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Impact of Land Use/Land Cover Types on Surface Humidity in Northern China in the Early 21st Century Postprint

Authors: JIN Junfang, YIN Shuyan, YIN Hanmin

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Abstract

In the context of global change, promoting the rational development and utilization of land resources, improving regional ecological environmental quality, and fostering harmonious development between humans and nature are essential for regional sustainability. We identified land use/land cover types in northern China from 2001 to 2018 using ENVI images and ArcGIS software. Meteorological data were selected from 292 stations in northern China, potential evapotranspiration was calculated using the Penman–Monteith formula, and both reanalysis humidity and observed humidity data were obtained. The reanalysis minus observation (RMO), defined as the difference between reanalysis humidity and observed humidity, can effectively characterize the impact of different land use/land cover types (forestland, grassland, cultivated land, construction land, water body, and unused land) on surface humidity in northern China during the early 21st century. The results showed that from 2001 to 2018, forestland area expanded (increasing by approximately 1.80$×10^{4}$ km^2), while unused land area decreased (by approximately 5.15$×10^{4}$ km^2), indicating improved regional ecological environment. Consequently, land surfaces in most areas of northern China tended to become wetter. The contributions of land use/land cover types to surface humidity changes were related to regional ecological environmental quality. The six land use/land cover types made the highest contributions to surface humidity in northeastern northern China, where the ecological environment is better, and the lowest contributions in northwestern northern China, where the ecological environment is fragile. Surface humidity was closely related to variations in regional vegetation coverage; when regional vegetation coverage with positive (negative) contributions expanded (decreased), the land surface became wetter. Forestland and water body made the greatest positive contributions to surface humidity, while unused land and constructi

Full Text

Preamble

Impact of Land Use/Land Cover Types on Surface Humidity in Northern China in the Early 21st Century

JIN Junfang[1], YIN Shuyan[1]*, YIN Hanmin[2]

[1]Shaanxi Normal University, Xi'an 710119, China
[2]Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi 830011, China

Abstract

In the context of global change, promoting the rational development and utilization of land resources, improving regional ecological environmental quality, and fostering harmonious development between humans and nature are essential for regional sustainability. We identified land use/land cover types in northern China from 2001 to 2018 using ENVI images and ArcGIS software. Meteorological data were selected from 292 stations in northern China, potential evapotranspiration was calculated using the Penman–Monteith formula, and both reanalysis humidity and observed humidity data were obtained. The reanalysis minus observation (RMO), defined as the difference between reanalysis humidity and observed humidity, can effectively characterize the impact of different land use/land cover types (forestland, grassland, cultivated land, construction land, water body, and unused land) on surface humidity in northern China during the early 21st century. The results showed that from 2001 to 2018, forestland area expanded (increasing by approximately 1.80×10^{4} km^2), while unused land area decreased (by approximately 5.15×10^{4} km^2), indicating improved regional ecological environment. Consequently, land surfaces in most areas of northern China tended to become wetter. The contributions of land use/land cover types to surface humidity changes were related to regional ecological environmental quality. The six land use/land cover types made the highest contributions to surface humidity in northeastern northern China, where the ecological environment is better, and the lowest contributions in northwestern northern China, where the ecological environment is fragile. Surface humidity was closely related to variations in regional vegetation coverage; when regional vegetation coverage with positive (negative) contributions expanded (decreased), the land surface became wetter. Forestland and water body made the greatest positive contributions to surface humidity, while unused land and construction land were associated with the most serious negative contributions. Affected by the regional distribution pattern of vegetation, surface humidity in different seasons decreased from east to west across northern China. Seasonal variation in surface humidity was closely related to vegetation growth: surface humidity was highest in summer, followed by autumn and spring, and lowest in winter. Based on these results, surface humidity is expected to increase in north-

eastern northern China, decrease in the northern region, and likely increase in northwestern northern China.

Keywords: surface humidity; land use/land cover change; reanalysis minus observation; Penman–Monteith formula; climate change; northern China

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1. Introduction

Land use/land cover change (LUCC) represents the most direct signal of human activity impacts on Earth's natural surface ecosystems. As a critical link between human socioeconomic activities and natural ecological processes, LUCC has become a central topic in global climate and environmental change research [?, ?, ?, ?, ?, ?]. Studies have demonstrated that LUCC is closely related to surface material cycling and biological processes, with at least one-third of Earth's surface directly affected by human activities through land resource exploitation and land cover modification [?, ?, ?]. Additionally, as a key process in terrestrial ecosystems, LUCC plays important roles in material cycles and energy flows, primarily affecting biogeophysical processes such as surface albedo, soil fluxes, and vegetation evapotranspiration. Land coverage is essential not only for energy transfer between land and atmosphere but also for maintaining and optimizing ecosystem services, and it serves as an "indicator" in global climate change studies [?, ?, ?, ?, ?, ?, ?, ?].

