Analysis of water yield changes in the Yellow River basin based on the INVEST model

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Abstract. As one of the most important ecological environments in northern China, the productivity of the Yellow River basin as well as the conservation of water resources is of vital importance. The study of water production mechanisms in the basin is important to maintain environmental and ecological harmony.Based on the understanding of spatial analysis, this study combined with the InVEST model to conduct water yield analysis of the Yellow River basin, using the measured data of precipitation, evapotranspiration, and land use types in the Yellow River basin for the four years 2005, 2010, 2015, and 2020, respectively, to summarize the factors affecting the water yield of the basin. The conclusions show that the total water yield of the Yellow River and its basin increased by 49.7 mm from 2005 to 2020, with high water yield concentrated in the western and southwestern parts of the basin and low water yield concentrated in the northwestern part. High water yield was found in areas with high precipitation intensity in the basin; the influence of grassland was the most significant, providing nearly 62.6% of the total water yield.

Keywords: The Yellow River and its watershed, Total water production, Changes in land use types, INVEST model, spatial analysis, precipitation, evapotranspiration.

1. Introduction

Since the release of the Millennium Ecosystem Assessment (MA) report, there has been a growing understanding of ecosystem services that are directly related to sustainable human development [1]. The InVEST model is an integrated assessment model of ecosystem services and trade-offs, developed jointly by several institutions. It enables the analysis of ecosystem services and the assessment of changes in their value according to different scenarios [2]. This makes the trade-offs between regional economic and social development and natural resource conservation more scientific and effective for policy formulation [3]. Therefore, this study combined InVEST with water yield analysis based on different geomorphological forms, different precipitation intensities, different evaporation intensities, and different root depths in the Yellow River basin to summarize the changes of water yield in the Yellow River basin and provide a basis for ecological environmental protection in the Yellow River basin.

2. Study area and data

2.1. Overview of the study area

In Northwest China, where the climate is generally arid and semi-arid, the Yellow River, a major river in the interior of Northwest China, in terms of water production plays a vital influence on the surrounding cities. The Yellow River originates from the Tibetan Plateau and flows from west to east through nine provinces (autonomous regions) before finally flowing into the Bohai Sea, with a total length of 5,464 km, a drop of 4,480 meters, and a total basin area of 795,000 km^2. It is the second longest river in China. Yellow River basin east-west drop, flowing through a wide range of landscapes, seasonal temperature differences, precipitation concentration, unequal distribution, inter-annual variation, between 400 ~ 600 mm, precipitation spatial distribution from southeast to northwest gradually decreasing, regional variation is significant, evaporation of about 1000 mm, high evaporation intensity.

2.2. Data source and processing

In this study, the factors affecting the water yield of the basin, such as evaporation, precipitation, land use type, and root depth, were analyzed and processed to calculate the water yield of the Yellow River basin using the four years of 2005, 2010, 2015, and 2020 as the study period. Precipitation and evaporation data were analyzed at a temporal resolution of 1 year, and land use type was removed after background values, raster mosaic, and the Yellow River basin was annually The data were reclassified to China and the first level of land use type classification. All the above data were cropped, projection transformed and resampled with a spatial resolution of 1000m. Multi-year precipitation and evapotranspiration data for the basin during the study were obtained from the National Earth Science Data Center.

3. Research Methodology

3.1. InVEST model

The analysis of water production is based on the InVEST model, which is based on water balance, assuming an annual average value of x for water production within each small raster in the basin[4], with the following equation:

$$W_u = 1 - AET_u/P_u \tag{1}$$

$$AET_u/P_u = (1 + w_u Y_u)/[1 + w_u Y_{uz} + (1/y_u)] \tag{2}$$

$$Y_u = (h_u \times ET_{0u})/P_u \tag{3}$$

$$w_u = Z \times (VWC_u/P_u) \tag{4}$$

$$VWC_u = Min(MSD_u, RD_u) \times PAWC_u \tag{5}$$

$$PAWC = 54.509 - 0.132 \times SG - 0.03 \times (SG)^2 - 0.55 \times SP - 0.006 \times (SP)^2 - 0.738 \times SC + 0.007 \times (SC)^2 - 2.688 \times C + 0.501 \times (C)^2 \tag{6}$$

where:W_u,AET_u ,$P_u$respectively, denote the average annual water production , the actual annual evapotranspiration and the annual precipitation of the grid u.$Y_u$is the dryness index of the grid u ,dimensionless; ET_{0u} is the potential evapotranspiration within the grid u ,using Modified-Hm2.argreaves formula to calculate [4].

