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Quantitative analysis on the ecological impact of large-scale water transfer project on water resource area in a changing environment

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Abstract

The interbasin long-distance water transfer project is a key support for the reasonable allocation of water resources in a large-scale area, which can optimize the spatiotemporal change of water resources to reinforce the guarantee of the access of water resources. And large-scale water transfer projects have a deep influence on ecosystems; besides, global climate change causes the uncertainty and additive effect of the ecological impact of water transfer projects. Therefore, how to assess the ecological and environmental impact of large-scale water transfer projects in both construction and operation has triggered a lot of attention. The water-output area of the western route of China's South-North Water Transfer Project was taken as the study area of the present article. According to relevant evaluation principles and on the basis of background analysis on the eco-environment of the study area, the influence factors were identified and evaluation indexes were established. The climate-hydrology-ecology coupled simulation model was used to imitate the laws of ecological and environmental change of the water resource area in a changing climate. The emphasis of influence analysis and quantitative evaluation was placed on the reservoir construction and operation scheduling, representative river corridors and wetlands, natural reserves and the water environment of river basins below the dam sites. In the end, an overall influence evaluation of the impact of the project on the water circulation and ecological evolution of the water resource area was conducted. The research results were as follows: the environmental impacts of the western route project in the water resource area were concentrated on two aspects, i.e. the permanent destruction of vegetation during the phase of dam construction and river impoundment, and the significant influence on the hydrological situation of natural river corridor after the implementation of water transfer. Its impact on local climate, vegetation ecology, typical wetlands, natural reserves and the water environment of river basins below the dam sites was small.

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1 Introduction

With the increase of the world's population, the rapid development of agriculture and industry and the increasing urbanization, the uneven spatiotemporal distribution of water resource and its quality deteriorate. To cope with the serious limitation of water resource to economic development, many countries have undertaken water transfer projects. From 1940 to 1980, the world witnessed the peak period of the construction of large-scale long-distance interbasin water transfer projects (Yang, 2003; Wang, 2009). After 1980, with the uprising consciousness of environmental protection, people became cautious of the construction of water transfer projects and a series of reports concerning the negative ecological impacts of both construction and operation of these projects (Davies et al., 1992; Meador, 1992; Nardini, 1997) came out. Since then, countries all over the world began to conduct ecological influence evaluation on water transfer projects, and carry out thorough researches on environmental problems and ecological influence caused by those projects (Graf, 2006; Morais, 2008; Braatne et al., 2008; Kittinger et al., 2009; Baran and Myschowoda, 2009; Growns et al., 2009; Wu et al., 2010; Olden and Naiman, 2010). At the same time, laws and regulations specialized in the construction and the operation of water transfer projects were published so as to mitigate and even prevent the ecological and environmental problems (Yang, 2003; Wang, 2009). Besides, studies on evaluation of ecological and environmental influence of water transfer projects have gradually developed into an important field (Doledec, 1996; Bombino et al., 2006; Shah and Kumar, 2008). Meanwhile, accompanied by the aggravation of the global climate change, the evaluation concerning the ecological influence of the water transfer project in a changing environment has become increasingly valued, and a few studies in this field were carried out (Zeilhofer and Moura, 2009; Olden and Naiman, 2010; Doll and Zhang, 2010; Moiwo et al., 2010; Pittock and Finlayson, 2011).

Oversize water transfer projects, especially those which cross rivers and are of long distance, are all huge systematic projects. They have a large span of space and time

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and therefore impose a broad array of impacts on the ecosystems of a river basin (Petts, 1984; Casado et al., 1989; Poff et al., 1997; Rosenberg et al., 1997; Friedl and Wüest, 2002; Brismar, 2004; Burke et al., 2009). What's more, the environmental and ecological influence of project under the background of global climate change is extremely complex, thus there is considerable uncertainty. Present relevant studies are short of global, comprehensive and systematic research as they are focused on a certain aspect of the ecological influence, such as the hydrological situation, pollutant transport patterns and biodiversity (Morais, 2008; Hu et al., 2008; Koutsos et al., 2010; Ouyang et al., 2011), or they are targeted at a certain area, such as the water-output area, water-intake area and the river delta (Xu et al., 2011; Ligon et al., 2011; Restrepo and Cantera, 2011). And the climate change aspect has been inadequately treated in the environmental impact assessment of large water transfer projects. Judging from the experiences of existing water transfer projects, the estimation of their impact on ecology and environment is insufficient, and the negative influence of projects in the phase of operation is becoming increasingly significant. The western route of China's South-North Water Transfer Project (SNWTP) locates its water-output area in the Qinghai-Tibet Plateau, which is the sensitive area of global climate change. Therefore, studies of the ecological influence evaluation of this area are of great importance and have triggered a lot of concerns (Yang et al., 2002; Berkoff, 2003; Ghassemi and White, 2006).