Scholars worldwide employ two main methods to study the climatic impacts of LUCC. The first involves scenario simulations, which model climatic factors under specific scenarios to predict potential LUCC impacts on a global scale [?, ?]. For example, Hurtt et al. [?] reconstructed interannual variation characteristics of global LUCC through a global land-use model and explored LUCC responses to the global carbon cycle and climate change. Many scholars have also assessed LUCC impacts on global climate through multiple climate models or interdisciplinary approaches [?, ?, ?, ?]. The second method is sensitivity analysis, which explores regional climatic impacts of LUCC in local areas over short time periods through remote sensing imagery integrated with sediment, fossil, or tree-ring data [?, ?, ?]. Studies using this method have focused primarily on precipitation and temperature. For instance, numerous scholars [?, ?, ?] have shown that LUCC exerts far-reaching impacts on regional climate, particularly precipitation and temperature, mainly by affecting surface energy budgets, the Bowen ratio, and the partitioning of precipitation among evapotranspiration, infiltration, and runoff. Under global climate change, regional surface humidity has a direct and significant impact on vegetation coverage. Considering only natural factors, high regional vegetation coverage results in high surface humidity, and vice versa; this relationship has been previously validated. However, due to the close and complex relationships among Earth's spheres, different vegetation cover types may also influence regional climate characteristics (e.g., evaporation, transpiration, and water retention by roots, stems, and leaves), potentially producing different impacts on regional surface humidity. Therefore, in long-term studies of regional surface dry-wet conditions, the influence of LUCC on surface humidity cannot be ignored.

Northern China spans a vast area (4.76$×10^{6}$ km^2), accounting for approximately half of the entire country. The climate exhibits obvious regional heterogeneity and transitional characteristics, with most of northern China located in the dry-wet transition zone where the ecological environment is highly fragile. Consequently, northern China is sensitive to global climate change. Based on comprehensive consideration of various climatic factors, we objectively explored the impact of LUCC on surface humidity and its regional heterogeneity in northern China to provide a theoretical basis for rational land resource development and utilization, regional ecological environmental protection, and promotion of harmonious development between regional socioeconomic and ecological environments.

2.1 Study Area

Located north of the Qinling-Huaihe Line, northern China covers a vast area between 73°33′–135°05′E and 35°00′–53°33′N. Based on regional differences, we divided the 15 provinces, autonomous regions, and municipalities in northern China into three regions: the northeastern region (Heilongjiang, Jilin, and Liaoning Provinces), the northern region (Inner Mongolia Autonomous Region, Beijing, Tianjin, Shanxi, Hebei, Shandong, and Henan), and the northwestern region (Shaanxi, Gansu, Ningxia Hui Autonomous Region, Qinghai, and Xinjiang Uygur Autonomous Region). Significant differences exist between regional dry and humid zones in terms of climate and vegetation types, spanning four dry-wet zones (humid, semi-humid, semi-arid, and arid) from east to west, with corresponding vegetation types transitioning from forestland to grassland and even desert. Thus, northern China represents a sensitive area of global climate change.

2.2 Surface Humidity Data and Processing

Climate data used in this study were derived from daily surface climate datasets provided by the China Meteorological Data Service Centre (http://data.cma.cn). After excluding sites with missing data, 292 meteorological stations with complete observations from 1991 to 2018 in northern China were selected for comparative study with land use data (Fig. 1 [Figure 1: see original paper]). Main climatic elements included daily average temperature, daily maximum temperature, daily minimum temperature, sunshine duration, 2-minute mean wind speed, daily precipitation, average water vapor pressure, and atmospheric relative humidity. For each variable, we interpolated missing or abnormal data from a few sites using mean values from adjacent stations for the same period. Furthermore, to compare seasonal differences in surface humidity and natural vegetation distribution, we divided the time series into four seasons: spring (March, April, May), summer (June, July, August), autumn (September, October, November), and winter (December, January, February). Notably, based on the latitudinal position of the Qinling-Huaihe Line and map operation feasibility, we defined the area north of 35°N as northern China (the study area) (Fig. 1) to reduce errors in statistical analyses based on administrative divisions. Therefore, meteorological and land use/land cover data from the provinces, autonomous regions, and municipalities considered in this study represent changes north of 35°N in China.

