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SPATIO-TEMPORAL CHANGES IN ECOLOGICAL VULNERABILITY AND ITS DRIVING FACTORS IN WESTERN JILIN, CHINA IN THE LAST 30 YEARS

HAOXUAN JIANG, CHUNWEI SONG, CHENG HAN AND HUISHI DU*

Jilin Normal University, College of Tourism and Geographic Science, Siping Jilin 136000, China

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Abstract

In order to explore the quality of the ecological environment in the interlaced zone of agriculture and animal husbandry in western Jilin, this study used the vulnerability domain map evaluation model to select evaluation indicators based on GIS and RS technology. The principal component analysis method was used to carry out research on the ecological sensitivity of western Jilin from 1990 to 2020. Results showed that in terms of space-time distribution, severe and moderate vulnerability is mainly distributed in the northern part of the research area, and the moderate vulnerability area accounts for more than 73.13% of the area of the research area. From 2000 to 2020, the ecological vulnerability gradually decreased, and the overall ecological environment tended to improve, severe vulnerability is mainly distributed in unused land, and changes in different land types affect changes in ecological vulnerability, the ecological vulnerability in western Jilin has a strong correlation and is mainly located in the northern part of the research area. The area of high-high aggregation, hot spots and cold spots areas accounts for 1.84, 15.54 and 6.68% of the area of the research area, respectively.

Introduction

As a special attribute of an ecosystem, ecological vulnerability can comprehensively reflect both the extent of an ecosystem's inability to resist adverse effects and the damage risk to the ecological environment when facing adverse effects of external disturbances (Sun *et al.* 2021). Rapidly intensifying climate change and human activities have significantly changed the regional and global ecosystem. Deforestation, soil degradation, desertification and biodiversity loss seriously threaten the value of ecosystems to improve their service. Ecosystems' resilience and self-purification are declining, showing an increasingly fragile trend (Li *et al.* 2021, Shinde *et al.* 2021). Ecological vulnerability research is a hotspot and focus in global change and sustainable development research. Ecological vulnerability assessment can scientifically identify the genesis mechanism and change laws of ecosystem vulnerability and clarify the direction of ecological protection and ecological restoration (Xu *et al.* 2020).

Experts and scholars in relevant fields in China and globally have recognized the transformation from thematic research to comprehensive research and from single methods to integrative methods, advancing research on ecological environmental vulnerability (Ippolito *et al.* 2010, Furlan *et al.* 2011, Huang *et al.* 2017, Zhang *et al.* 2018). Furlan *et al.* (2011) used a comprehensive evaluation method to screen evaluation indicators and assess the vulnerability of Brazilian coastal ecosystems from four perspectives: geology, topography, soil type, vegetation and land use. The above- mentioned scholars have carried out research from many aspects such as evaluation methods, but there are also some limitations, ignoring the correlation between indicators, thus affecting the accuracy of evaluation. Therefore, it is urgent to use the vulnerability scoping diagram (VSD) approach to grasp correlations among various research indicators in the study area, so as to conduct a comprehensive assessment of regional ecological vulnerability.

*Author for correspondence: <duhs@jlnu.edu.cn>.

The western portion of Jilin is a transitional region between regions of animal husbandry in the west of China and agriculture in the east. The tension between agriculture and animal husbandry, especially the use of grassland and cultivated land, is particularly prominent. At the same time, this region is an area with a high concentration of ecological problems. It is located in the transitional zone between forest, grassland and desert areas. The presence of an unstable internal structure, low precipitation, and strong sandstorms creates a vulnerable external environment. Therefore, based on the VSD model framework, this paper systematically evaluated the ecological vulnerability of the study area of western Jilin by using 12 index factors, spanning climatic conditions, land use, ecological environment and social economy, combining the methods of AHP and PCA. Besides in the present study attempts were takan to provide decision-making reference for coordinated regional development and promote the construction of ecological civilization and the coordinated development of ecological protection.

