Abstract

The Haihe River Basin is one of the most water scarce regions in China, in which natural vegetation plays an important role in the eco-hydrological process. In this study, the historical eco-hydrological evolution law of natural vegetation was studied in Haihe River Basin. Distributed hydrological model WEP and ecological model BIOME-BGC were applied to calculate changes of net primary product (NPP) and evapotranspiration (ET) of the basin in the last decades. The analysis demonstrated that the annual NPP increased slightly from 1980 to 2005 in the basin, mountain area and plain area, and the main impacting factor is the climate situation rather than land use change. The ET of forest, grass and wetland all decreased from 1956 to 2005 in the basin, mountain area and plain area.

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1. Introduction

Natural vegetation plays an important role in the earth system through interactions between atmosphere, soil and hydrological cycling[1]. The Haihe River Basin is one of the most water scarce regions in China as well as in the world. The natural vegetation is under great threat of drought and human activity. Therefore, it is necessary to find out the history eco-hydrological evolution law of natural vegetation in Haihe River basin for the ecosystem protection and water resources management. In this paper, distributed hydrological model WEP and ecological model BIOME-BGC were applied to study the eco-hydrological evolution law of natural vegetation in Haihe River Basin. The historical changes of net primary product (NPP) and evapotranspiration (ET) of the basin is calculated and analyzed to demonstrate the spatial and temporal evolution law.
2. Methods and modeling

2.1. WEP-L model

The distributed hydrological model WEP-L (Water and Energy transfer Process in Large river basins) was developed from the WEP model[2,3]. The WEP-L model has the following features: (1) realizes coupling simulation between water cycle and energy transfer process; (2) with “contour band within sub-basin” as calculation cell, considering diversity of land cover within the cell by means of a “mosaic” method, describes spatial variation of hydrological variables rationally; (3) simulates by adopting “varied time intervals” for each element of hydro-cycle to ensure rational description of dynamic mechanism and efficient calculation.

2.2. BIOME-BGC model

BIOME–BGC is a process-based geobiochemistry model developed by Numeric TerraDynamic Simulation Group (NTSG) of Montana University in the USA [4]. This model can simulate daily states and fluxes of carbon, water, and nitrogen of ecosystem ranging from 1 m² to globe. The BIOME-BGC model can calculate and output information of plant growth and carbon cycle, such as annual maximum leave area index (LAI, m²/m²), annual evaportransporation (mm), and annual net primary product (NPP, gC/m²/a)[5].

2.3. Model improvement and coupling

The BIOME-BGC model is a point simulation model and not suitable for application in large basins. So the main program of the model was rewritten to realize multi-unit simulation. BIOME-BGC shared the same calculation units with the WEP-L model (the sub-basins). Considering the variation of land use and plant types, “mosaic” was used which is categorizing land into several types in which simulation is carried out and the average outputs of every unit is calculated by areas. In the simulation process, BIOME-BGC model would provide ecological parameters such as LAI, while WEP-L model would provide the point information. BIOME-BGC model simulates the planting of grass and forest in every unit, and then transforms the outputs to WEP-L to reflect the influence of ecosystem to hydrological process.

3. Application and discussion

3.1. Introduction to the Haihe River basin

The area of Haihe River basin is 317 800 km², of which 189 000 km² is mountainous and the remainder is plain. The Hai River starts from the western Taihang Mountains and reaches the eastern Bohai Sea. The basin is located between 35°~43°N and 112°~120°E, which belongs to the warm temperate zone with a semi-humid and semi-arid climate. The average annual precipitation is 548 mm, about 80% of which falls during June–September.

3.2. Model construction and verification.

The input data include the following categories: (1) hydro-meteorology; (2) land cover information including land use, vegetation, soil and water conservation, crop patterns, etc.; (3) topography, soil and
hydrogeology; (4) river networks, river sections and hydraulic structures (dams/reservoirs); and (5) water use and social-economy [5]; and (6) CO₂ concentration.

The natural vegetation was simulated from 1956 to 2005 by the model. The daily vegetation parameters such as LAI, NPP, gross primary product (GPP) and net ecosystem product (NEP) were calculated. Because the measuring NPP in such large area is difficult, the NPP of forest and grass were verified by literature values of other research. Liu et al. [6] has simulated the ecosystem of the North China Plain. Zhu et al. [7] and Piao et al. [8] have simulated the NPP of China by the remote sensing data and CAVA model. After comparing the results of this simulation and other literature values, it demonstrates that this result is close to the literature values. The simulated annual NPP of forest is 275.3 gC/m²/a, which is similar to the result of Zhu et al(367.1), and in the range of the result of Liu et al(271-560) and Piao et al(250–450). the simulated NPP of grass is 90.6 gC/m²/a, which is a little lower than the results of Liu et al(97–278), Zhu et al(226.2) and Piao et al (120–180). The verification rules of runoff content: (a) minimum annual runoff errors, (b) maximum Nash–Sutcliffe index. The runoff verification is based on the monthly runoff observation data of main hydrological stations from 1956 to 2005. The verification results are shown in Fig. 1.

Fig. 1 Runoff simulation of the main station in the Haihe River basin

The annual natural vegetation NPP change trends of the Haihe River Basin were got by analyzing the annual NPP of the basin. The trend shows the annual natural vegetation NPP fluctuated under the impacts
of land cover and climate change from 1980 to 2005 (Fig. 2), which range is between $0.025 \text{ PgC·a}^{-1}$ ($\text{Pg}=10^{15}\text{g}$) and $0.035 \text{ PgC·a}^{-1}$. The annual natural vegetation NPP is increasing slightly in these 26 years, which increasing rate is $8 \times 10^{-5} \text{ PgC·a}^{-1}$.