The surface wetness index (SWI) is an important indicator used to measure regional surface dry-wet conditions, characterizing water balance at different spatial and temporal scales through the relationship between precipitation and evapotranspiration [**?**, **?**, **?**]. Based on existing research and considering the influence of regional climate conditions on reanalysis method accuracy, we selected the Penman–Monteith formula, which has the highest accuracy and clearest physical meaning in both arid and humid areas, to calculate potential evapotranspiration [**?**, **?**, **?**, **?**]. The Penman–Monteith formula is also the only standard method recommended by the Food and Agriculture Organization of the United Nations (FAO) for calculating potential evapotranspiration. The calculation process is as follows:

Δ γ(1 SWI P / ET , where ET0 is the potential evapotranspiration (mm/d); Rn is the net surface radiation of crops (MJ/($m^2 \cdot$ d)); G is the soil heat flux (MJ/($m^2 \cdot$ d)), which is approximately zero when calculating daily potential evapotranspiration; γ is a wet-dry constant obtained from a table (kPa/°C); T is the average temperature at 2.0 m height (°C); u2 is the wind speed at 2.0 m height (m/s); es is the saturated vapor pressure (kPa); ea is the actual water vapor pressure (kPa); Δ is the slope of the saturated vapor pressure curve (kPa/°C); SWI is the surface wetness index; and P is precipitation (mm/d). The larger the SWI value, the more humid the surface, and vice versa.

In research on LUCC impacts on climate, some scholars have proposed the "observation minus reanalysis" method [**?**]. Following this approach, we defined atmospheric relative humidity (ARH) data observed at 1.5 m above ground (recommended by the National Meteorological Research Center) as observed humidity values and SWI as reanalysis humidity values. Since the SWI calculation involves both ARH influencing factors and underlying surface characteristics, we applied the reanalysis minus observation (RMO) principle by subtracting observed humidity (ARH) from reanalysis humidity (SWI) in the study area. This yields the surface humidity difference (RMO) and fully considers spatial heterogeneity in surface humidity caused by differences in underlying surface physical and chemical properties. RMO can effectively characterize the impact of different land use/land cover types on surface humidity. Therefore, we selected RMO to characterize surface humidity at 1.5 m above ground. The calculation process is as follows:

RMO = SWI - ARH, where ARH is atmospheric relative humidity observed at 1.5 m above ground recommended by the National Meteorological Research Center (%) and RMO is the difference between SWI and ARH (%), primarily used to characterize surface humidity.

Since the slope of a linear trend can characterize change trends in different indicators, we fitted RMO values from 292 meteorological stations in the study area during 1991–2018 using univariate linear regression to obtain RMO change trends. The corresponding formula is:

$\text{Slope} = (i\times xi) - (i\times xi)/n / \; i^2 - (i)^2/n$, where slope is the RMO linear fitting slope degree; n is the time series length; i is the year; and xi is the RMO value in year i. A slope value greater than zero indicates increasing RMO, while a value less than zero indicates decreasing RMO.

2.3 Land Use/Land Cover Data and Processing

MCD12Q1 remote sensing image data used in this study were provided by the Google Earth Engine (GEE) platform with 500 m spatial resolution. Image data were preprocessed and interpreted using ENVI 5.3 and ArcGIS 10.2, with main processing steps including band combination, reclassification, image clipping, and confusion matrix accuracy verification [?]. Based on the International Geosphere-Biosphere Programme (IGBP) classification, we divided land use/land cover types in the study area into six categories: forestland, grassland, cultivated land, construction land, water body, and unused land (bare surfaces such as desert and Gobi), using a combination of supervised classification and visual interpretation with reference to the Chinese Academy of Sciences land use classification method [?, ?]. Finally, using the GEE platform, we evaluated land use/land cover data accuracy in 2001, 2010, and 2018 via confusion matrix method [?]. Overall classification accuracies were 98.54%, 98.68%, and 97.83% respectively, with corresponding Kappa coefficients of 0.969, 0.972, and 0.955, satisfying this study's accuracy requirements.