Materials and Methods

The western part of Jilin Province is located in the west of the Songnen Plain and the north of the Liaohe Plain, covering an area of about 55,400 km^2 (121°38′–126°11′E, 43°22′–46°18′N). This area is composed of TaoBei, TaoNan, DaAn, ZhenLai, and TongYu under the jurisdiction of Baicheng City and NingJiang, FuYu, QianAn, ChangLing, and QianGuo under the jurisdiction of Songyuan City, NongAn in Changchun City and ShuangLiao in Siping City (Fig.1). The river system is developed in the region, mainly consisting of the Songhua River system. Transit rivers include the Nenjiang River, Songhuajiang River and Taoerhe River. Three kinds of steppe soils, namely black soil, chernozem soil and chestnut soil, are distributed in zones from east to west in the region. It is not only a transitional zone between grassland and forest land ecosystems, but also a transitional zone of black soil and wetland ecosystems, with a vulnerable ecological environment that is very sensitive to the influence of human activities (Li *et al.* 2020).

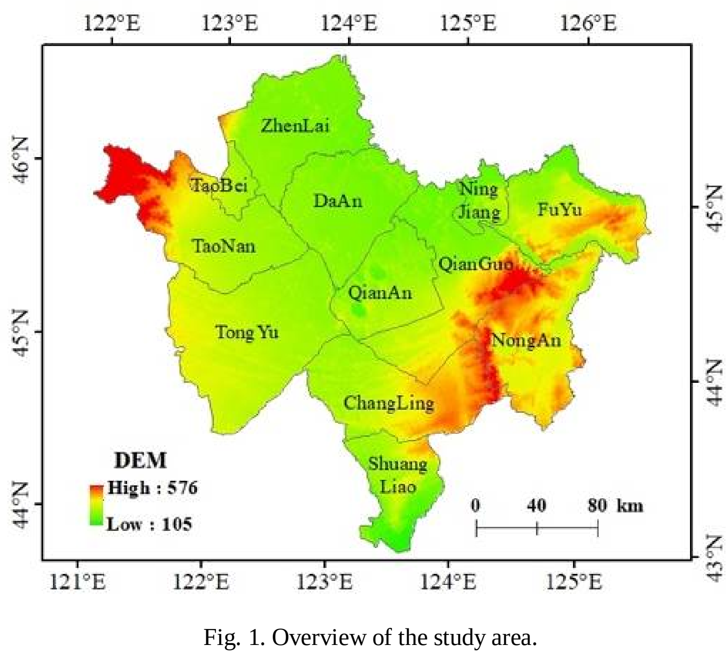

Fig. 1. Overview of the study area.

The VSD model mainly analyzes ecological vulnerability through three dimensions, namely exposure degree, sensitivity and adaptation, and thus, it is also called the "exposure-sensitivity-adaptation" model (Li *et al.* 2018). Exposure captures the degree of external stress or interference. Both natural and human factors change the exposure, and a high degree of exposure indicates an area is very sensitive to disturbance of its ecological environment (Zhang *et al.* 2018). The exposure sources of the study area are mainly reflected in average temperature, average precipitation, average evaporation, sunshine duration and population density. Sensitivity reflects the degree to which exposed units are susceptible to positive or negative effects of stress, which is influenced by the combination and interaction of natural and anthropogenic factors (Zhang and Li 2018). The sensitivity sources of the study area are mainly reflected in data on soil type, elevation, slope, river network density, land use and the net primary productivity of ecosystems. Adaptability captures the internal self-adjustment ability of a system or the restoration ability after external intervention, mainly reflected at the levels of social economy and policy (Lin *et al.* 2018). The adaptability of the study area is mainly reflected by per capita GDP.

At present, the weight of each index factor is mainly defined using a subjective and objective method. Results of the former are greatly influenced by the subjective judgment of experts, while the latter tends to overestimate the weight of human factors (Li 2017). Therefore, this study adopted a method combining AHP (subjective) with spatial PCA (objective) to define the weight of each factor. In order to better assess the ecological vulnerability status in western Jilin, the ecological vulnerability index in western Jilin is graded based on the natural breakpoint method, and the ecological vulnerability is divided into four levels: potential vulnerability [0-1.8], mild vulnerability [1.8-3.8], moderate vulnerability [3.8-6.4], and severe vulnerability [6.4-10].

