

Land Use Change and Its Influence on Water Resource Pressure

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Abstract:

In recent years, the global land use pattern has changed significantly. Urban land has expanded, agricultural land use has adjusted, forest areas have changed, and arable land abandonment has become increasingly frequent. These changes have far-reaching impacts on regional water resources systems. This paper systematizes the main types of land use change and the manifestations of water resource pressure. It reveals three main paths through which land use change affects water resource systems. These paths are the increase of impermeable surfaces, the decrease of forest cover, and the expansion of agriculture. As a result, pressure on water quantity, water quality, and water ecology is triggered. On this basis, two typical cases are selected. One is the Beijing mega-city cluster, and the other is the agricultural area in northern India. The study analyzes the response mechanism of water resources systems driven by urbanization expansion and irrigated agriculture. The results show clear impacts. In Beijing, the expansion of urban construction land has led to more surface runoff. At the same time, groundwater recharge has decreased. This has put the regional water resources system's carrying capacity under serious challenge. In northern India, agricultural expansion and high-intensity irrigation water use have caused long-term over-exploitation of groundwater. The trend of regional groundwater depletion continues to worsen. Research indicates effective solutions. Rational optimization of land use structure, regulation of water use, and strengthening of water ecological restoration are important ways. It can alleviate water resource pressure and enhance the sustainable use of regional water resources.

Keywords: Land use change; Water resource pressure; Water quantity regulation; Water quality safety; Case analysis.

1. Introduction

Land use change, as an important driver of global environmental change, directly alters regional hydrological processes, water resource utilization patterns and ecosystem service functions [1, 2]. In recent years, the global urbanization process has continued to advance, and agricultural expansion and forest area reduction have occurred frequently, especially in developing countries. The conversion of arable land to construction land, increased agricultural intensity, and deforestation not only aggravate water resource development pressure but also cause water pollution and ecological degradation. Consequently, regional water resource security is increasingly severe.

Currently, scholars have conducted many studies on the relationship between land use change and water stress. Some scholars have focused on the impact of urban land use expansion on surface runoff and groundwater recharge processes, revealing the mechanisms by which increased impervious surfaces contribute to urban flooding and reduced water resource regulation. Other studies focus on the impacts of agricultural expansion on the demand for irrigation water and the impacts of chemical residues on water quality and safety. However, most of the existing studies focus on a single area or a certain type of land use change, and lack a comprehensive study that systematically analyzes the synergistic mechanism of the triple pressures on water quantity, water quality, and water ecology from the perspective of multiple types of land use changes.

The purpose of this paper is to systematically sort out the types of land use change and the manifestation of water resources pressure, and to construct a model of the path mechanism of land use change on the water resources system. It also selects the Beijing mega-city cluster in China and the agricultural area in northern India as typical cases, and empirically analyzes the response mechanism of the regional water resources system driven by land use change from the perspectives of urbanization expansion and water use for irrigated agriculture, respectively. It reveals the characteristics of different types of land use changes on water resources pressure, and provides theoretical support and decision-making reference for regional water resources management optimization and land use restructuring.

2. Pathways of Land Use Change Impact on Water Resources

2.1 . Main types of land use change

In recent years, the global land use pattern has undergone significant changes, with different regions showing dif-

ferent development trends and types of characteristics, mainly in terms of urban land expansion, agricultural land restructuring, changes in the forest area and the phenomenon of abandonment of arable land.

First, urban land expansion has become an important form of land use change. There is a general expansion of urban land globally, but there are differences in time and space. The urbanization process in developed countries has matured and the growth of urban land has been slow, while developing countries are still in the stage of accelerated expansion. For example, the Atlantic coast mega-city belt and the Yangtze River Delta urban agglomeration are typical regions of urbanization expansion [3]. Urban land expansion has two distinctive features. One is the continuous growth of construction land area, and the other is the rapid increase of impervious surface. This not only threatens food security and ecological safety, but also leads to problems such as urban flooding, intensified heat island effect and waste of land resources, which in turn triggers the imbalance of urban spatial functions.

