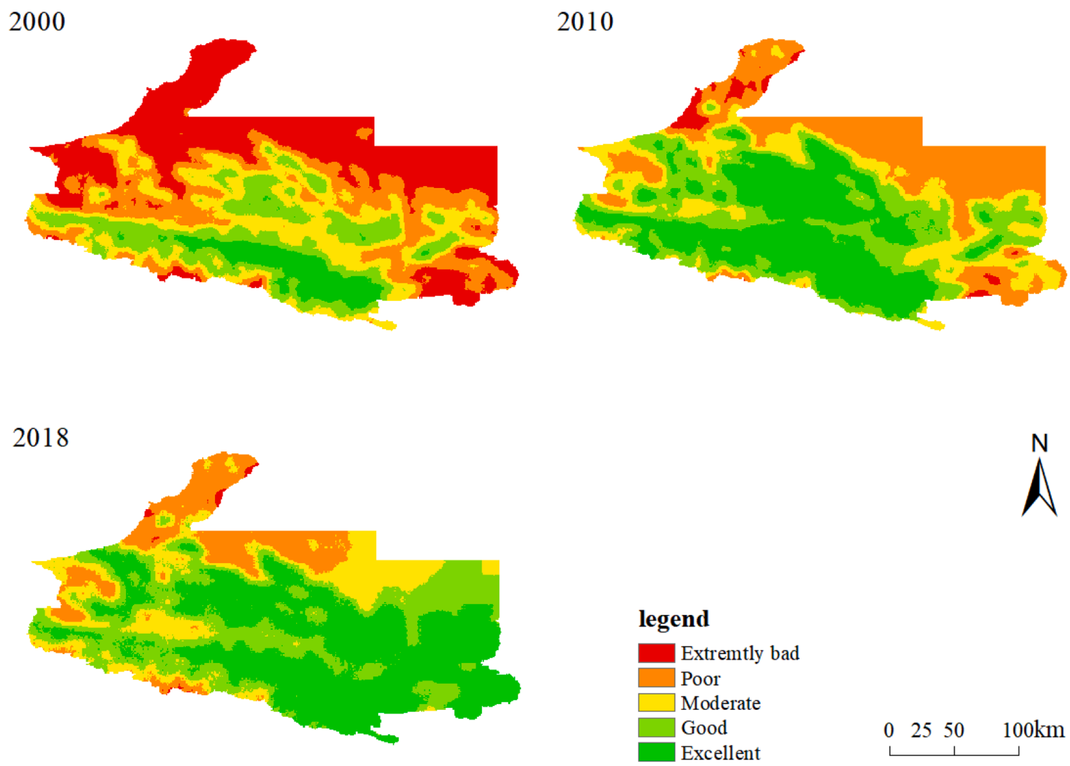

Fig. 3. Spatial distribution of eco-environmental quality.

Table 6
Eco-environmental quality classes and area statistics.

	2000		2010		2018	
Class	Count	Percentage	Count	Percentage	Count	Percentage
Extremely bad	14,592	39.45%	1557	4.21%	638	1.73%
Poor	6837	18.48%	11,093	29.99%	6858	18.54%
Moderate	5490	14.84%	5645	15.26%	5582	15.09%
Good	5532	14.96%	6374	17.23%	7832	21.18%
Excellent	4537	12.27%	12,313	33.29%	16,078	43.47%

away from urban built-up areas, indicating that the main reason for the strong variation in quality is natural factors. The other part was distributed in the northeast region. The greater the impact of human activities on the quality of the ecological environment, the more complex the types of changes; and (3) in deserts, Gobi, high mountain plateaus and other areas with less human activities, the ecological environment quality had not changed much, and was mainly stable; at the same time, the closer to the urban built-up area, the greater the impact of human activities on the ecological environment quality, and the change types became more complex.