Results and Discussion

From 1990 to 2020, the ecological vulnerability in western Jilin was mainly concentrated in moderate vulnerability and slight vulnerability areas, accounting for more than 73.13% of the study area (Fig. 2). From 1990 to 2020, the area of moderate vulnerability increased by 9,733.78 km^2, or 72.33%, while the areas of severe vulnerability, slight vulnerability and potential vulnerability all showed different decreasing trends. The area of severe vulnerability decreased by 531.84 km^2, or 11.27%; that of slight vulnerability decreased by 7,539.94 km^2, or 27.89%, and that of potential vulnerability decreased by 1,662.00 km^2, or 16.38%.

Severe vulnerability and moderate vulnerability increased from 1990 to 2000. This was mainly caused by the rapid development the of social economy, human exploitation and ecosystem utilization, and the increase of cultivated land area altered the structure of other land use types, thus damaging the originally balanced ecosystems. From 2000 to 2020, the area of severe vulnerability shifted towards moderate vulnerability, mainly owing to the improvement of the awareness of environmental and resource protection, the gradual improvement of the protection system of cultivated land and wetland and the successive introduction of protection policies; thus, the blind reclamation of cultivated land and wetland has been gradually controlled. Since 2000, wetlands in some areas were mostly artificial wetlands, reservoirs of various sizes captured surface water substantially, natural water supply wetlands continued to shrink, some rivers were cut off, riverbeds dried up and part of the ecosystem was irreversibly damaged.

Areas of severe vulnerability and moderate vulnerability were mainly because the surface is composed of Quaternary alluvium, and the soil is dominated by loess-like sub sandy soil, sandy soil and silty fine sand. The soil structure is loose, and its water and fertilizer retention abilities are poor. When disturbed by drought and waterlogging, the natural structure is easily destroyed, and this has become a key cause of land desertification in the area. The plain sediment has high viscosity and poor permeability, and the water network is not developed; thus, water cannot flow out after long-term stagnation, and soluble salts are not readily discharged. At the same time, owing to high rates of evaporation in summer, the land is prone to salinization. Areas of slight vulnerability and potential vulnerability were mainly because the favorable ecological background conditions, abundant resources, moist climate and environment and superior water, soil, light and heat conditions.