Secondly, changes in agricultural land use show regional differences. The overall expansion of global arable land area, the general shrinkage of arable land area in developed countries, while South America, Southeast Asia and sub-Saharan Africa and other regions have become the main regions of agricultural land expansion due to abundant land resources [4]. At the same time, some resource-constrained developing countries have improved output per unit area and enhanced agricultural intensity through agricultural mechanization, planting structure adjustment and crop variety improvement.

Changes in forest area have also been significant, from 4.128 billion hectares in 1990 to 3.999 billion hectares in 2015, and although the average annual rate of loss has declined from 0.18% in the 1990s to 0.08% over the past five years, the trend of forest decline persists. The rate of forest loss in low-income countries has remained high for a long time, while the forest area in middle- and high-income countries has stabilized or even increased [4].

In addition, the phenomenon of the abandonment of arable land is spreading globally. The phenomenon first appeared in Europe at the beginning of the 20th century, and then gradually spread to developed countries such as North America, the Mediterranean region and Japan. In recent years, with the acceleration of urbanization and the massive outflow of rural labor, the phenomenon of cropland abandonment has also occurred in the mountainous and hilly areas of developing countries such as China and India [5-7].

2.2 . Expressions of water stress

Global water scarcity, water pollution and degradation of water ecosystems are becoming increasingly serious problems, which are manifested in four ways: declining surface and groundwater supplies, rising water demand, increasing water pollution and degradation of water ecosystem functions.

Firstly, the supply capacity of surface water and groundwater continues to decline. Global surface water accounts for only 0.017% of total water, and the freshwater resources directly available to humans are extremely limited [8]. About 35% of the global population is dependent on groundwater, especially in Asia, Africa, and the arid regions of the Americas. Water levels of major aquifers continue to decline in many parts of the world, especially in China, India, Pakistan and North Africa [9, 10].

Secondly, water demand has increased significantly. The continued growth of the global population, coupled with the rapid advancement of industrialization and the scaling up of agriculture, has led to a constant rise in water demand. For example, in order to ensure food security in the Heilongjiang region of China, agricultural water consumption continues to grow, further exacerbating the conflict between water supply and demand.

Thirdly, the problem of water pollution is becoming increasingly serious. The discharge of large quantities of industrial wastewater and domestic sewage has led to eutrophication of water bodies, while the use of fossil energy sources, such as oil and coal, releases large quantities of sulfur oxides and nitrogen oxides to form acid rain. Toxic and harmful chemicals in industrial wastewater are discharged directly into water bodies, causing serious pollution, as in the case of Minamata disease in Japan. In addition, in the context of climate change, the release of pollutants in the soil increases and enters water bodies through rainfall runoff, further aggravating the degree of water pollution [11]. For example, the area of Poyang Lake has plummeted from thousands of square kilometers to only 50 square kilometers, and the concentration of pollutants in the original water body has increased, forming the “concentration effect” and deteriorating the water quality of rivers and lakes [12].

Finally, water ecosystems continue to be degraded. Degradation of water ecosystems not only destroys the ecological balance of water bodies, but also adversely affects water quality, biodiversity and socio-economic development. On the one hand, obvious coupling problems exist between urbanization and water ecosystems. Specifically, urban expansion has changed the water body environment, forcing ecosystems to weaken their adaptability. On the other hand, the habitat of aquatic organisms has been

destroyed, biodiversity has been drastically reduced, and the stability of water ecosystems has been compromised.

From a comprehensive point of view, the current water resources are facing pressure in three aspects: water quantity, water quality and water ecology. Among them, the water pressure is mainly manifested in the uneven distribution of regional water resources, overdevelopment, and the demand continues to grow. Water quality pressure is reflected in the water pollution overload, chemical oxygen demand and ammonia nitrogen concentration is high. Water ecological pressure refers to urbanization, water resources development and water ecological function imbalance, biodiversity decline [13, 14].

2.3 . Mechanisms of land use change affecting water resources

2.3.1 Effects of Impervious Surface Expansion

In the process of urbanization, a large amount of agricultural land, forest land and grassland has been converted into building land and roads, resulting in a significant increase in impervious surface in the region, which has changed the characteristics of the original hydrological process. As the proportion of impervious surface rises, the surface runoff coefficient increases, making it difficult for rainwater to infiltrate during precipitation, and a large amount of rainwater quickly pools to form surface runoff, which can easily lead to an increase in the risk of urban flooding. At the same time, the amount of precipitation infiltration is reduced, groundwater recharge is inhibited, which triggers a continuous decline in the groundwater level, and the regional water resources regulation capacity is weakened. This process can be expressed by the surface runoff formula (1):

$$Q_F = PRE \times \alpha \quad (1)$$

where Q_F is the surface runoff volume, PRE is the precipitation, and α is the runoff coefficient.