In the present article, some explorations of the evaluation of the ecological influence of the western route project on its water-output area in a changing climate are conducted. This study aims to contributing to show how, and to what extent, the western route project of SNWTP will impact on ecology and environment in water resource area and regions related to water transfer. The specific objectives of this paper are to (1) evaluate the influence of the reservoir construction on the local climate of the water resource area; (2) evaluate the influence of water transfer on the hydrological situation of typical water-reduction river reaches; (3) evaluate the influence of water transfer on typical wetlands and natural reserves; and (4) evaluate the influence of water transfer

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on water environment below the dam sites. The quantitative assessment of the four aspects above are based upon a simulation and forecast platform which will be introduced in Sect. 2.5. However, for saving space, the assessment results other than the model itself are focused on in this article.

2 Materials and methods

2.1 Study area

The first-stage of western route project of SNWTP is located at the southeast edge of the Qinghai-Tibet Plateau, with the geographic coordinates of Latitude 99°20′–102°10′ E and Longitude 31°30′–33°20′ N. It covers seven counties in three provinces, i.e. Banma County in Guoluo Tibetan autonomous prefecture of Qinghai Province, Dege, Ganzi, Seda county of Ganzi Tibetan autonomous prefecture in Sichuan Province, Rangtang and Aba County of Aba Tibetan and Qiang autonomous prefecture in Sichuan Province and Maqu County of Gannan Tibetan autonomous prefecture in Gansu Province. The dam sites of water transfer are located in Ganzi section at the upper reaches of the Yalong River's mainstream, in Daqu and Niqu section of the upper reaches of the Xianshuihe River, a branch of the Yalong River, in Sequ and Duke section of the upper reaches of Chuosijia River, the west branch of the Dadu River, and in Marke and Ake section of the upper reaches of Zumuzu River, the east branch of Dadu River. Seven water transfer reservoirs are scheduled to be constructed, which are: Reba, Aan, Renda, Luoruo, Zhuanda, Huona and Keke. Figure 1 shows the arrangement of the western route project.

The water-output area of the western route project is an ecologically fragile region as well as the ecological shield of the upper stream of Yangtze River. It is probable that the construction and running of the project would impose an influence of various degrees on the eco-environment and society and economy of this area. To carry out an objective eco-environmental evaluation of the western route project on the area in a

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changing climate is of great significance for putting forward a scientific and systematic hydrological control plan so as to give reasonable guidance to the planning, construction and operation of the project.

2.2 Main considerations and the focus of the evaluation

According to the characteristics of large-scale water transfer projects, the present article attaches special importance to the correlation and superimposed influence between projects and the interrelation among all kinds of ecological factors in the process of evaluation. In view of the strategic level, the construction and operation of the whole water transfer project is integrated in the evaluation system.

First of all, background analysis on the eco-environment of the study area is conducted based on existing meteorological, hydrological, soil and vegetation information and the data collected by field survey. And the influence identification and evaluation indexes are determined based on relevant evaluation criterions. Then, based on the eco-environmental evolution laws of the water resource area in a changing environment imitated by the climate-hydrology-ecology coupled simulation model, the influence analysis and quantitative evaluation, the emphasis of which are the reservoir construction and operation scheduling, typical river corridors, typical wetlands, natural reserves and the water environment of river basins below the dam sites, are performed. In the end, a comprehensive influence assessment on the ecological evolution of the water resource area is conducted. The evaluation covers five aspects: (1) influence on the local climate and vegetation; (2) influence on typical river corridors and hydrological situation; (3) influence on wetlands; (4) influence on the climate and hydrology of natural reserves; and (5) influence on the water environment of typical river basins below the dam sites.