The land use/land cover transfer matrix represents a Markov model application in LUCC that can comprehensively describe the quantity and dynamics of mutual transfers among different land use/land cover types in a region. This matrix derives from quantitative description of system state and state transfer in system analysis. We calculated transfer matrices for various land use/land cover types in each period through ENVI supervised classification to obtain change and transfer areas of different types. We then introduced the area growth index to explore changes in different land use/land cover types and their influence on surface humidity. Finally, combined with expansion and reduction of land use/land cover types in different regions, we made simple judgments on future regional surface humidity trends:

$Nc = (At+1 - At)/At \times 100\%$, where Nc is the area growth index (%); At+1 is the area of the ith land use/land cover type in period t+1 (km^2); and At is the area in period t (km^2) [**?**].

3.1.1 Time Series Characteristics of Surface Humidity

Temporal variations of ARH and SWI in the study area from 1991 to 2018 are shown in Figure 2a [Figure 2: see original paper]. This comparison reveals that ARH in northern China declined slightly but remained stable during the study period, generally exhibiting a slight drying trend. However, SWI showed obvious fluctuation characteristics: before 2000, SWI fluctuated mainly downward with small amplitude, while after 2000, fluctuation amplitude increased and an upward trend became evident. Therefore, SWI variation trends were inconsistent with ARH trends, with the difference attributable to underlying surface influencing factors interfering with SWI much more strongly than with ARH.

Combined with Figure 2b [Figure 2: see original paper], RMO variation trends in the study area were highly consistent with SWI trends. RMO also showed a decreasing then increasing trend during 1991–2018, with 2000 as the inflection point. Fluctuation trends were almost synchronous. Accordingly, from 1991 to 2018, northern China's surface showed a drying then wetting trend, with wetness in the later period much higher than in the earlier period. In general, under a background of declining ARH, northern China's surface became wetter during the study period (1991–2018). After the beginning of the 21st century, regional surface humidification was particularly obvious, potentially related to LUCC impacts.

3.1.2 Contributions of Different Land Use/Land Cover Types to Surface Humidity

Land use/land cover types exhibited significant regional differences in RMO values due to their unique physical and chemical properties. In poorly covered areas, land surfaces were mostly exposed, and topsoil moisture was easily lost due to direct wind and solar radiation influence, resulting in low surface humidity. Conversely, in well-covered areas, vegetation protected the land surface, and water retention and holding characteristics prevented direct surface water loss. Additionally, plant evapotranspiration increased local ARH and promoted regional water cycling, ultimately increasing surface humidity. To highlight sensitivity of RMO value differences to land use/land cover types, we used zonal statistical tools to determine contributions of different land use/land cover types to regional RMO in northern China during the 21st century (Fig. 3 [Figure 3: see original paper]).

From the entire study area perspective, different land use/land cover types showed remarkable differences in RMO contributions within the same region. Forestland and water body made the most positive contributions to RMO, while unused land and construction land made the most negative contributions. Regarding different partitions, regional differences for the same land use/land cover type were exceedingly obvious due to different geographical environments. Forestland in the northeastern region made the largest positive contribution to RMO (66.54%), followed by the northern region (21.93%) and northwestern region (15.20%). Similarly, water body, which made a large positive contribution to RMO, also showed a characteristic of gradually decreasing from northeast to northwest. Nevertheless, the negative contribution of unused land to RMO was lowest in the northeastern region (–19.63%), followed by the northern region (–24.81%) and northwestern region (–29.80%). Due to strong human activity influence, construction land also made large negative contributions to RMO. In the northern and northwestern regions, construction land negative contributions were –0.72% and –14.82% respectively. Notably, RMO contributions from different land use/land cover types were highest in the northeastern region and lowest in the northwestern region. Except for unused land, all other land use/land cover types in the northeastern region featured positive contributions to RMO. In the northwestern region, except for water body and forestland, other land use/land cover types displayed varying degrees of negative contributions to RMO.

In summary, the contribution of the same land use/land cover type to RMO varied under different ecological environments. For example, in the northeastern region with better ecological environment, forestland contribution was obviously greater than in the northwestern region with fragile ecological environment. Similarly, the obvious negative contribution of unused land to RMO was far lower in the northeastern region than in the northwestern region, indicating that LUCC impact on surface humidity was related to regional ecological environmental quality.