4.4. Spatial aggregation mode of ecological environment quality

EQI can well reflect the spatial distribution characteristics of the ecological environment quality of the urban agglomeration on the northern slope of Tianshan Mountains. In order to further explore the aggregation mode of the distribution characteristics, the local Geary index (G_i^*) was used to generate the spatial aggregation distribution map of the ecological environmental quality of the urban agglomeration on the northern slope of Tianshan Mountains. The distribution of spatial aggregation and distribution of various levels of ecological environment quality in different time periods exhibited similarities, but there were also certain differences (Fig. 6). The ecological environment quality of the urban agglomeration on the northern slope of the Tianshan Mountains presented a "ring-shaped" distribution pattern, with obvious spatial aggregation characteristics and even distribution. High-value agglomeration areas (hot spots) were mainly concentrated in the southeast of the urban agglomeration on the northern slope of the Tianshan Mountains, showing contiguous and large areas. The spatial distribution of the area indicates that the areas with better ecological environment in the urban agglomeration on the northern slope of the Tianshan Mountains were characterised by high concentration, most of which were located in the moderate and lower reaches of the northern slope of the Tianshan Mountains. Meanwhile, the low-value aggregation areas (cold spot areas) were concentrated in the Tianshan Mountains. In the northeastern part of the northern slope city cluster, areas with poor ecological environment quality were highly concentrated, and most of them were located in the higher altitude areas on the northern slope of the Tianshan Mountains, desert areas and low hilly areas. There was a higher number of cold spot areas than hot spot areas. Due to the existence of large-scale desertification, salinisation and other phenomena, the governance and restoration of the ecological environment has been severely restricted.

On the whole, the ecological environment quality of the urban agglomeration on the northern slope of the Tianshan Mountains was distributed in two aggregation modes: high and low. The characteristics of a high concentration of hot spots and a high concentration of cold spots were also presented, which further illustrate that the ecological

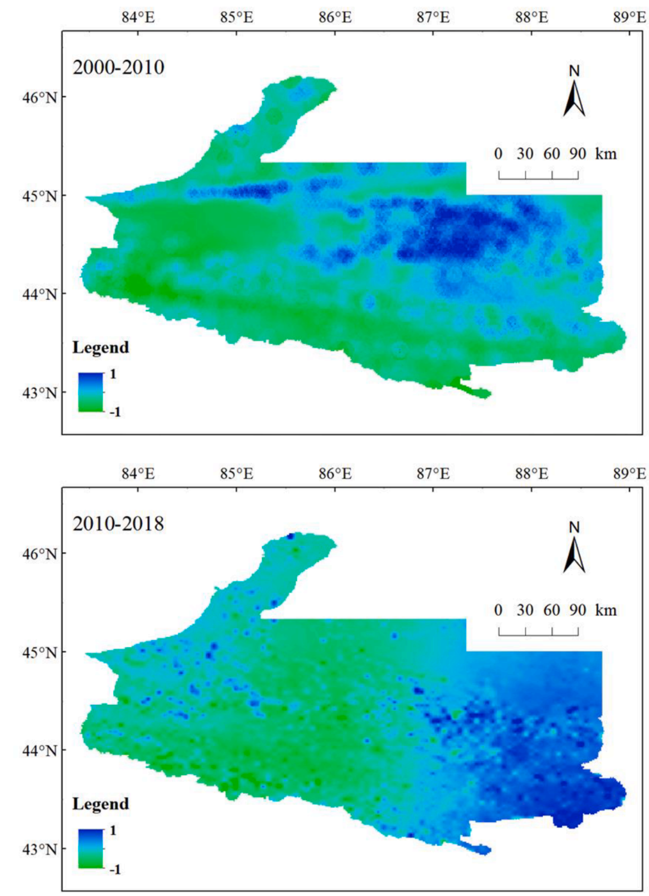

Fig. 4. EQI changes from 2000 to 2018.