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2.3 Evaluation index system

Firstly, the present article employs 8 primary indexes and 137 secondary indexes of geography, atmosphere, hydrology, soil, biology, population and economy, natural disaster and soil deterioration in order to give a comprehensive and objective characterization of the ecological environment of the upper stream of Yangtze River. And a ladder model is built to form a general indicator system. Then, the 1–9 scale method in analytic hierarchy process is employed to mark the importance of the indexes and build the structural judgment matrix for the possible influence of the western route project on the environment. Five primary indexes are chosen by analytic hierarchy process, which are atmosphere, water, creature, soil, natural disaster and soil deterioration. And 32 indexes based on the five primary indexes are determined to form the indicator system of the ecological evolution of the western route project area. In the end, direct relevant indexes chosen from the indicator system are used to determine the ecological evolution laws in the water resource area and the influence of water transfer on the ecological environment of the area. And through further selection by taking into account the importance of all indexes and their relation with the water transfer project, as well as the accessibility of the information, 4 primary indexes and 8 secondary indexes, as shown in Table 1, are determined to act as the diagnostic indexes of the ecological evolution of the western route project. These indexes can give about 70 % information of the target level, which can basically meet the demand of the eco-environmental diagnosis of the water resource area of the western route project. Furthermore, relevant indexes aiming at different typical areas for evaluation, are chosen from the above-mentioned 8 diagnostic indexes and used to give quantitative analysis of the influence of water transfer project on the eco-environment in all typical areas.

2.4 Evaluation scope

Taking into account the particular geographical location and ecological characteristics of the western route of SNWTP, the influence of the western route project on the water

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resource area can be divided into three categories, (i) large-scale area oriented to global change (Category I area), i.e. the Southeast Asia; (ii) medium-scale area oriented to local water resources allocation (Category II area), i.e. the Yangtze river basin above Yibin; and (iii) the apparent influence area (Category III area), which includes water catchment above the dam site (Category III-A area) and typical water-reduction river section below the dam site (Category III-B area). In addition, since the project is located in a sensitive area to climate change, the area of climate change imposed by the project including some areas belonging to Category III should be included (Category III-C area).

Therefore, the present article gives evaluation on the following three scales: Southeast Asia, Yangtze River Basin above Yibin and the area of important influence (see Fig. 3). On the Southeast Asia scale, the main consideration is put to the impact of global climate change on the local environment and the influence of changes in the underlying surface on the climate change; on the scale of Yangtze River Basin above Yibin, the emphasis of evaluation is placed on the influence of climate change on local water circle and vegetation, the role of local underlying surface change in the climate change and the influence of water transfer on the local water circulation and ecological environment; on the scale of the area of important influence, the evaluation is focused on the influence of climate change and project construction on the typical water-reduction river reaches (river corridors) below the dam sites and the water storage area above the dam sites.

2.5 Key supporting technology: climate-hydrology-ecology coupled simulation platform

To identify the influence of the western route project of SNWTP on the eco-environment of the water resource area is the premise of the planning and design of the project, as well as the focus of arguments of stakeholders. And meanwhile, prevision of the changes on the water circulation and the ecology and environment of the related area is the key to the forecast of transferable water amount in the process of operation scheduling of the project, which directly affects efficiency and service condition of the project. The key technical supports for the two practical needs mentioned above require the development of a climate-hydrology-ecology coupled simulation model and a forecast platform with unified mechanism based on the multilayer observation on hydrology, meteorology/climate and ecology. The simulation platform should possess the following functions: (1) it can give historical analogue simulation and forecast on the water circulation, ecology and environment of the water resource area; (2) it can identify the main mechanism of mutual action among climate, hydrology and ecology; (3) it can objectively characterize the key driving mechanism in the water circulation and ecological and environmental evolutions; and (4) it can simulate the changes in water circulation, eco-environmental evolutions in a comprehensive regulation context.

Under the demand of practical needs, we firstly clarify the mechanism of mutual action among energy flow, natural-social water circulation, and ecological process (with the carbon circulation as the main line). Then, by giving full play to the simulation advantages of each model (Table 2), and under the guidance of the framework of climate-hydrology-ecology coupled simulation (Fig. 4), the modeling is performed using modular technology. In the end, the coupled simulation platform was developed with a unified physical mechanism.

Verification of the model in terms of multiple process and scale is listed in Table 3. From the verification result, it can be seen that the model can meet the demand of the quantitative evaluation of the influence of the western route project on local ecology and environment.

