Study on ecological environment change of water source area of the middle route of South-to-North Water Diversion Project in the past 20 years

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Abstract—The South-to-North Water Diversion Project (SNWDP), which began operation in 2013, is an important step in China's water resources development, and the middle route of SNWDP is one of the most important parts. However, this project has caused a certain negative impact on the ecological environment of Danjiangkou reservoir, the water source area of this project. This study uses DEM data and Landsat data for different years to analyze land-use changes in QGIS software and discusses the causes and impacts of the middle route of SNWDP. The results show that the present area of water and vegetation increased significantly, while the cultivated land and human area (including urban, rural and other areas of human activity) decreased obviously compared with 1999. The reasons for this change include natural conditions, engineering construction and policies, but policies such as raising the Danjiangkou dam and returning farmland to forests have played a bigger role. The impacts of SNWDP include water quality deterioration, soil erosion, changes in vegetation area, changes in biodiversity and changes in the lives of residents in the area. These impacts have positive reference significance for the construction of water conservancy undertakings in China in the future.

1. Introduction
The South-to-North Water Diversion Project (SNWDP) is one of the most important water conservancy projects in China. It has three lines, east, middle and west. The middle route of SNWDP diverts water from the Danjiangkou reservoir in the upper and middle reaches of the Han River, the largest tributary of the Yangtze River. It starts from the project in Xichuan County, Henan Province, on the east bank of the Danjiangkou reservoir, and flows to Beijing, through the watershed of the Yangtze River basin, Huaihe River Basin, the Yellow River and the west side of the Beijing-Guangzhou railway[1]. It focuses on solving the problem of water shortage in Henan, Hebei, Beijing and Tianjin, providing more than a dozen large and medium-sized cities along the route with water for living, industry and agriculture. The water supply area covers a total area of more than 155,000 square kilometers, with a total length of 1,277 kilometers of main channels and a 155-kilometer branch line of Tianjin water supply. The project officially began in 2003 and was completed in 2013. On December 12, 2014, the project was officially put into operation[2]. By July 20, 2021, the first phase of the middle route of SNWDP had been safe for more than 2,000 days, and 40 billion cubic meters of water had been transferred to the north, benefiting
60 million people along the route[3]. Figure 1 shows the schematic diagram of the middle route of SNWDP.

However, in the process of engineering operation, some problems are gradually occurring. Due to the increase of reservoir water volume and the rise of reservoir water level, the situation of water quality and soil erosion is not optimistic, which brings many adverse effects on the environment[4]. Due to the needs of SNWDP, some residents need to emigrate, which has changed the use of land in Danjiangkou reservoir area. At the same time, the economic and re-employment level of the immigrant masses also need to be found out and improved[5]. Therefore, this study used QGIS software to conduct a quantitative analysis of change in the use of land in Danjiangkou reservoir area from 1999 to 2020 to find the causes and impacts of the middle route of SNWDP.

![Fig.1 Schematic diagram of the middle route of SNWDP](image)

**2. Methods**

This study uses DEM data and Landsat data for different years to analyze land-use changes in QGIS software. Remote sensing images include Landsat-7 ETM+/ Landsat-8 OLI in 1999, 2013 and 2020 to quantify land use, which were obtained from the official website of THE United States Geological Survey (https://earthexplorer.usgs.gov/). The various band combinations were used to show a visual representation of the land use within the last three years. DEM data could indicate the terrain profile of wetland region and help judge the general distribution of land use types in wetland region.

This study use QGIS software to clip the remote sensing image and generate surface reflectance layers. According to "National Land Classification" and combined with the actual situation of Danjiangkou reservoir wetland, the wetland land types of Danjiangkou reservoir are divided into five categories: vegetation, water area, plow land and human area.

**3. Results**

After processing the remote sensing satellite images, three years of land use distribution and area data of each land type were obtained. Orange area indicates cultivated land, the green area indicates vegetated areas, the pink area indicates human areas and the blue area indicates water area.

Because of the topography, most of the areas of human concentration are located in the valleys in the west and the plains in the east. And most human areas are rural areas. The cultivated land is mainly distributed in the eastern plain, and the vegetation is distributed in the western hills. This constitutes the basic distribution of the whole wetland area.