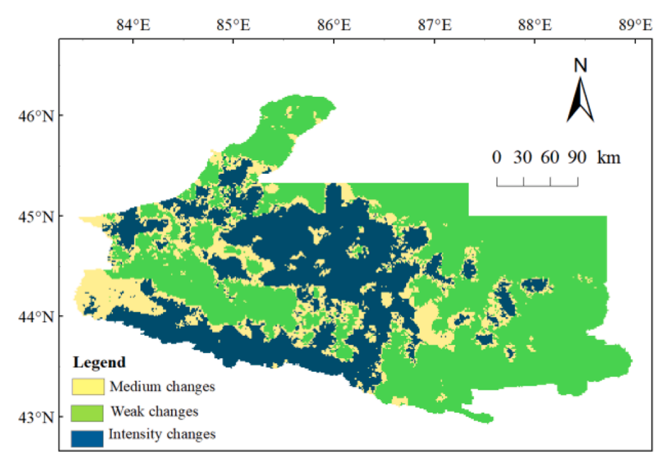

Fig. 5. The stableness of eco-environmental quality.

environment quality of the urban agglomeration on the northern slope of the Tianshan Mountains was distributed alternately in the northwest-southeast direction. There was also obvious spatial heterogeneity exhibited by the ecological environment quality of the basin.

4.5. *Influencing factors of ecological environment quality*

4.5.1. *Single factor detection analysis*

In order to further analyse the internal reasons for the changes in the ecological environment quality of the urban agglomeration on the northern slope of the Tianshan Mountains, a factor detector was introduced in the Geodetector as an analysis tool to reveal the internal driving factors of the ecological environment quality. The q value indicates the degree of influence of the factor on the ecological environment), and the P value indicates whether the factor passes the significance test level (Table 7). For convenience, the four social indicators were named X1, X2, X3, and X4. The statistics of the results of the Geographic Detector show that the four indicators were ranked according to the total q value. The q value of the land use type was above 0.619, and the impact was relatively high, mainly because of the urban construction land and large area. The desert area effectuated a significant burden on the economic development of the urban agglomeration on the northern slope of the Tianshan Mountains. The urban agglomeration on the northern slope of the Tianshan Mountains was deep inland, with sparse precipitation, strong evaporation, and sparse vegetation. The vegetation coverage was mainly low and medium–low. Affected by topographical factors, river flow, flow direction, oasis distribution and human activities, the different levels of ecological environmental quality indexes were roughly distributed in the northwest-southeast direction. The regional population was concentrated in the oasis, and there were few human activities in the mountains and deserts of the region. The quality of the ecological environment was relatively stable. The stable pattern of the change map mostly overlapped with the regions with low ecological environment quality index.

4.5.2. *Multi-factor detection and analysis*

The detection results of the research are shown in Fig. 7. The ecological environment quality index of the urban agglomeration on the northern slope of Tianshan Mountain in 2000, 2010 and 2018 was interactively probed with four factors. Compared with a single factor, the interaction of two factors enhanced the explanatory power of the ecological environment index. The results of factor interaction detection in the present study show the effects of two-factor enhancement type and nonlinear enhancement type, and there was no independent and weakening relationship, indicating that the decisive power of the interaction result was higher than the original independent determinative power of the two factors, which promoted changes in the ecological environment quality of the urban agglomeration on the northern slope of Tianshan Mountain. An observation can be made from Table 7 that the strongest impact on the ecological environment in 2000 and 2010 was the interaction of NDVI ∩ population density, and the specific explanatory power values were $q = 0.86$ and $q = 0.77$, respectively. Additionally, an observation can be made that the interactive detection values between land use types and other index factors were considerably high. In 2018, the interaction of land use type ∩ road network density had the strongest impact on the ecological environment, among which the interaction between road network density, land use and other factors had higher explanatory power. An observation can be made that land use, as the dominant social factor in the spatial distribution of the ecological environment quality of the urban agglomeration on the northern slope of the Tianshan Mountains, had the greatest impact on the ecological environment quality under the interaction with other environmental factors.

The nonlinear enhancement shows that the influence of the two-factor interaction result q on the ecological environment quality change of the urban agglomeration on the northern slope of Tianshan Mountain was greater than the influence of two single factors. The factor effect of nonlinear enhancement in 2000 was as follows: economic density ∩ road network density ($q = 0.65$). The factor effect of nonlinear enhancement in 2018 was as follows: population density ∩ road network density ($q = 0.62$). The results show that the factor with the least explanatory power of single-factor detection results had a considerably obvious effect on increasing influence under the combined action of other detection factors after interactive detection.