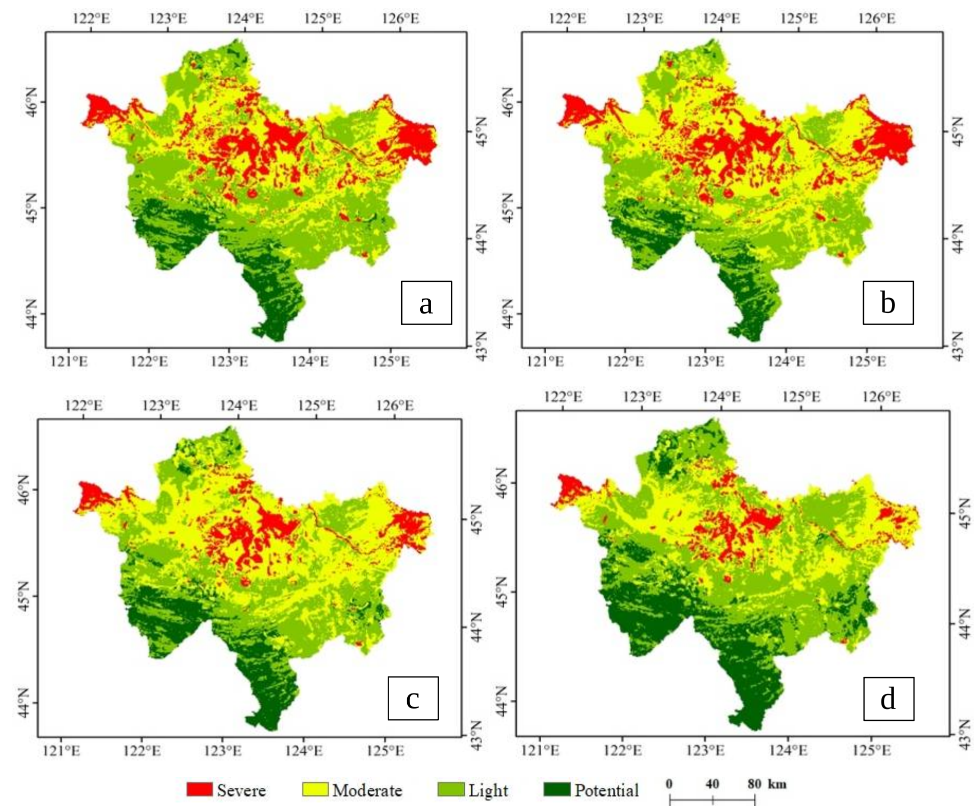

Fig. 2. Distribution of ecological vulnerability in western Jilin (a. 1990; b. 2000; c. 2010; d. 2020).

From 1990 to 2020, the land use area in western Jilin showed changes to different degrees (Fig. 3). The area of cultivated land, forestland and urban land showed a gradual increasing trend, with cultivated land increasing by 6,304.34 km^2 (19.88%), forestland increasing by 523.31 km^2 (60.88%) and urban land increasing by 107.06 km^2 (87.01%). The area of grassland and water decreased first and then increased. In 2010, the areas of grassland and water decreased to their minimum values of 7,390.81 km^2 and 966.34 km^2, respectively. The unused land area decreased first, then increased and finally decreased. Compared with 1990, the unused land area in 2020 decreased by 1,059.53 km^2 (13.06%). The area of severe vulnerability in western Jilin is dominated by cultivated land, water and unused land. The unused land is mainly saline-alkali land with a lot of sandy land. Artificial surface was distributed in towns and villages, including various residential land as well as mining and transportation facilities, making already vulnerable ecosystems even more vulnerable. Large-scale reclamation of agricultural land and land salinization were the main factors of the water area degradation of western Jilin. The main reason for the change in areas of moderate and slight ecological vulnerability in western Jilin is the transformation of grassland and unused land into cultivated land and forestland, the ecological background environment of grassland and the relative fragility of unused land. With agricultural and economic development, the area of cultivated land has been constantly increasing, and land desertification and salinization have been constantly exacerbated.