3 Results and discussion

3.1 Quantitative evaluation on the climate of the water resource area

Based on Regional Climate Model, a study on the influence of the reservoir construction on the local climate of the water resource area was conducted by setting up two

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scenarios of underlying surface with or without the reservoir. Four sets of experiments were set up: the control experiment A (current climate without the reservoir), contrast experiment B (current climate with the reservoir), contrast experiment C (future climate without the reservoir) and contrast experiment D (future climate with the reservoir). The horizontal resolution of the mode was 30 km and the modeling was carried out in two separate periods: situation of historical climate (1993–2002) and situation of future climate (2040–2049). The results of the experiments indicated the following conclusion: the construction of the reservoir had little influence on the wind speed, humidity and temperature, which means that the climatic field of the water resource area will not undergo significant change in the future. However, local rainfall will increase to some degree. The results are specified as follows:

1. *Influence of the reservoir construction on the local energy process of the water resource area.*

   In historical climate background, the reservoir construction increases the wind speed in summer, autumn and winter by 0.3–0.8 m s^{-1}. The wind speed in spring is hardly affected. In future climate scenario, the influence on wind speed is insignificant, while the influence on the humidity field at the location of 2 m is significant, which is reflected by the decrease of humidity in the northwest and increase in the Sichuan region in the east.

   In historical climate background, the reservoir construction has no influence on the spatial distribution of local average temperature. The temporal change of temperature is as follows: after the construction of the reservoir, the temperature in spring, autumn and winter increases, and that in winter, with an annual increase of 0.15°, is the most significant. In future climate scenario, the project has some influence on the spatial distribution of local temperature: the low temperature area in the northwest of the water resource area decreases while the central value of the high temperature area in Chengdu Plain in the east increases. In terms of the seasonal distribution, it has been observed that, after the construction of

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the reservoir, the local temperature will rise in summer and winter and slightly decreases in spring and autumn. It increases by approximately 0.28° in winter.

2. *Influence of the reservoir construction on the local water circulation.*

   In general, the average annual rainfall of the reservoir area tends to increase. In the future climate scenario, the average annual rainfall increases by about 22 mm. In terms of the seasonal distribution of rainfall, rainfall tends to decrease in winter, spring and autumn, and that in spring, with a decrease of 19 %, is the most significant. Rainfall in summer increases by about 7 %.

3.2 Quantitative evaluation on typical water-reduction river reaches

3.2.1 Influence on the water amount of downstream river reaches

According to the diversion plan of 8 billion m^3 water in the first-stage of the western route project, the channel flow of the downstream section will significantly decrease after the construction of water transfer reservoir is completed. Combined with the monthly distribution of discharged water flow after the reservoir water transfer, the main stream of the Yalong River suffered from the impact to the most extent in June, and the discharged flow of Reba reservoir in June accounted for only 11.0 % of the mean monthly flow for many years; the Xianshui River system also suffered from the most significant influence of the water transfer project in June, and the discharged flow of Aan and Renda reservoirs in June, compared with the mean monthly flow for many years, decreased by 88.1 % and 89.6 %, respectively; the Sequ River of Chuosijia River system, where the Luoruo reservoir is located, was most influenced by the water transfer project in October, with its mean monthly flow decreased by 83.6 %; the Dukehe River, where Zhuanda reservoir is located, was most influenced by the water transfer project in June, with the mean monthly flow of the downstream reach below the dam site decreased by 92.1 %; and the Zumuzu River system was most influenced by the water transfer project in May.

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With the convergence of water flow from the dam cross-section to the river delta, the ration that the flow of control cross-sections at the lower reaches takes in the total flow for many years tends to recover gradually after the water transfer. The cross-section flow at Lianghekou of Yalong River after the water transfer can be restored to 55.2 % of that before the water transfer; and cross-section flow at river delta of Xianshui River, Chuosijia River and Zumuzu River after the water transfer can be restored to 76.6 %–86.3 % of that before the water transfer.

3.2.2 Influence on river hydraulics indexes

After the construction of reservoirs, with the decrease of the downstream channel flow as well as the corresponding decrease of water depth, flow speed, water surface width and surface area of the water-reduction river reaches (see Fig. 5), the water ecology within the river course might be influenced. Meanwhile, with the increase of the catchment area below the dam sites, the quantity of water flowing into the water-reduction river reaches rises, which means the impact of the water transfer on river hydraulics indexes is decreasing. The water transfer has significant influence on the hydrological process of flood season, which is mainly reflected by the decrease in both flow and frequency of flood peaks. While with the increase of water catchment area and water inflow, the influence of the water transfer on the hydrologic process of river is gradually weakened. In both dry season and wet season, with the remarkable decrease of the downstream flow below the dam sites, the flow speed, water depth and water surface width at cross-sections of river will significantly decrease.