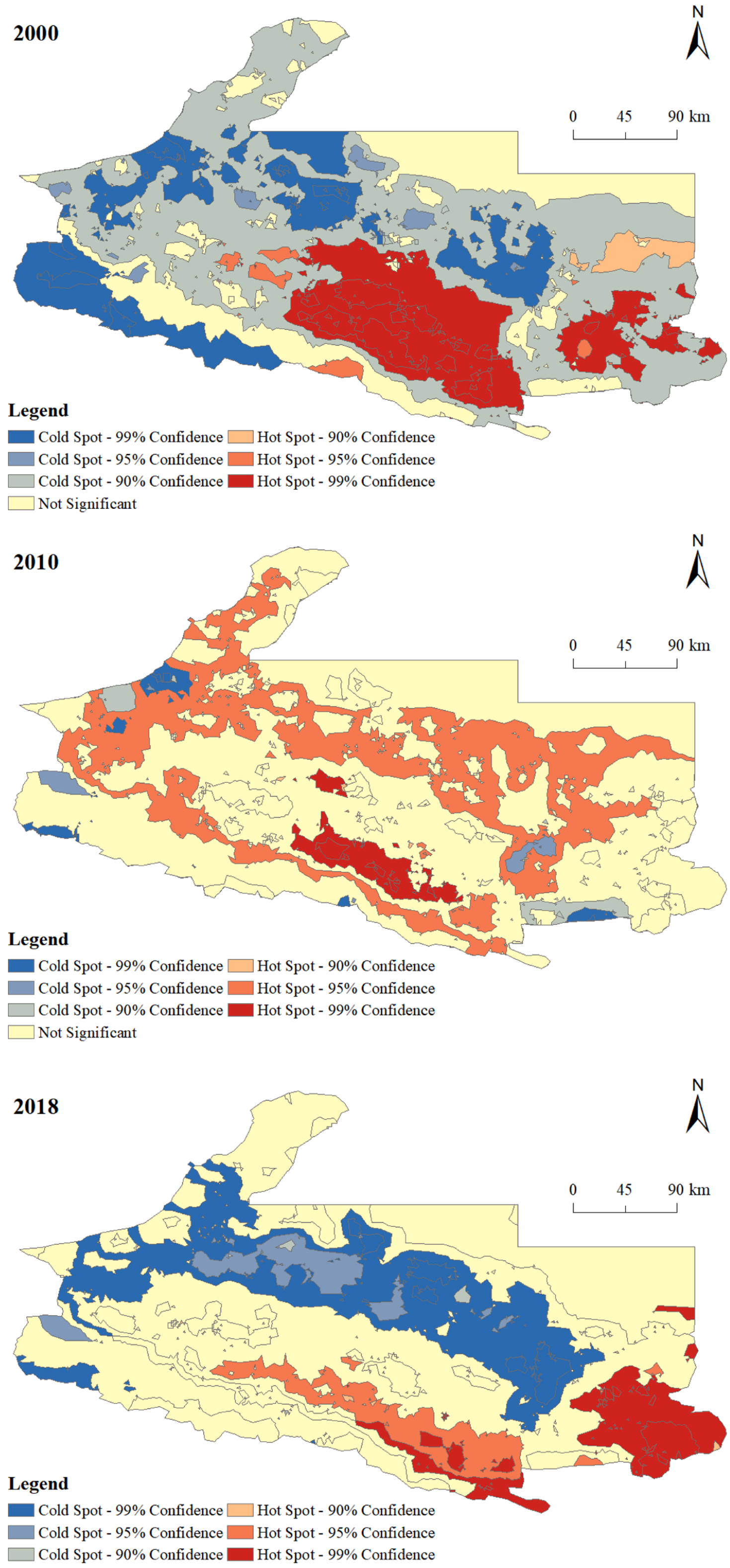

Fig. 6. Spatial aggregation distribution of eco-environmental quality.