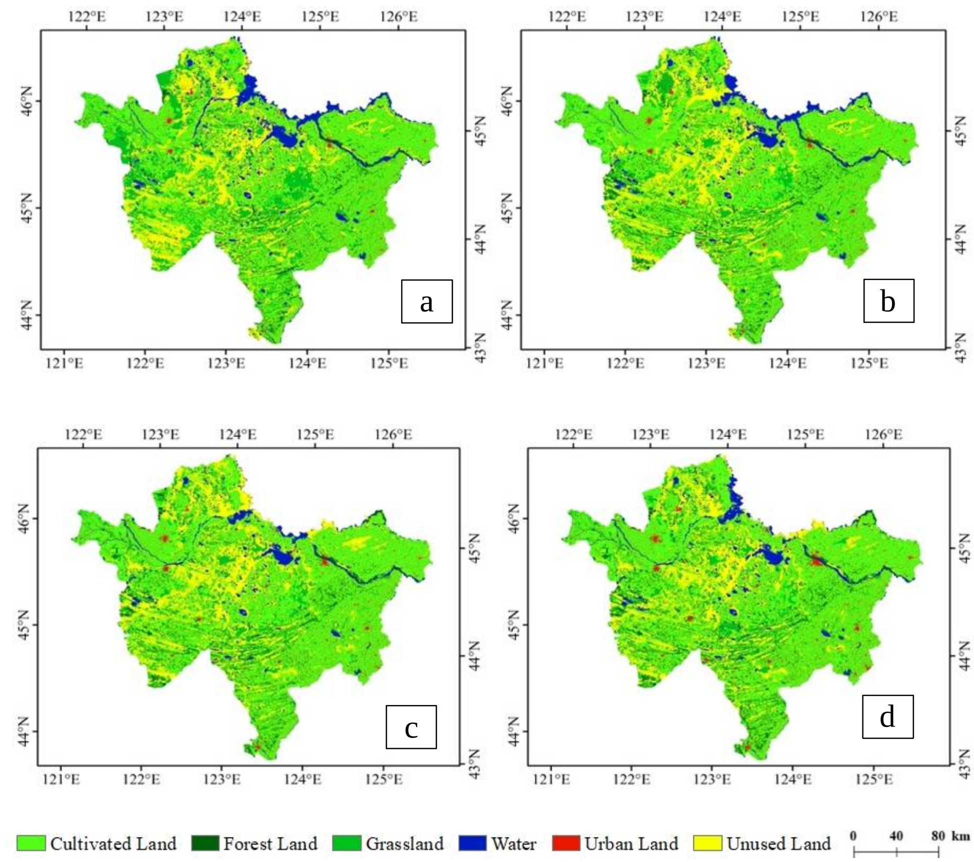

Fig. 3. Spatio-temporal distribution of ecological vulnerability in western Jilin (a. 1990; b. 2000; c. 2010; d.2020).

From 1990 to 2020, the ecological vulnerability in western Jilin showed significant spatial aggregation and hotspots (Figs 4 and 5). In 1990, the area of high-high aggregation was mainly distributed in the northwestern part of the study area. Other regions also had a small amount of the distribution, accounting for 6.23% of the study area. Most of the study area was dominated by severe vulnerability areas. Low-low aggregation was scattered in each region of the study area, accounting for 2.68% of the total study area. This region is dominated by areas of moderate vulnerability, slight vulnerability and potential vulnerability. Other aggregation evaluation units were not significant. After 1990, aggregation expansion and migration also occurred between different years. In 2020, high-high aggregation and low-low aggregation were scattered throughout the study area, accounting for 1.84 and 0.52% of the study area, respectively. Most areas were dominated by areas of moderate vulnerability, slight vulnerability and potential vulnerability. Spatial hotspot analysis in 1990 was mainly conducted for TaoBei, TaoNan, ZhenLai, DaAn, QianGuo, NongAn, FuYu and NingJiang, accounting for 6.60% of the study area. However, spatial cold spot analysis was mainly conducted for TongYu, DaAn, QianGuo, ChangLing and ShuangLiao, which accounted for 5.74% of the study area. In 2020, spatial hotspot analysis was mainly conducted for TaoBei, TaoNan, ZhenLai, DaAn, FuYu and NingJiang, accounting for 15.54% of the study area. The spatial cold spots were mainly distributed in TongYu, DaAn, QianGuo and ShuangLiao, accounting for 6.68% of the study area. Compared with 1990, hotspots and cold spots increased by 135.45 and 16.38%, respectively. The ecological vulnerability of the hotspot map is mainly comprised of areas of moderate vulnerability and slight vulnerability, while that of the cold spot map is mainly comprised of areas of moderate vulnerability, slight vulnerability and potential vulnerability.