The distribution of land use types of Danjiangkou reservoir from 1999 to 2020 is shown in Figure 2 and Figure 3. In the past 21 years, the main landscape types of Danjiangkou reservoir were vegetated land and cultivated land, the area of human and cultivated land decreased greatly, and the area of vegetated land, water area and increased on the whole. The area of humans decreased the most, with a
decrease of 1974.809 km², and its proportion decreased from 27.50% to 8.28%. Vegetated area increased the most, with an increase of 2150.746 km², and its proportion increased from 48.28% to 69.08%. The proportion of water area and plow land increased from 3.65%, and 20.57% to 11.04% and 11.60% (Fig.2).

Fig.2 Images of land use from 1999-2020

Fig.3 Changes of land-use from 1999-2020
4. Discussion

4.1. The reasons for the land-use change in the wetland area

The main changes that took place were in the natural environment and in areas where people congregated. In 1999, the Danjiangkou reservoir wetland was undeveloped. By 2008, the landscape pattern has great change, because the middle route of SNWDP construction in 2000 and the people of immigrants, causing some damage to the reservoir area ecological environment, resulting in vegetation and arable land decrease, water loss and soil erosion aggravate, plus residents' ecological consciousness and the ecological environment protection measures, poor reservoir area ecological environment worsening. Until 2012, with the gradual completion of SNWDP, the improvement of residents' ecological awareness, and the continuous improvement of relevant institutions' ecological and environmental protection measures, the Danjiangkou reservoir wetland gradually recovered and tended to be stable. This section mainly discusses the causes of natural conditions and anthropogenic policies[6].

4.1.1. Natural cause of formation

The terrain of the Danjiangkou reservoir area is mainly hilly, with large terrain fluctuation, low vegetation coverage, poor ability to resist external erosion and destruction, and low self-regulation ability of the ecosystem, which is fragile on the whole. The soil in the region is mainly yellow-brown earth, which is viscous and poor in permeability. The surface layer is loose and thin, which is not resistant to drought and flood, easy to be eroded, and weak in the ability to resist precipitation and water erosion[7]. The annual water volume in the region is large, which easily causes soil erosion and soil erosion. During the construction period from 1999 to 2008, these factors led to a decrease in the area of green plants and arable land, and caused ecological damage. However, with the construction of the water source wetland reserve since 2012, the influence of natural factors has decreased.

4.1.2. Engineering and policy

This part discusses the impact of engineering construction and policies on land-use change. In the early stage of the middle route of SNWDP, the government raised the Danjiangkou reservoir dam to improve flood control and water supply. But as a result, the land around the reservoir area was flooded, and most rural residents were distributed close to the reservoir area, so a large number of people needed to be relocated. However, during the same period, cities around the reservoir area developed rapidly, and the land was less inundated, and the area of rural and urban human activity areas still increased[8]. After the water supply began in 2012, the demand for water supply increased year by year, so the water area increased again. At the same time, in order to protect the ecological environment of the reservoir area, measures such as returning farmland to forest and closing factories further lead to the rapid reduction of human activity areas[6].

4.2. Environment impacts of the middle route of SNWDP

4.2.1 Water quality deterioration

Danjiangkou reservoir has been raised to meet the demand of 9.5 billion cubic meters of water to be transferred from south to north soon and 12 billion to 13 billion cubic meters of water to be transferred from south to north[9]. The project enlarged the capacity of the reservoir and the normal water level of the reservoir, but also caused the deterioration of water quality. As a result, the water in the reservoir inundated the surrounding land, causing nitrogen and phosphorus elements in the land to enter the water, resulting in serious water pollution. In the Chinese government's classification of water quality, a lower number indicates better water, while a higher number indicates worse water. From Class I to V, water quality changes from the best to the worst. From 2004 to 2005, the total ammonia was in the range of 0.73-2.22mg/L, and the maximum value was in Class V water. During the monitoring from 2016 to 2020, about 70% of the water quality was in Class III, and 25% was in Class IV, indicating that the water quality was not optimistic[10]. It is noted that the water quality of the reservoir is also affected by sewage
produced by other factors such as human life, farmland sewage, pesticides, fertilizers and soil erosion, which is not considered in this study.