3.3 Quantitative evaluation of the influence on typical wetlands

The dam construction for water intake has no influence on wetlands below the dam site, while its influence on those above the dam site is uncertain. After the water storage with the dam construction begins, the water level goes up and the river cross-section is widened in the river reachs belonging to the backwater area of reservoir, which might

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cause changes in the groundwater recharge relationship between the river flow and riverside wetlands: the situation of wetlands supplying the river bed could be turned into the opposite. At the same time, the flooding effect above the dam site is enhanced, thus the flooding wetland area is increased and even new wetland is formed, which increases the wetland area above the dam site. Based on theoretical analysis and model calculation, the evaluation of the western route project on wetlands is listed in Table 4. In order to give a reasonable evaluation of the influence of this project on both ecology and environment, the evolution trend of wetland landscape pattern in future climate scenario with or without the western route project is analyzed (Table 5).

3.4 Quantitative evaluation of the influence on natural reserves

The influence of the western route project on natural reserves lies in the impact of both the change of water quantity and the submergence of the reservoir area caused by the water transfer on the forest vegetation, the ecosystem below the dam site and the biodiversity of the water resource area.

In detail, after the water storage of reservoir begins, it is estimated that 1651 hectares of forest land and 2561 hectares of shrub forest land will be submerged, which could lead to the destruction on wild animals, plateau rare medicinal resources and wild fungus resources. In addition, fish migration route is blocked by dam and the rise of water level will lead to the submergence of the torrent habitats and spawning places required by some fish, all of which will exert adverse effect on the biodiversity. Besides, with the increase of the reservoir wetland area, new eco-hydrological patterns of wetland will be formed to provide new habitats for species. Waterfowls and wading birds will increase in population, which increases the biodiversity to some degree. After the water storage begins, the discharge flow below the dam site will be significantly reduced, which leads to the decrease of available water in such natural reserves as Xialatuo Area in Luhuo county and Kasha Lake. But the water available in these two zones can basically satisfy their need and no major damage will be caused. The comprehensive evaluation of the influence of the western route project on natural reserves is listed in Table 6.

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3.5 Quantitative evaluation of the influence on water environment below the dam sites

3.5.1 Quantitative analysis of the influence on the water quality of main river reaches below the dam sites

For the Ake River section, in the three target years after the water transfer, BOD_5 can meet the standard I, and COD_{Mn} and NH_3-N can meet the standard II, with annual average flow and without consideration of pollution control. Compared to the situation before the water transfer, the estimated change is minor. In February of dry season, water quality above and below Aba County on Ake River is different. With consideration of pollution control, all estimation indexes show significant improvement compared to that without consideration of pollution control. Under the context of annual average flow, in the three target years after the water transfer, the BOD_5 of Ake River can meet the standard I, and its COD_{Mn} and NH_3-N can meet the standard II. In February of dry season, except that the BOD_5 of Ake County section in 2020 and 2030 slightly exceed the standard II (in line with the standard III), under other conditions, its BOD_5 can meet standard I, and its COD_{Mn} and NH_3-N can meet the standard II. The results indicated that, with effective pollution control, the water quality of the county town can rise by 1 to 2 levels. Water environment quality evaluation of Ake River section under different situations and in different target years is listed in Table 7.

For other river reaches, even without pollution control, the water quality of other seven rivers in the three target years after the water transfer can still meet Standard II, with no change in categories of water quality compared to the situation before the water transfer.

After the water transfer, the ammonia nitrogen concentration of various river reaches at the initial stage of the raining season, compared to that before the water transfer, significantly decreases by 27 %–41 %. This is mainly caused by the purification effect of the water transfer reservoirs at the upper reaches. Even though the ammonia concentration after the water transfer still exceeds the classification demand of Standard II (the standard limit value of which is 0.5 mg l^{-1}), the purification effect of the reservoir tends to reduce the ammonia pollution in the river reaches below the dam site at the initial stage of raining season, and the water quality is significantly enhanced.

3.5.2 Capacity influence analysis and sensitivity analysis on the environment of the cross-section at the county town

After the water transfer, water inflow from the upper stream is reduced; hence the environment capacity of COD_{Mn}, NH_3-N at different control sections is reduced by 13 %–32 %. However, the surplus environment capacity remains high even with some reduction caused by the water transfer. Before or after the water transfer, the pollution discharge of the two county towns along the main stream of Yalong River is far inferior to the environment capacity of river reach at the cross-section of county town. This indicates that the water transfer has no effect on the category of water quality in the main stream of Yalong River. The environment capacity of both Make River and Duke River is high enough that after the water transfer the pollution discharge in the county towns will not exceed the environment capacity of county town river section.