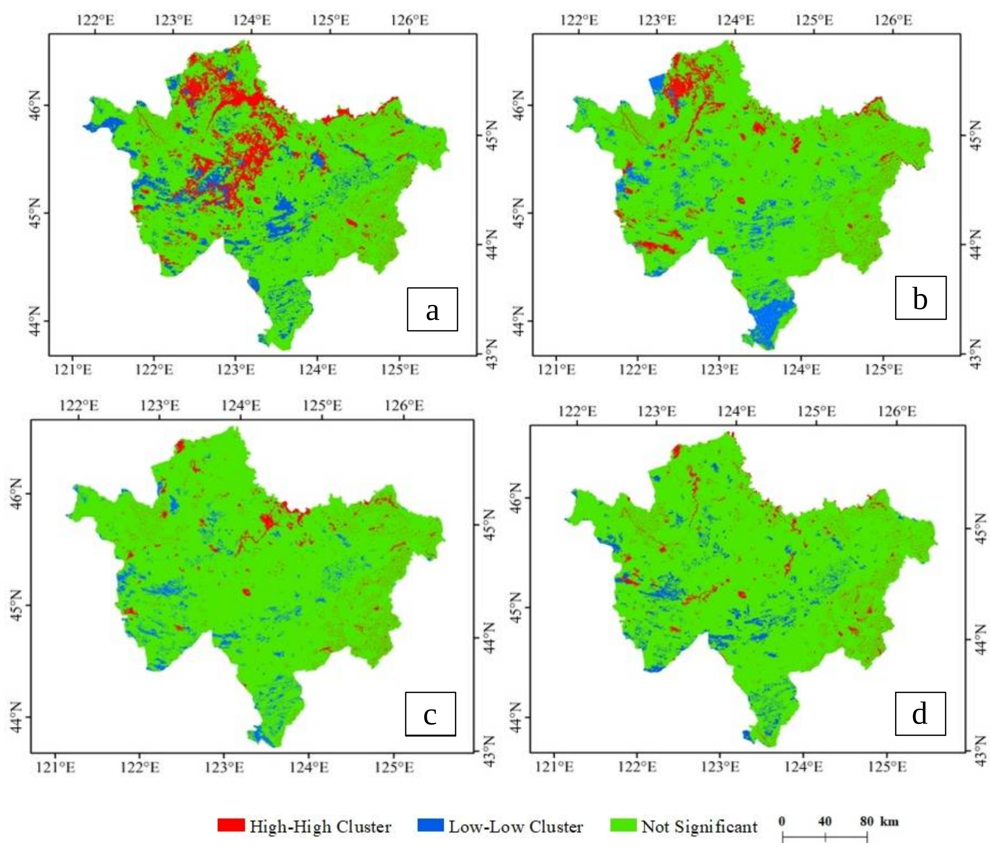

Fig. 4. Aggregation characteristics of ecological vulnerability in western Jilin (a. 1990; b. 2000; c. 2010; d.2020).

Natural factors are among the causes affecting regional ecological vulnerability (Luo *et al.* 2006, Zhu *et al.* 2021). Li *et al.* (2021) analyzed the spatio-temporal evolution of ecological vulnerability and factors driving it in Kashgar, Xinjiang, China and concluded that air temperature, terrain and vegetation coverage were the main natural factors driving the spatial differentiation of ecological vulnerability in the region. Zhang *et al.* (2021) assessed and analyzed the main factors driving ecological vulnerability in the arid region of Northwest China and found that soil and climate factors were the main driving factors of the spatial pattern distribution of ecological vulnerability in the region. There are some differences in the natural conditions between western Jilin, which is located in a farming-pastoral zone, and the previous study area in the arid area in Northwest China, but they are very similar.