2.3.2 Effects of Forest Cover Change

Forest vegetation plays a good role in water conservation and soil conservation. The forest canopy, the litter layer and the root soil layer can effectively retain precipitation, slow down runoff, promote rainwater infiltration, maintain soil moisture and reduce water evaporation. Among them, the leaf litter layer helps to improve the water permeability of the ground surface, enhances the water-holding capacity of the soil, and ensures the water supply in the dry season. The reduction of forests leads to a decrease in the regional vegetation cover, an increase in the area of bare ground, an increase in surface runoff during rainfall, a worsening of soil erosion problems, and an increase in the amount of sediment entering the river, which not only

affects the function of water regulation, but also poses a threat to the safety of the water quality of water bodies. Anthropogenic activities—including excessive logging, deforestation, reclamation, and forest fires—further damage forest water retention and aggravate ecological deterioration [1].

2.3.3 Effects of Agricultural Expansion

While guaranteeing food security, the expansion of agricultural land and the increase in agricultural intensity have significantly increased the demand for irrigation water, especially in arid, semi-arid and seasonally water-stressed areas, where agricultural water consumption has long accounted for more than 70 per cent of total regional water consumption. In some areas, rough irrigation methods, such as flood irrigation, have been used, leading to massive infiltration of irrigation water, which has raised the water table, induced salinization of the land and threatened the ecological security of soils and water bodies.

In addition, the extensive use of chemical fertilizers and pesticides in agricultural production leads to soil accumulation of chemical residues. These residues then enter groundwater and surface water bodies via rainfall runoff or seepage, thus increasing the risk of pollution of the water environment. Eutrophication of water bodies occurs frequently, and water quality exceeds the standard in local areas, threatening the safety of drinking water and the stability of water ecosystems. Agricultural expansion poses a double burden of “water stress” and “water quality stress” on water resources. The overlapping effects of these stresses pose a greater challenge to regional water resource management safety.

3. Case studies

3.1 Beijing Megacity: Urban Expansion

With the continuous acceleration of urbanization, the problem of regional water resources system carrying capacity in megacities is becoming more and more prominent. As a typical megacity in China, Beijing’s land use restructuring and population expansion have far-reaching impacts on the pattern of water resources supply and demand. Xie et al. and others selected the Beijing urban agglomeration as the research object, and used the DPSIR (Driving forces-Pressure-State-Impact-Response) model to construct the Using the DPSIR (Driving forces-Pressure-State-Impact-Response) model, they constructed an index system for evaluating the sustainability of urban water resources system, and systematically analyzed the characteristics of the evolution of the water resources system in Beijing from 2000 to 2018 [15].

The study integrates data from multiple sources, such as total water resources, water use structure, water quality, population density, economic development level, and changes in land use pattern, and applies entropy weighting to determine the weights of the indicators, and calculates the sustainability index of urban water resources system based on the comprehensive evaluation method of multiple indicators. Through the DPSIR framework, the indicators are classified into five categories: driver, pressure, state, impact and response, which comprehensively reveal the coupled relationship between land use change and water resource pressure driven by the urbanization process.

The results of the study show that the sustainability index of Beijing’s water resources system generally showed an upward trend from 2000 to 2018, but is still at a low to medium level. The continuous expansion of urban construction land has led to an increase in surface runoff and a decrease in groundwater recharge, exacerbating the contradiction between water supply and demand. At the same time, the city’s dependence on south-north water transfer and groundwater extraction is too high, and there is a large uncertainty in the level of regional water security. The results further suggest that land use change is one of the core drivers of water system stress, and that the growth of land use density and the expansion of impervious surfaces have significant impacts on water quantity, quality, and water ecosystems.