The calculation formula is : $ET_0 = 0.0013 \times 0.408 \times RA \times (T_a + 17) \times (TD - 0.0123P)^{0.76}$,where RA is the total solar radiation intensity, T_a is the mean value of temperature in the basin; TD is the difference between the basin average T_{max} and T_{min} ; P_u is the annual precipitation of the raster u ; w_u is an empirical parameter to characterize climate and soil properties; VWC_u is the water content that can be used by the vegetation; Z is an empirical constant characterizing the distribution and depth of precipitation[5]; MSD_u a for maximum soil depth; RD_u for root depth; PAWCa Indicates the amount of water in the soil that is effective for plants; SG for soil sand particles;SP for soil powder particles;SC for soil clay particles;C is the content of soil organic carbon.Using the above equations and combining them with the InVEST model, it can

be concluded that actual precipitation and evapotranspiration are the main factors affecting the water yield of a watershed, while differences in vegetation cover and land use type mainly affect the evapotranspiration of a watershed.

3.2. Spatial auto-correlation

The water production capacity of watersheds differs between land use types because of the different properties of soils, such as soil water content, soil infiltration capacity, and crop water holding capacity. Studies have shown that the water production capacity of a land use type is inversely proportional to the evapotranspiration of vegetation on that type of land [6]. There is no vegetation on the construction land, so the evapotranspiration is lower and the water production capacity is higher; the surface evapotranspiration capacity of water bodies is higher, so the water production capacity of watersheds is lower. For the water yield of the watershed, this study used the analysis of spatial autocorrelation to integrate the relationship between water yield at different scales using spatial time as the variable (Figure 1)[7]. During the study period, we may observe that at the source of the Yellow River, its water yield is steadily the highest in the basin due to the constant recharge of snow and ice melt water, the higher vegetation cover and the lower evaporation.From 2005 to 2020, the average annual water yield of different utilization types of soils in the Yellow River watershed fluctuates, with paddy fields, dry land, forest land, low cover grassland and bare rock land showing an increasing trend, while forest land, construction land and watersheds show a change pattern of first increasing and then decreasing.