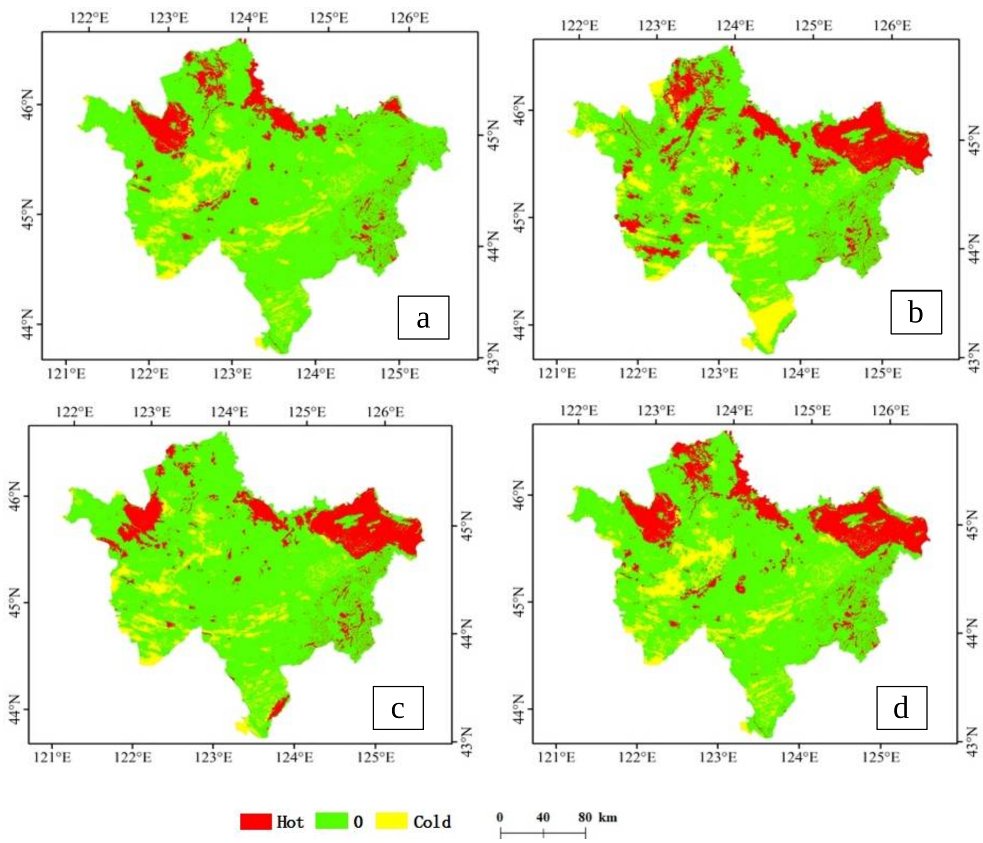

Fig. 5. Heat map of ecological vulnerability in western Jilin (a. 1990; b. 2000; c. 2010; d. 2020).

In addition to natural factors, there is also disturbance caused by human activities (Guo *et al.* 2018). Land use types are an important form of manual intervention in the ecological environment. In areas with fragile ecological environment, human activities are very easy to lead to ecological environmental degradation (Liu and Li 2021). The present study showed that the western part of Jilin is obviously affected by human activities. The background environment in the western part of Jilin is relatively fragile, mainly planting and animal husbandry, and the land use has changed significantly, indicating that the influence of human activities on western Jilin is gradually increasing, and this trend deserves the vigilance of local administrators. Therefore, the local government should improve the policy system, coordinate the balance between economic activities, such as agricultural production and ecological vulnerability management, in western Jilin take correct and appropriate measures and methods to curb the rising trend in ecological vulnerability in western Jilin. Owing to limited data availability, the present study only considered two indicators that reflect human economic activities at a macro scale, the per capita GDP and population density, as indicators of human disturbance influence, and did not used further indicators to investigate specific human disturbance activities affecting the spatio-temporal pattern and evolution of ecological vulnerability in western Jilin. This is not conducive to the application of this model for practical purposes. In subsequent research, data source and index system need to be further optimized.

From 1990 to 2020, the ecological vulnerability of western Jilin was mainly concentrated in areas of moderate vulnerability and slight vulnerability, accounting for more than 73.13% of the study area. Compared with 1990, the area of moderate vulnerability increased by 9,733.78 km^2 in 2020, or 72.33%. The area of cultivated land, forestland and urban land increased, while that of grassland, unused land and water decreased. The area of cultivated land increased by 6,304.34 km^2, or 19.88%, and that of water decreased by 690.93 km^2, or 35.38%. In 2020, high-high aggregation and low-low aggregation were scattered throughout the study area, accounting for 1.84 and 0.52% of the study area, respectively. Most areas were dominated by moderate vulnerability, slight vulnerability and potential vulnerability. In 2020, the spatial hotspots and cold spots were both distributed throughout in the study area, accounting for 15.54 and 6.68% of the study area, respectively, and most of the areas of ecological vulnerability were mainly of moderate vulnerability and slight vulnerability.

Acknowledgments

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