3.6 Quantitative evaluation of the comprehensive influence

Based on analysis and evaluation results previously stated, ecology and environment of typical landscapes affected by the western route project as well as the affected factors and influence degree are listed in Table 8. All in all, the western route project has a significant influence on flow speed, river width and water depth of the river corridors at the water resource area, while the influence on local climate and vegetation, typical wetlands, natural reserves and water environment below the dam site is limited.

Quantitative and qualitative analyses are both employed in the evaluation of the western route project SNWTP on water circulation and eco-environment in water resource area. On the basis of single-item evaluation, threshold value of influence degree is estimated by expert estimation system, and the influence levels are classified respectively.

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Based on the results of comprehensive evaluation, the comprehensive environmental influence distribution map of the western route project is drawn, as shown in Figs. 6 and 7.

As is indicated by the evaluation results, under the planning water transfer of 8 billion m^3, the impact of the project on water circulation and water ecology of the water resource area is focused on three aspects: the permanent destruction of vegetation caused by the land occupation during the implementation of the water transfer project; the permanent destruction of vegetation in the reservoir area via the submergence caused by the water storage; the influence on the hydrologic situation of original river corridors after the water transfer is significant, which is mainly reflected in three aspects, namely, water quantity of river channel, river width and water depth.

4 Conclusions

Based on the actual needs of the evaluation of ecological and environmental influence of the western route project of SNWTP in a changing climate and supported by climate-hydrology-ecology coupled simulation model, the present article, by focusing on local climate, typical river corridors, typical wetlands, natural reserves and the water environment of river basins below the dam site, has undertaken quantitative analysis in three different scales of space, namely, the Souteast Asia, the river basin above Yibin and the area of the most influence. The conclusions are as follows:

1. The influence on the climate of the water resource area: the reservoir construction has little influence on the wind speed, the humidity and the temperature. The climate of the water resource area generally has no major changes after the construction of the reservoir, but the local rainfall indeed increases to a certain degree. In the future climate situation, the annual average rainfall will rise by 22 mm approximately.

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2. The influence on typical river corridors: after the construction of the water transfer reservoir is completed, the stream flow below the reservoir will go through a sharp decrease, accompanied by the reduction of mechanics indexes of the river course, such as the water depth, the flow rate, the water surface width and the water surface area. This reduction results in a certain impact on the water ecology of the river course. With the inflow of water from the dam section to the river delta, the ration that the water flow of the control sections at the lower reaches after the water transfer takes in the overall water flow tends to recover and the impact of the project on the hydrological dynamics of the river tends to be weakened.

3. The influence on typical wetlands: there is generally no impact on the wetlands of overland flow recharging type below the dam site. However, the influence on wetlands above the dam site is uncertain. It is possible that the situation of the wetlands recharging the river basins is transformed into the opposite. Meanwhile, the area of wetland above the dam site increases after the construction of dam.

4. The influence on natural reserves: after the storage of water in the reservoir, it is estimated that 4212-hectare forests will be submerged, which cause certain degree of damage to the biodiversity in the natural reserves. However, with the increase in wetlands, new wetland ecological patterns are formed to provide new habitats for species. After the water transfer begins, water supply in the natural reserves at the lower reaches suffers from reduction to a certain degree, which is, however, not severe enough to cause any serious damage.

5. The influence on the water quality at the lower reaches: with no consideration of pollution control, the water quality of the Ake section in three target years after the water transfer can meet the II water standard. But in February when it's in dry season, the water quality of the river reaches below Ake County might be inferior to the III water standard. When pollution control is taken into account, all of the estimation indexes of water quality decrease compared to that without consideration of pollution control. For other sections, the water quality in the

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seven sections in three target years after the water transfer, even without pollution control, can still meet the II water standard, with no changes in water quality compared to that before the water transfer. In addition, with the purification effect of ammonia nitrogen of the water transfer reservoir at the upper reaches, the concentration of ammonia at the initial stage of raining season in all of the river sections shows an apparent decrease by 27 %–41 %.

In general, the major environmental impacts of the western route project of SNWTP lies in the permanent destruction of vegetation during the phase of dam construction and river impoundment as well as the apparent impact on the hydrological situation of the river corridors after the implementation of water transfer. Its influence on local climate and vegetation, typical wetlands, natural reserves and water environment below the dam sites is limited.

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Table 1. Environmentally and ecologically diagnostic indexes of the western route of SNWTP.