4.6. Literature review

At present, there are numerous existing studies on the ecological environment of different regions. Compared with a previous study on the temporal and spatial changes of the ecological quality of the Yangtze River Basin from 2001 to 2019 (Yang et al., 2020), the ecological environmental quality of the study area appears to have improved year on year. The driving factors were also considered, but the driving factor in the Yangtze River Basin was altitude, while the driving factor in the present study area was the land use type, which may be the cause of differences in the functional areas. The human influence was relatively small, while the human influence of the urban agglomeration on the

Table 7
Geographical detector results on 4 impact factors of eco-environmental quality.

Factor	2000			2010			2018		
	q value	P value	q ranking	q value	P value	q ranking	q value	P value	q ranking
X1	0.767	0.000	1	0.697	0.000	1	0.619	0.000	1
X2	0.321	0.000	4	0.366	0.000	3	0.44	0.000	2
X3	0.537	0.000	2	0.249	0.000	4	0.168	0.000	4
X4	0.354	0.000	3	0.437	0.000	2	0.255	0.000	3

X1: Land use type; X2: Roads net density; X3: Population density; X4: Economic density.

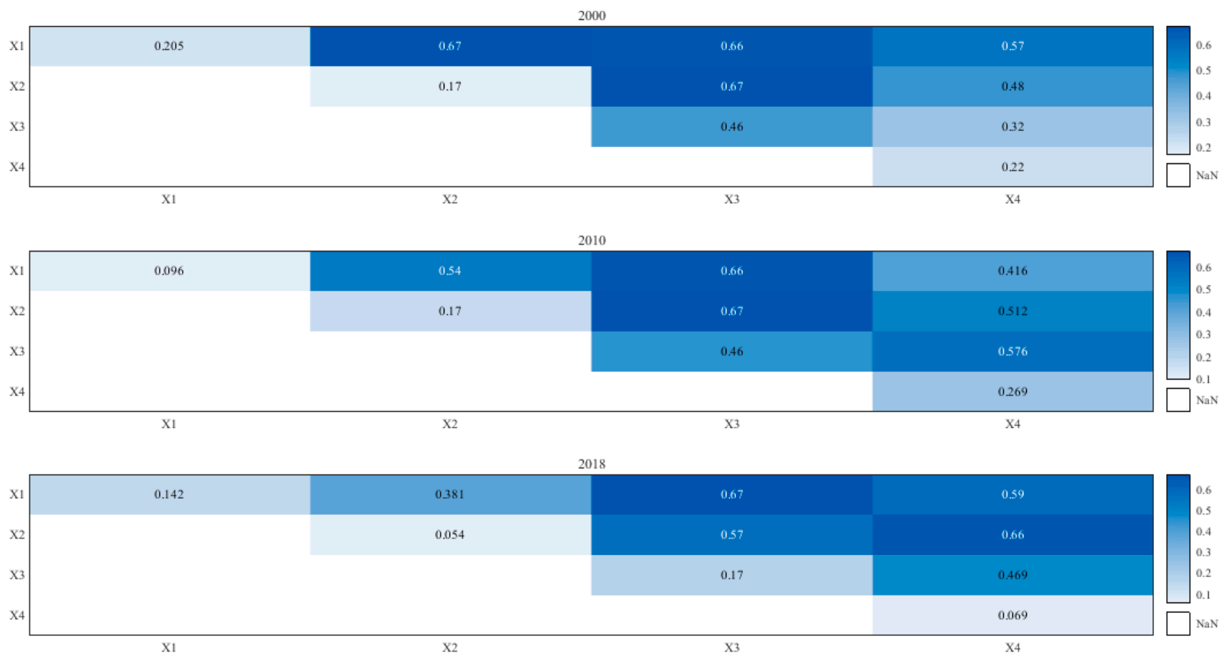

Fig. 7. Multi-factor detection results.