3.2.1 Spatial Variation Characteristics of Land Use/Land Cover Types

Combining spatial LUCC distribution in northern China during the 21st century (Fig. 4 [Figure 4: see original paper]) with statistical areas of LUCC in the study area (Table 1) reveals serious grassland shrinkage in the northeastern region, decreasing by approximately 1.04$\times10^{4}$ km^2 from 2001 to 2018. Main degradation areas concentrated in northern Heilongjiang and southeastern Liaoning. Remaining land use/land cover types showed various degrees of expansion: forestland expanded by 0.67$\times10^{4}$ km^2, mainly concentrated in eastern and central forestland of the northeastern region. In the northern region, forestland, cultivated land, and construction land areas expanded by 1.10$\times10^{4}, 0.95\times10^{4}, and 0.41\times10^{4}$ km^2 respectively. The other three land use/land cover types decreased, with unused land decreasing most (1.53$\times10^{4}$ km^2), followed by grassland (0.90$\times10^{4}$ km^2). In the northwestern region, except for considerable unused land reduction (decreasing by approximately 3.70$\times10^{4}$ km^2), remaining land use/land cover types displayed different degrees of expansion, with cultivated land expanding by approximately 2.23$\times10^{4}$ km^2 and grassland by approximately 1.36$\times10^{4}$

km^2. In conclusion, northern China's ecological environment improved in the study area, with forestland coverage expanding (increasing by approximately 1.80$×10^{4}$ km^2) and unused land coverage reducing (decreasing by approximately 5.15$×10^{4}$ km^2).

3.2.2 Sensitivity of Spatial Variations in the RMO to LUCC

Changes in different land use/land cover type areas across northern China in the 21st century were obtained using transfer matrices (Table 2). Spatial LUCC distribution (Fig. 4 [Figure 4: see original paper]) and RMO trend value changes (Fig. 5 [Figure 5: see original paper]) demonstrated good correlation. In the northeastern region, forestland and water body areas expanded with the largest positive contributions to RMO, and the RMO trend was relatively large, with the most rapid growth rate of 0.34/10a. In the northern region, especially in western Inner Mongolia and western Shanxi where forestland and grassland expanded and unused land decreased, RMO showed an increasing trend, while most other areas showed an overall decreasing trend due to obvious negative contributions from unused land and construction land. Similarly, in the northwestern region dominated by unused land reduction accompanied by different degrees of forestland, grassland, and water body expansion, RMO exhibited an increasing trend and the regional surface tended to become wetter. In some areas where construction land and cultivated land expanded, such as Gansu, Ningxia, and Shanxi, the RMO trend value was smallest (minimum value of 0.89/10a), and land surface drying trend was strongest. In general, during the 21st century, surface humidity in northern China mainly exhibited weak humidification. Surface humidity change was closely related to regional vegetation coverage variation; when regional vegetation coverage with positive (negative) contributions expanded (decreased), the land surface became wetter.

3.3 Sensitivity Comparison of Seasonal RMO Changes to Land Use/Land Cover Types

Northern China, located north of the Qinling-Huaihe Line, experiences clear temperature changes across four seasons (with average temperature below 0°C in January) and significant surface coverage variation. Based on these characteristics, exploring seasonal RMO variation in northern China is necessary.

Spatial correlation between seasonal RMO values (Fig. 6 [Figure 6: see original paper]) and natural vegetation distribution (Fig. 7 [Figure 7: see original paper]) was analyzed and compared. Seasonal RMO variation in northern China was closely related to natural vegetation distribution. Generally, RMO values gradually decreased from east to west across different seasons, corresponding well with the pattern of more natural vegetation in the east and less in the west. In spring, RMO values were low across the study area, with high-value ranges not extensive, mainly distributed in the northeastern region where forestland is concentrated. In summer, RMO values increased significantly, with high-value ranges expanding from forestland in the northeastern region to grassland in the northern region and eastern part of the northwestern region. In autumn, RMO values showed a decreasing trend, with high-value ranges reducing compared to summer. In winter, high RMO value ranges concentrated in forestland of the northeastern region, while land surfaces in the northern and northwestern regions entered an abnormal drought period. Notably, low-value RMO centers in all four seasons consistently concentrated in unused land.

4. Discussion

Land use/land cover type transformation is a dynamic process, and LUCC is the product of this process. With rapid socioeconomic development, humans continuously reshape Earth's land surface over increasingly larger areas, changing land use/land cover types and vegetation coverage to some extent. It is generally known that China, with its complex terrain and diverse underlying surface types, is one of the regions with the highest intensities of human activities worldwide, making it one of the most representative LUCC research areas [?]. Similarly, northern China not only spans a large area but also features complex and diverse terrain, creating obvious east-west climate differences. Thus, affected by uneven regional water and heat distributions, LUCC in each region presents characteristics of synchronous expansion and reduction, with quite different change ranges.