Target level	Criterion level	Index level	Weight of index
Ecological and hydrological control of the water resource area of the western route of SNWTP	Atmosphere 0.1681	Annual average temperature	0.0922
		Annual rainfall	0.1078
		Dryness of atmosphere	0.0938
	Water 0.4631	Ecological flow	0.1745
		Area of wetland	0.1656
		Run-off coefficient	0.1344
	Creature 0.2270	γ biodiversity index	0.1117
	Disasters and soil deterioration 0.1418	Soil erosion modulus	0.1199

Table 2. Simulation process of essential factors and the selection of prototypes.

Basic process	Selection of process of Essential factors	Prototype selection	Characteristics of the model	Satisfaction degree of the study requirement
Energy flow process	Earth surface radiation process, sensible heat flux, latent heat flux, soil canopy heat flux, etc.	CWRF, RegCM3	It is good at the simulation of energy; only vertical process is taken into account and the horizontal process of the water circulation and ecological process is left out.	It is able to realize the energy process modeling of all the layers.
Water circulation process	Canopy interception, evaporation and transpiration, Earth surface water process, soil process, underground process, natural hydrological process such as overland flow concentration and channel flow concentration, social hydrologic process of intake, transportation, using, consumption and drainage	WEP Reasonable allocation model of water resources based on criteria and optimized technology	It is inaccurate in energy process simulation and no dynamics of ecological process are taken into account; both vertical and horizontal processes are considered	It is able to realize natural-social water circulation simulation and to provide basic data of river habitat, such as water level, flow quantity, flow speed and water depth
Ecological process	Net initial productivity, material distribution and transportation, competition for light, reproduction, species invasion, bioclimatic process, death and soil organic material decomposition, simulation of the growth and succession of vegetation	GeoPro, CLM, DGVM and DSSAT	GeoPro mode is based on leaf scale; CLM contains canopy flux model; DGVM can simulate natural vegetation growth and succession; DSSAT can simulate crop growth and succession	It is able to realize basic simulation of ecological process and to identify quantitatively ecological and environmental evolutions
Water environment process	Transportation and transformation process of pollutants, pollution load and environment capacity evolution	One-dimension dynamic model of water quality	It is able to simulate the transportation and transformation of pollutants along river sections.	It is able to realize basic simulation of water environment

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Table 3. Multi-process and step-by-step verification result of the model.

Scale	Variable	Correlation coefficient	Relative inaccuracy (%)	Nash coefficient
Large-scale	Rainfall	≥0.65	≤10.3	–
	Temperature	≥0.89	≤4.2	–
Medium-scale	Run-off	≥0.85	≤5.29	≥0.72
	NPP	≥0.81	≤7.4	–
Small-scale	Run-off	≥0.90	≤8.27	≥0.75
	NPP	≥0.86	≤6.89	–
	Vegetation type	≥0.70	≤13.65	–
	COD	≥0.78	–	–
	NH_3-N	≥0.78	–	–

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Table 4. Comprehensive evaluation of the influence of the western route project on wetlands.

Wetlands classified according to their sources		Area affected by the project (percentage of area)		Influence range		Influence effect		Influence degeree (percentage of area)	Influence type	
				Integral influence	Local influence	Percentage	Positive or negative		Restorability	Irreversibility
Water recharge via overland flow concentration	70 %	No		They are not within the influence range of the water resource area, therefore not affected by the project.						
Water recharging via river	30 %	20 %	No	They are located at upstream water sources area, not affected by the project.						
Water recharging via river	30 %	10 %	Yes			2 %	+	0.2 %		
						8 %	–	5.0 %	3.5 %	1.5 %

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Table 5. Wetland landscape pattern evolution tendency and its influence factors.

Situation		Wetlands with water charging via overland flow concentration					Wetlands with water charging via river					Influence of climate change (%)	Influence of other human activities (%)	Influence of the western route project (%)
		Area (km^2)	Number of patches (%)	Hetero-geneity	Connec-tivity	Produc-tivity	Area (km^2)	Number of patches (%)	Hetero-geneity	Connec-tivity	Produc-tivity			
Before current year	1980–2000	+60.8	−0.010	+	+	+	+9.0	0.02 %	+	+	–	70 %	30 %	/
	2000–2009	−6.5	+0.005	–	–	–	−4.3	+0.010 %	+	–	–	40 %	60 %	
Current year to 2030 (estimate value)	Without the western route project	−26.7	+0.020	–	–	–	−20.2	+0.020 %	+	–	–	30 %	70 %	/
	With the western route project	+3.2	+0.001	+	+	–	−11.5	−0.005 %	–	+	+	20 %	30 %	50 %

Table 6. Comprehensive evaluation concerning the influence of the western route project on natural reserves.