4.2.2. Soil erosion
Soil erosion refers to the phenomenon of simultaneous loss of water and soil, due to the influence of natural or man-made factors. It leads to rainwater can not be absorbed on the spot, and then flows down homeopathy and washes the soil. Danjiangkou reservoir has a serious situation of soil erosion. According to statistics, about 93.5% of the reservoir land has mild soil erosion, and 6.4% of the reservoir land erosion is moderate or serious[6]. The influence of soil erosion is very far-reaching, including the siltation of river reservoirs, water pollution, serious and even lead to river flow interruption, inducing natural disasters. There are many reasons for this. Firstly, due to the increase of water storage area of the reservoir, the surrounding land is flooded, resulting in soil erosion. Secondly, the soil in the region is mainly yellow-brown soil, lime soil, etc. The soil texture is sticky and has poor permeability. And the surface layer is loose and thin, which is not resistant to drought and flood. Thus, it is easy to be eroded, resulting in soil erosion. Thirdly, the precipitation of Danjiangkou reservoir is more and more intensive in summer, which leads to more serious soil erosion in summer. Fourth, the mountainous valley in the west of Danjiangkou reservoir alternates with undulation, and the terrain gradient is large, which aggravates the occurrence of soil erosion to a certain extent[11,12].

4.2.3. Changes in vegetation area
As mentioned above, the vegetation area of Danjiangkou reservoir increased both after the middle route of SNWDP started construction and after its completion. The changes include the decrease of arable land area and the increase of woodland and grassland area. The reasons are manifold. One is the migration policy of the reservoir population, which has left the Danjiangkou reservoir area in large numbers. Another reason is the Chinese government's policy of returning farmland to forests. Returning cultivated land to forest means stopping the cultivation of sloping land which is easy to cause soil erosion in a planned and step-by-step manner. And then, people plant trees according to the principle of suitable trees and restore forest vegetation according to local conditions. The project of converting farmland to forest includes two aspects: one is converting slope farmland to the forest; the other is afforestation of waste mountains and wasteland. Danjiangkou City was included in the pilot cities of the National Program of returning farmland to the forest in 2001 and was officially included in the implementation of the National Program of returning farmland to the forest in 2002. During the nearly 20 years, the whole city has completed the return of farmland to the forest of 421,500 acres, among which 172,000 acres of farmland to forest and 249,500 acres of barren mountain afforestation[13]. This project improves the green environment and is conducive to the sustainable development of the middle route of SNWDP.

4.2.4. Biodiversity impacts
The construction of the middle route of SNWDP has changed the ecological pattern of Danjiangkou reservoir. First of all, the increase of the water storage area of the reservoir could change the zoning of vegetation. However, since vegetation is widely distributed and the inundated green space is not large, the type of vegetation does not have a great impact. Secondly, due to the increase of the storage area of the reservoir, the increase of nutrients in the water could benefit the survival of fish and other animals in the reservoir, and also provide sufficient food for animals that depend on fish, such as birds and other animals, which is of positive significance to the protection of biodiversity in Danjiangkou area. Thirdly, the implementation of the middle route of SNWDP has changed the local ecological pattern. Some plants and animals will be eliminated due to their inadaptability to the new ecological environment, while some plants and animals that can adapt can get a suitable development prospect[14].

Human water conservancy projects will inevitably destroy the original ecological environment, but fortunately, we have advanced scientific and technological guidance, which can reduce the damage to biodiversity to the maximum extent. At the same time, coupled with the good ability of animals to adapt
to the environment, biodiversity can be increased. The protection of biodiversity requires strict compliance with laws and regulations[15], and effective measures and alternatives to ensure the sustainable development of the Danjiangkou area.

4.3. Residents impacts of the middle route of SNWDP

According to this study, the sharp decline in the living area after 2013 is closely related to China's reservoir migration policy. Since the 1980s, the Chinese government has been experimenting with reservoir resettlement. About 382,000 people have left the Danjiangkou reservoir for new homes since the Danjiangkou reservoir was piloted in 2008 due to the construction of the middle route of SNWDP. A large decrease in population has also led to a decrease in the area of arable land and an increase in areas such as woodland and grassland. After emigration, the Chinese government has taken appropriate subsidies and guidance, including compensation for land acquisition and housing construction, to increase the income of the villagers who emigrate. At the same time, the government actively strengthens psychological counseling and language adaptation for immigrants, and most people are satisfied with the results of immigration. But there are also a series of problems in the process of immigration. Most notably, infrastructure has not been secured, especially in the case of railways, where only one railway can be used for transportation. Most migrants still use road transport, which reduces travel efficiency[16]. Meanwhile, for a small number of non-farming immigrants, they not only lose their jobs, but also find it difficult to get national security and subsidies. Their living conditions are not optimistic, which is also a problem that the local government needs to solve later[17].