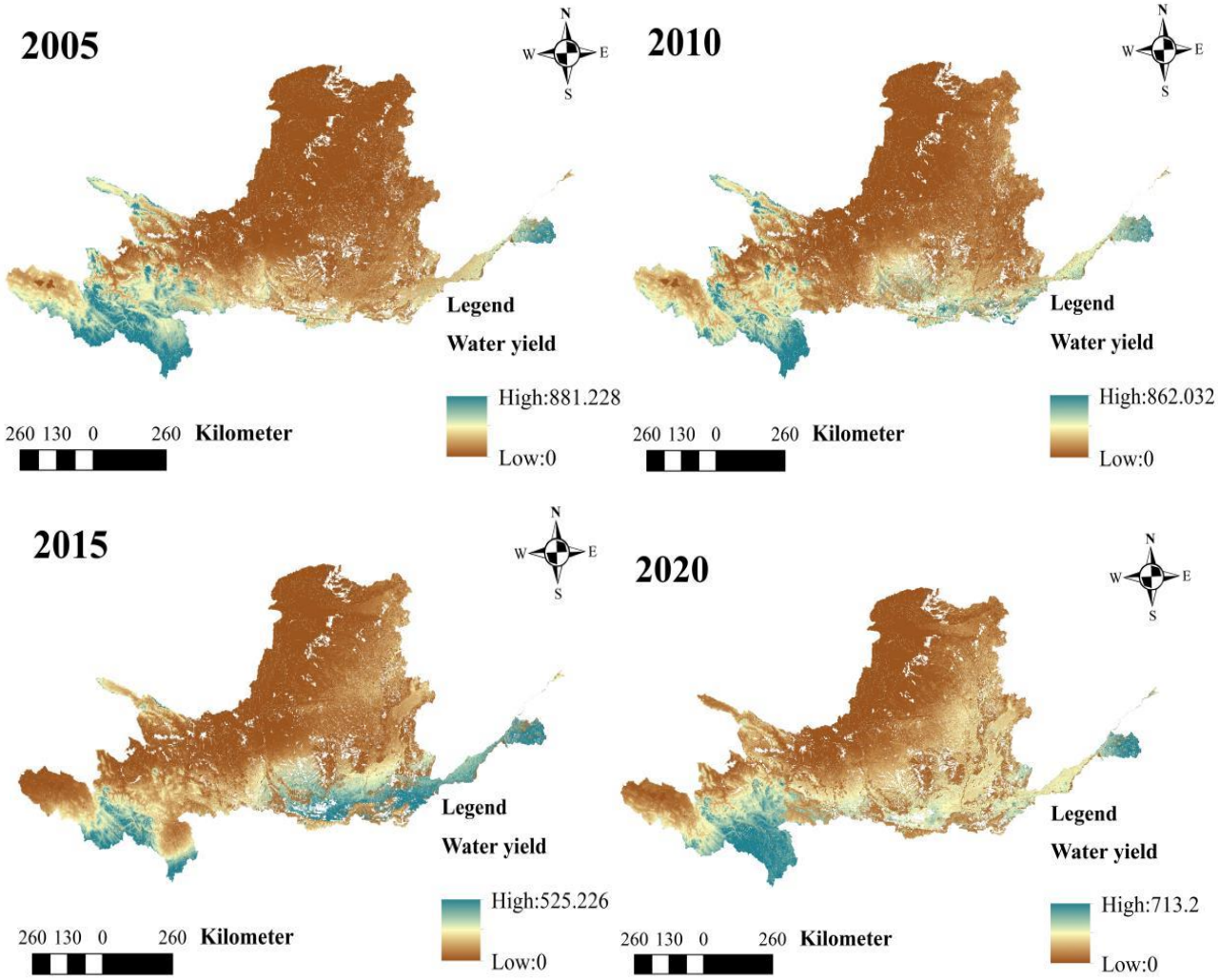


Figure 1. Spatial pattern of changes in water production in the Yellow River Basin in 2005, 2010, 2015 and 2020

4. Results and Discussion

4.1. Water production in the Yellow River basin

From 2005 to 2020, the water yield in the Yellow River basin ranged from 426 to 863 mm. the total water yield in 2005, 2010, 2015 and 2020 was 722, 575, 426 and 863 billion m^3, respectively,the water yield of the Yellow River basin shows a trend of a small decrease and then a large increase, and the water yield varies greatly in different periods, but in general, it shows a more consistent pattern, for example, the lower water yield of the basin is mainly in the northwest direction, and the higher water yield in the southwest and southeast.[8]. In 2005, the headwaters of the Yellow River basin were the areas with high water production, and the water production in the northern regions steadily increased, and by 2015, the Yellow River hinterland became the area with high values of water production, while at the same time, there was a significant decrease in water production in the source and downstream areas of the basin.This pattern is mainly due to the difference in average annual precipitation and the different types of soil use in the watershed, which is roughly summarized as follows: areas with high precipitation and low evaporation have a strong water production capacity; areas with low precipitation and high evapotranspiration have a weak water production capacity.From 2015 to 2020, the water production increases year by year, but shows irregular basin variation characteristics, with the source and middle basin of the Yellow River being the main growth points of water production, (in the first 10 years, the source and downstream of the Yellow River were the main sources), such that the incremental change in water production can form a contrast. During this study period, the water production in the middle basin continued to increase and gradually jumped to the highest in the basin, about 140 mm, while the downstream declined year by year, with the fastest decline in water production being at the mouth of the sea.