The case shows that megacities need to optimize the land use pattern and water resource management, enhance the proportion of ecological land, strictly control the expansion rate of impervious surfaces, and strengthen the reuse of water resources, water quality assurance and ecological restoration measures. It has an important methodological reference and a law cognitive value for the study of the coupling mechanism of land use change and water resource pressure in this paper.

3.2 Northern India: Agricultural Groundwater Depletion

As a globally populous country, India has long relied on irrigated agriculture to guarantee food security. Since the end of the 20th century, the rapid expansion of cultivated land area and the significant increase in irrigation intensity in northern India have caused serious over-exploitation of groundwater resources, and the situation of regional water resources security has become increasingly severe. Asoka et al. and others used GRACE satellite gravity anomaly monitoring data and the measured information from the state’s groundwater wells to systematically analyze the characteristics of groundwater storage dynamics in northern India from 1996 to 2016 to explore the trend

of continuous evolution of groundwater drought driven by agricultural irrigation [16].

The study integrates GRACE satellite remote sensing monitoring data, groundwater well observation data and meteorological precipitation data, and utilizes trend analysis and correlation tests to assess the coupling between spatial and temporal variations in groundwater storage and precipitation and irrigation water use. The analysis focuses on the main agricultural areas of Uttar Pradesh, Punjab and Haryana to identify high-risk zones for groundwater depletion and their formation mechanisms.

The results of the study showed that despite the inter-annual fluctuations in precipitation, there is a significant trend of continuous decline in regional groundwater storage, indicating that irrigation pumping far exceeds the natural recharge capacity. Especially during the peak agricultural cultivation period, the groundwater level declined the most. Although groundwater recharge is buffered in years of abundant rainfall, it is not enough to reverse the long-term depletion trend. The study points out that the expansion of agricultural land and the extensive cultivation of water-intensive crops (e.g., rice, wheat) are the root causes of groundwater overdraft.

This case verifies that the structural adjustment of agricultural land use and the increase of irrigation intensity have exerted continuous pressure on the groundwater system, which is of great significance in supporting the study of the coupled mechanism of land use change and water resources pressure in this paper. It suggests that developing countries' agricultural areas urgently need to optimize the land use structure, adjust the cropping system, and promote water-saving agriculture and rainwater storage measures, so as to effectively alleviate the trend of groundwater resources depletion and guarantee regional water security.

4. Conclusion

This paper systematically explores the mechanism of land use change and water resource pressure, and clarifies that different land use types affect the regional water resource system through multiple paths, thus triggering the triple pressure of water quantity, water quality and water ecology. The results of this study show that the increase in impervious surface area during urbanization significantly alters regional hydrological processes, resulting in increased surface runoff, decreased groundwater recharge, and reduced water resource regulation capacity, which exacerbates urban flooding and the conflict between water supply and demand. Changes in forest cover affect the water conservation function and soil conservation capacity by regulating the process of precipitation retention, infil-

tration and runoff, and the reduction of forest area leads to increased soil erosion and increased risk of water quality pollution. Agricultural expansion, while guaranteeing food security, has dramatically increased the demand for irrigation water, especially in arid and semi-arid areas, where agricultural water use has long taken up the bulk of the total water resources in the region, and where sloppy irrigation practices in some areas have led to the over-exploitation of groundwater and increasingly serious problems of water environment pollution.

Based on the above mechanism analysis, this paper selects the Beijing urban agglomeration and the agricultural area in northern India as typical cases, and verifies the paths of different types of land use changes on the pressure of the water resources system and their performance characteristics. The case results show that the expansion of urban construction land use and the increase of agricultural irrigation intensity are the main factors driving the change of water resources pressure, with the former leading to the weakening of the water regulation function and the latter triggering the long-term over-exploitation of groundwater along with the deterioration of the water environment.

Overall, land use change is an important driving force for the pressure change of the regional water resources system, which constitutes an important influence on the regional ecological environment security by changing the water quantity regulation, water quality security and water ecosystem function. In the future, the regional development should optimize the land use structure, reasonably control the expansion rate of construction land, increase the proportion of ecological land, promote water-saving agricultural technology and ecological restoration measures, and comprehensively improve the carrying capacity of water resources system and ecological environment quality, to provide a strong support for the regional high-quality development and ecological civilization construction.

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