4.4. Countermeasures

4.4.1. Appropriately adjust the scope of protected areas

Satellite images show that the east of Danjiangkou reservoir wetland is still surrounded by residential areas, roads and farmland[18]. These unexpected human activities are threatening the survival of the wetland, which affects the water quality in the middle route of SNWDP. These resettlement sites containing a large number of residents can no longer meet the standard of the conservation area, they could be transferred out of the conservation area. However, the fertile but ecologically fragile areas, such as new floodplains formed by water storage, meet the standard of the conservation area and should be protected, which could reduce the amount of pollution in the region of human activities.

4.4.2. Strengthen wetland ecological development

Nowadays, the ecological benefits brought by ecological vegetation restoration projects such as returning farmland to forest and closing mountains for afforestation are increasingly obvious[7]. The area of green plants is greatly increased and the ecological structure of the water source area is enhanced, but the fragile ecological structure of the water source region has not been completely reversed[18]. In addition to accelerating the construction process of vegetation restoration projects, wild animals in the protected areas also need to be protected[19]. Through the construction of animal rescue centers, animal rescue and breeding places, and the establishment of isolation zones, a good survival and reproduction environment for wild animals can be provided. At the same time, the control of invasive alien species should be strengthened[18-20].

4.4.3. Strengthen prevention and control of environmental pollution

First of all, the government needs to improve the level of ecological environment monitoring by establishing an ecological environment monitoring network which can master the characteristics, functions, values and dynamic changes of the wetland resources in Danjiang reservoir area[19][20]. Secondly, the government needs to reduce pollution from the source by building waste transfer stations, phasing out or renovating polluting enterprises in a planned and step-by-step manner, shutting down mineral exploitation, and banning industries with high water consumption and heavy pollution[6][18]. Most importantly, the government should adjust agricultural structure, improve agricultural production
conditions, vigorously develop ecological agriculture and popularize water-saving agriculture. In order to reduce the wetland pollution of agricultural production[18].

5. Conclusion
This study focuses on the changes in land use in the Danjiangkou reservoir wetland area from 1999 to 2020 and discusses the causes of its changes and its influence on the Danjiangkou reservoir wetland area.

The study used QGIS and satellite imagery to analyze the evolution of Danjiangkou Wetland from 1999 to 2020, and discussed the reasons for changes in wetlands and impacts of the SNWDP. From 1999 to 2020, the area of human and cultivated land decreased greatly, and the area of vegetated land, water area and increased on the whole. The area of human and cultivated land decreased 19.22% and 8.97% respectively in the whole study area. The area of water and vegetation increased 7.39% and 20.8% respectively in the whole study area. The causes of the change include natural conditions, engineering construction and policy. Danjiangkou dam heightening directly causes the increase of water area and the decrease of human area. Ecological protection policies such as returning farmland to forest lead to an increase in vegetation area.

As for the influence, the first influence is the deterioration of water quality caused by the middle route of SNWDP. The increase of the storage area of the reservoir leads to the inundated land of the reservoir, increasing nutrient elements in the water, leading to water pollution. The second is that the construction of reservoirs leads to serious soil erosion, which affects the normal flow of river channels and causes siltation. The third is that the construction of the reservoir changes the basic pattern of local land use, which is mainly reflected in the increase of water area, woodland area and the decrease of arable land area. The fourth is a change in this region's biodiversity. The last is that the residents have to emigrate due to the construction of the middle route of SNWDP, which has changed the residents' lifestyle and income pattern. In all, the middle route of SNWDP has a profound impact on the Danjiangkou reservoir area.

In order to solve the current Danjiangkou wetland environmental problems, it is necessary to appropriately adjust the scope of protected areas, strengthen ecological construction and reduce environmental pollution. In these countermeasures, appropriate adjustment of the protected area is the most important, which can not only fundamentally solve the damage of human activities to the wetland area, but also reduce the unnecessary waste in funds of environmental protection. Ecological construction such as wildlife rescue centers can speed up the ecological restoration of wetland areas. And reducing industrial and agricultural production pollution directly alleviates the ecological pressure in wetland areas.

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