LUCC is one of the most important ways human activities affect Earth's climate. According to the National Research Council [?], LUCC contributions to climate change may even exceed those of greenhouse gases. Since the late 20th century, Chinese governments have implemented ecological protection projects to improve the ecological environment, control soil and water loss, and prevent wind and sand hazards in northern China [?, ?]. Affected by these efforts, land cover conditions in northern China have changed substantially. While the climate effects of global warming from increasing greenhouse gas emissions have received widespread attention, temperature data have advantages over humidity data in terms of greater availability, easier collection, longer time series, and better continuity. Therefore, studies on LUCC impacts on regional climate have concentrated mainly on temperature, whereas research on regional dryness and wetness degrees is relatively limited. Kaufmann et al. [?] studied urbanization impacts on precipitation in the Pearl River Delta and found that rapid urbanization led to regional precipitation reduction. Similarly, studies have shown that since the 1980s, rapid urbanization in Beijing has been closely related to decreased local summer precipitation [?]. Other studies suggest that urbanization has led to relative humidity decline in urban areas and slight increases in suburban areas [?, ?, ?]. Undoubtedly, LUCC patterns affect local climate. Understanding land use/land cover type change trends allows us not only to assess human activity impacts on land use types but also to judge the direction of land use/land cover type changes to predict regional surface humidity development trends. From the transfer matrix (Table 2), we can infer that surface humidity in the northeastern region will increase in the future, but attention must be paid to regional ecological protection to prevent continuous unused land expansion. Similarly, RMO in the northern region will decline in the future, and the land surface will tend to become drier; therefore, strict control of construction land expansion is necessary. Meanwhile, in urban planning, construction of artificial wetlands (artificial lakes, wetland parks, etc.) and forest parks could be appropriately increased as humidification projects to improve surface humidity and promote living environment suitability. Finally, RMO values in the northwestern region may increase in the future, and the land surface will become wetter. This region should continue strengthening governance of vast desert areas and improving regional ecological environmental quality.

Through the above analysis, we found that seasonal RMO variation in northern China strongly responded to regional natural vegetation growth. In winter and spring, limited by climatic conditions, grassland plant species could not grow normally, grasses dried out, and leaves withered. The original green vegetation basically lost water retention capacity. Therefore, underlying surface physical and chemical properties of grassland were similar to those of unused land, and surface water was easily lost directly. Consequently, in winter and spring, land surfaces in most northern China areas were dry except for forestland in the northeastern region, with winter drying degree and range much larger than in spring. In contrast, climatic factors in summer and autumn were very beneficial for regional natural vegetation growth. Especially in summer, vegetation coverage in most northern China areas reached annual maximum. On one hand, expanded vegetation-covered area facilitated maximum surface water absorption and retention, preventing direct water loss. On the other hand, expanded vegetation-covered area promoted regional hydrological cycling to some extent, creating a constructive cycle in the regional ecological environment and further humidifying the regional land surface.

In conclusion, ARH in northern China declined slightly but remained stable during the study period, generally exhibiting a slight drying trend. This conclusion agrees with previous research results [?, ?, ?]. Under this climate background, we selected northern China as an example to analyze regional land use/land cover type and surface humidity change trends, finding that land use/land cover type feedback effects on surface humidity exhibit obvious spatial heterogeneity. Finally, we assessed surface humidity change trends in different northern China regions, with conclusions basically consistent with previous studies [?, ?, ?]. However, by referring to previous theories [?], we used the RMO method to simply obtain surface humidity from SWI; nevertheless, further analysis of internal mechanisms and strongly influencing factors for both humidity types is lacking. In the future, we should strengthen relevant data positioning and research, conduct more numerical experiments and analysis, and distinguish LUCC impacts on climate more accurately.

5. Conclusions

In recent years, northern China's land surface has generally become wetter. RMO values for different land use/land cover types featured significant regional differences due to their unique physical and chemical properties. Generally, surface humidity change was closely related to regional vegetation coverage variation; when regional vegetation coverage with positive (negative) contributions expanded (decreased), the land surface became wetter. Additionally, regional surface humidity seasonal variation was closely related to vegetation growth in different seasons under the study area's special climatic conditions. We can infer that surface humidity will increase in both northeastern and northwestern northern China in the future, but the surface will tend to be drier in the northern region. Thus, special attention should be paid to rational land use/land cover type planning to improve regional ecological environmental quality. Based on these findings, future studies will explore planning status and problems of land use/land cover types in different regions and propose practical suggestions for sustainable regional ecological environment development from an ecological restoration perspective.

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