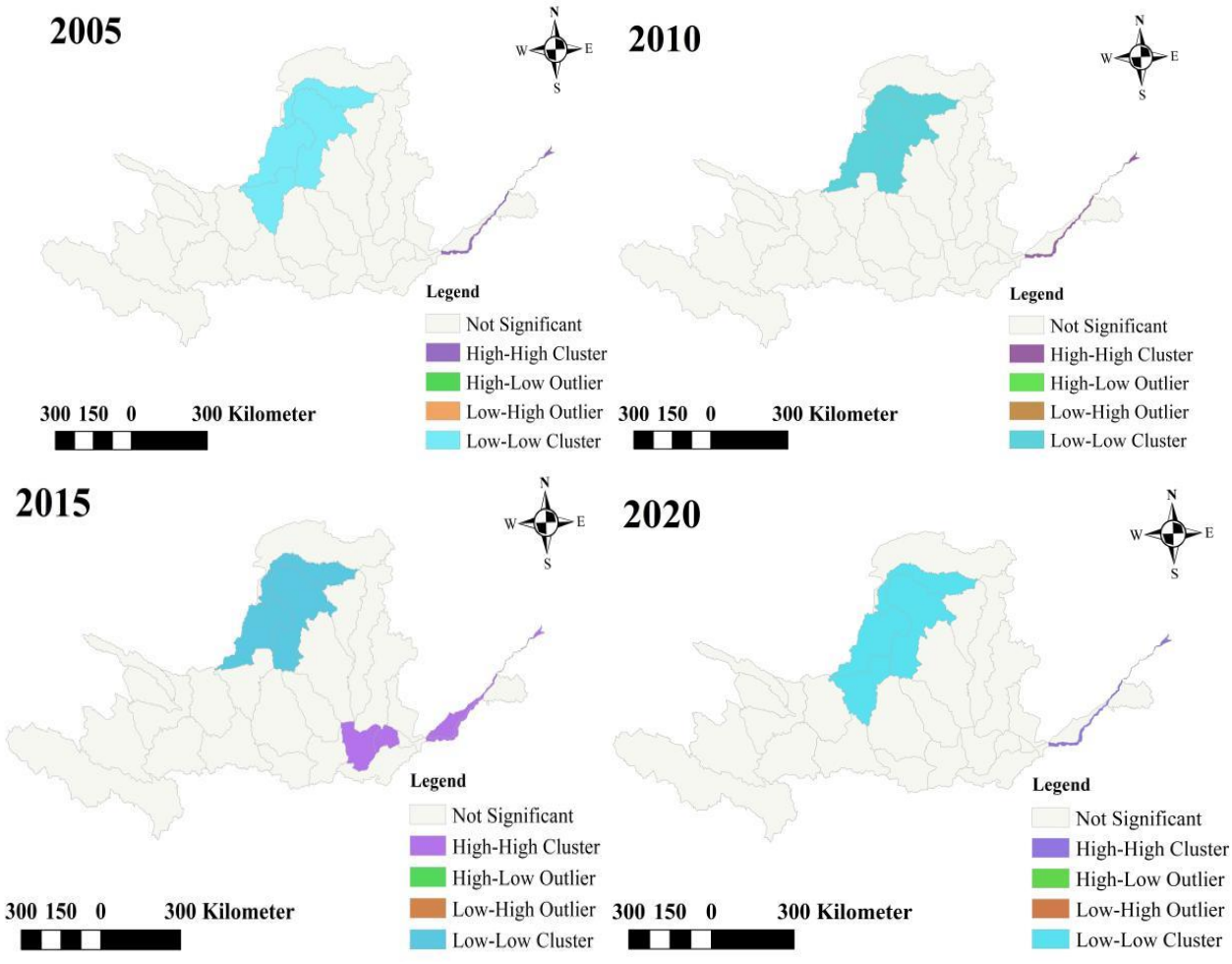


Figure 2. Spatial variation analysis of water production in the Yellow River Basin

4.2. Spatial and temporal patterns of water production in the Yellow River basin

The basin is the basic unit of water production. In the current research, based on the results of previous studies, we analyzed the water production patterns in each sub-basin[9].The relationship between sub-basins and to the whole basin was explored (Figure 2).The water yield in the first half of the basin area of the middle reaches of the Yellow River from 2005 to 2020 has been low and has not changed significantly. It is located on the Loess Plateau, with low vegetation cover, high evaporation, low precipitation and no tributary confluence, making it the driest area in the basin.The headwaters of the Yellow River and downstream near the mouth of the inlet are among the most productive areas of the basin.The source is recharged by snow and ice melt water, with high vegetation cover and low evaporation, and has the highest water production; the lower Yellow River estuary is an important water producing area because of its humid climate, high precipitation, high vegetation cover and high runoff [10]. Although the Yellow River basin has two sub-basins, the upper and lower reaches, which provide a large amount of water production, the dry climate, low precipitation and low vegetation cover of the areas through which the Yellow River flows have resulted in the average water production of the entire basin not being high, and there are even frequent problems of water shortage.

5. Conclusions

Based on the understanding of the water balance principles, this study analyzes the indicators for the Yellow River basin for the four years 2005, 2010, 2015 and 2015, taking into account the influence of different precipitation, different soils and different vegetation[11], as well as the integration of the InVEST water production model, leading to the following conclusions:1) The average annual water production of the Yellow River basin is 72.2, 57.5, 42.6 and 86.3 billion m^3 in 2005, 2010, 2015 and 2020, respectively. The trend of change is a slow decrease followed by a rapid increase.2) In the whole watershed, the different land use types also have some influence on the water production, according to the strength of the influence, it is roughly divided into: permanent glacial snow, arable land, grassland and construction land. There is a positive correlation between the above-mentioned land area and water production. In other words, the larger the area of arable land and grassland, the greater the water yield. The larger the area of forest land, water and construction land, the smaller the water yield, showing a negative correlation.3) The main land use type in the Yellow River Basin is grassland, which contributes significantly to the total water yield. Among all the factors affecting the magnitude of water production, precipitation is the most important influencing factor, while different soil types have less influence on the total water production.

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