northern slope of the Tianshan Mountains was relatively strong. In a study on the Wuleidao Bay National Wetland, (Zhang et al., 2021) a field survey was conducted with a full environmental assessment of the wetland system. The results show that the ecological environment of the entire wetland was good, while the distribution of the good ecological environment of the northern slope urban agglomeration in the Tianshan Mountains exhibited uneven spatial distribution. Such findings could mainly be attributed to the perfect environmental management of the wetland, which effectively prevented the serious pollution of the wetland water resources by industrial production, agricultural consumption and residential sewage. The ecological environment protection of urban agglomerations provided a practical reference. Compared with the analysis of the temporal and spatial evolution of the ecological vulnerability of Panzhihua City from 2005 to 2015 (Dai et al., 2021) , the ecological environment of the two gradually improved. At the same time, the large-scale land utilisation and frequent human activities, such as urbanisation, were the main reasons for the poor ecological environment of the two regions.

The research results of the ecological environment provide a scientific theoretical basis for the construction of the ecological security pattern and sustainable development of oasis-type cities, and can provide a preliminary basis for follow-up domestic and foreign research on the spatiotemporal evolution mechanism of urban habitat quality, which is useful for improving the urban ecological environment and optimising ecological security.

5. Research deficiencies and prospects

The present study provides a scientific basis for the rapid evaluation of the ecological environment quality of the urban agglomeration on the northern slope of the Tianshan Mountains and other similar arid area urban agglomerations, but several limitations still remain. For example, the selection of indicators that affect the quality of habitat may not be comprehensive. Due to data limitations, factors affecting ecological management and control policies were not included in the present study, such as returning farmland to forests, ecological safety zones, and major functional areas, which may lead to certain deviations in the research conclusions. In future research, the evaluation results of the ecological environment quality can be further verified through field investigations of the ecosystem conditions in the study area, so as to quantitatively reflect the relationship between social economy and EQI, and explore the specific degree of impact.

6. Conclusion

Based on RS and GIS, an ecological environment quality assessment of the urban agglomeration on the northern slope of Tianshan Mountain was conducted on a macro scale. The results show that the overall ecological environment quality of the watershed was still at a poor level, and that ecological environment management and restoration work were imminent.

1. Analysed from the spatial distribution characteristics, the ecological environment quality of the urban agglomeration on the northern slope of the Tianshan Mountains was found to be spatially

polarised, and at the same time, there was obvious spatial heterogeneity in the “Northwest-Southeast” direction. Areas with poor and poor ecological environment quality were mainly distributed in unused land areas such as bare land, deserts, and Gobi, while areas with good and excellent ecological environment quality were mainly concentrated in oasis areas and the middle and lower reaches of rivers;

2. According to the statistics of the areas of different levels of ecological environment quality, from 2000 to 2018, the areas of poor and intermediate levels had decreased, while the areas of good and excellent levels had increased;

3. From the perspective of time evolution, the overall ecological environment quality exhibited a trend of improvement in the past 19 years. The ecological environment quality in most areas had not changed significantly;

4. In terms of stability analysis, over 97% of the region’s ecological environment quality was stable between weak and medium variability, and regions with strong variability accounted for a considerably small proportion, and the regional ecological environment quality was relatively stable;

5. According to the aggregation mode of distribution characteristics, the spatial aggregation mode of the basin was mainly the two aggregation modes of high and low values, which had the characteristics of “circular” distribution, with a high concentration of hot spots and a high concentration of cold spots; and

6. From the single-factor detection results, the influence degree of land use type was relatively high. From the multi-factor interaction detection results, all factors exhibited synergistic enhancement effects under the interaction. The utilisation type had the strongest explanatory power for the spatial differentiation characteristics of ecological environment quality under the combined effect of road density and population density.

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CRediT authorship contribution statement

Yan Yibo: Methodology, Formal analysis, Software, Data curation, Writing – original draft, Visualization. **Chai Ziyuan:** Conceptualization, Project administration, Writing – review & editing. **Yang xiaodong:** Writing – review & editing. **Zibibula Simayi:** Funding acquisition. **Yang Shengtian:** Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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