The annual NPP of natural vegetation in each WRA3 (the third level national water resources assessment sub-basin in China) were calculated and the annual NPP of natural vegetation in mountain area and plain area of the basin were calculated by added up corresponding WRA3. According to the results, the annual NPP of natural vegetation in the mountain area is increasing slightly (about $8 \times 10^{-5} \text{ PgC·a}^{-1}$) (Fig. 2), which change range is between $0.02 \text{ PgC·a}^{-1}$ and $0.03 \text{ PgC·a}^{-1}$. The annual NPP of natural vegetation in plain area also increased in very slight rate (about $2 \times 10^{-5} \text{ PgC·a}^{-1}$) (Fig. 2), which fluctuated around $0.005 \text{ PgC·a}^{-1}$.

![Fig. 2 The annual NPP change trends of natural vegetation in the Haihe River Basin from 1980 to 2005](image)

In order to analysis the reason of NPP change, two scenarios were set. Scenario one: the land use kept the same as that of 1980. Scenario two: the meteorological data kept the same as that of 1980. Under these two scenarios, the annual NPP of natural vegetation were calculated and compared with the simulation result above.

Scenario one: By keeping the land use the same as that of 1980, the annual NPP of natural vegetation in the basin is calculated to analyze the climate impact. The annual NPP fluctuated under the impacts of climate, which is between $0.025 \text{ PgC·a}^{-1}$ and $0.035 \text{ PgC·a}^{-1}$ (Fig. 3). The calculated NPP is increasing slightly from 1980 to 2005, which increasing rate is $8 \times 10^{-5} \text{ PgC·a}^{-1}$. The annual NPP of natural vegetation in mountain area and plain area of the basin is also calculated. The annual NPP of natural vegetation in mountain area and plain area were both increasing slightly (Fig. 3A), which increasing rate is $8 \times 10^{-5} \text{ PgC·a}^{-1}$ and $2 \times 10^{-5} \text{ PgC·a}^{-1}$. According to the analysis above, the annual NPP change trends of natural vegetation in the whole basin, mountain area and plain area under the same land use are similar with the history simulation above.
Scenario two: By keeping the meteorological data the same as that of 1980, the annual NPP of natural vegetation in the basin were calculated to analysis impact of land use change. The results showed that the change of NPP is linear. From 1980 to 2005, the annual NPP is around 0.035 PgC·a$^{-1}$ and increases at the rate of 5×10$^{-6}$ PgC·a$^{-1}$ (Fig. 3B). The annual NPP of natural vegetation in the mountain area and plain area of the basin were calculated. The annual NPP of natural vegetation in the mountain area is around 0.032 PgC·a$^{-1}$ and decrease at the rate of 5×10$^{-6}$ PgC·a$^{-1}$ (Fig. 3B). However, the annual NPP of natural vegetation in the plain area is around 0.005 PgC·a$^{-1}$ and increase at the rate of 5×10$^{-6}$ PgC·a$^{-1}$ (Fig. 3B). According to the analysis above, the annual NPP of natural vegetation in the basin change little under the same meteorological situation.

From the above, the annual NPP of natural vegetation in the Haihe River Basin, the mountain area and the plain area are all increasing slightly from 1980-2005. According to the analysis, the change is impacted by the climate situation more rather than land use.
3.3. Changes of natural vegetation evapotranspiration.

The ET (evapotranspiration) of the forest, grass and wetland of the Haihe River Basin from 1956 to 2005 were calculated by adding up the ET of each type in each unit. According to the calculation results, the ET of the forest land is decreasing in these 50 years at the rate of 0.76 mm·a⁻¹ (Fig. 4A). The ET of the forest in mountain and plain area changed at the similar trend of the whole basin.

![Graph A](image1)

![Graph B](image2)

![Graph C](image3)

Fig. 4 The evapotranspiration change trends of forest (A), grass (B) and wetland (C) in the Haihe River Basin from 1956 to 2005.
The ET of the grass in Haihe River Basin decreased from 1956-2005 at the rate of 0.86mm·a⁻¹ (Fig. 4B). The ET of the grass in mountain area is a little larger than that in plain area (Fig. 4B). The change trends of the mountain and plain is similar with the whole basin (Fig. 4B).

The ET of the wetland in Haihe River Basin decreased from 1956 to 2005 at the rate of 0.81mm·a⁻¹ (Fig. 4C). The ET of wetland in mountain area is a little larger than that in plain area. The decreasing rate in mountain area is less than that of the whole basin, which is 0.69 mm·a⁻¹ (Fig. 4C). And the decreasing rate in plain is similar to the whole basin, which is 0.82mm·a⁻¹ (Fig. 4C).

4. Conclusion

This paper worked on the eco-hydrological revolution law of natural vegetation in Haihe River Basin. The ecological model BIOME-BGC and distributed hydrological model WEP were constructed and coupled in this study. After the model verification, the NPP and ET results of the basin, mountain area and plain area were calculated and analyzed. The analysis demonstrated that the annual NPP increased slightly from 1980 to 2005 in the basin, mountain area and plain area. After the analysis of set scenarios, the main impacting factor is the climate situation rather than land use change. The ET of forest, grass and wetland all decreased from 1956 to 2005 in the basin, mountain area and plain area.

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References