Way of influence	Subject of influence	Level of influence
Inundation	Bushes	Serious
Water transfer	Ecosystem of the natural reserves below the dam site	Weak
Species	Biodiversity	Weak

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Table 7. Water environment quality evaluation of Ake River reach under different situations and in different years.

	Situation	Index of water quality	BOD_5	BOD_{Mn}	NH_3-N	Water quality
Without pollution control	No water transfer	In three target years	I	II	II	II
		2010	I	II	II	II
	Water transfer	Upper stream in 2020 and 2030	I	II	II	II
		43 km below the county town in 2020	–	–	–	IV
		79 km below the county town in 2020	–	–	–	III
		The county town in 2030	–	–	–	V
		79 km below the county town in 2030	–	–	–	IV
With pollution control	No water transfer	In three target years	I	II	II	II
		2010	I	II	II	II
	Water transfer	Upper stream in 2020 and 2030	I	II	II	II
		43 km below the county town in 2020	I	II	II	II
		79 km below the county town in 2020	I	II	II	II
		The county town in 2030	III	II	II	II
		79 km below the county town in 2030	I	II	II	II

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Table 8. Influence of the western route project on typical landscape ecology and environment factors at the water resource area.

Eco-environment of Typical landscape	Affected factors	Influence degree
Local climate	Wind speed	Little influence
and vegetation	Humidity field	Significant at the location of 2 m
	Temperature	Little influence
	Rainfall	Annual average rainfall is increased by 22 mm
	Salix atopantha	Influence below Zhuanda Dam site
Typical river	Average flow speed at cross-sections	Decrease larger in flood season than normal season
corridors	River width at cross-sections	Monthly average river width is reduced by about 20 % in April, May and June when fish lay eggs
	Water depth at cross-sections	Monthly average water depth decreases significantly by 20 %–30 %
Typical wetlands	Wetland landscape pattern index	Little influence
Natural reserves	Natural reserves such as Yanboyeze wetland, Manzetang wetland and the Dugoula area of Rangtang County	Little influence
	Other wetlands	No influence
Water environment	Eutrophication at the water transfer reservoir	Minor possibility
below the dam site	Environment capacity	Reduced, but with little influence on water quality of river

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Fig. 1. Arrangement diagram of the project.

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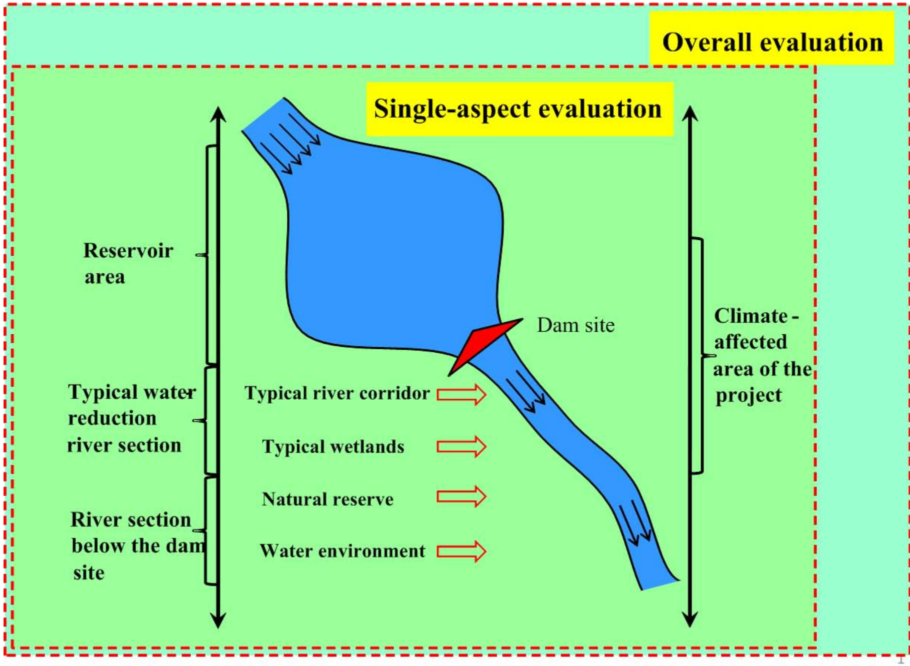

Fig. 2. Main considerations of the evaluation.

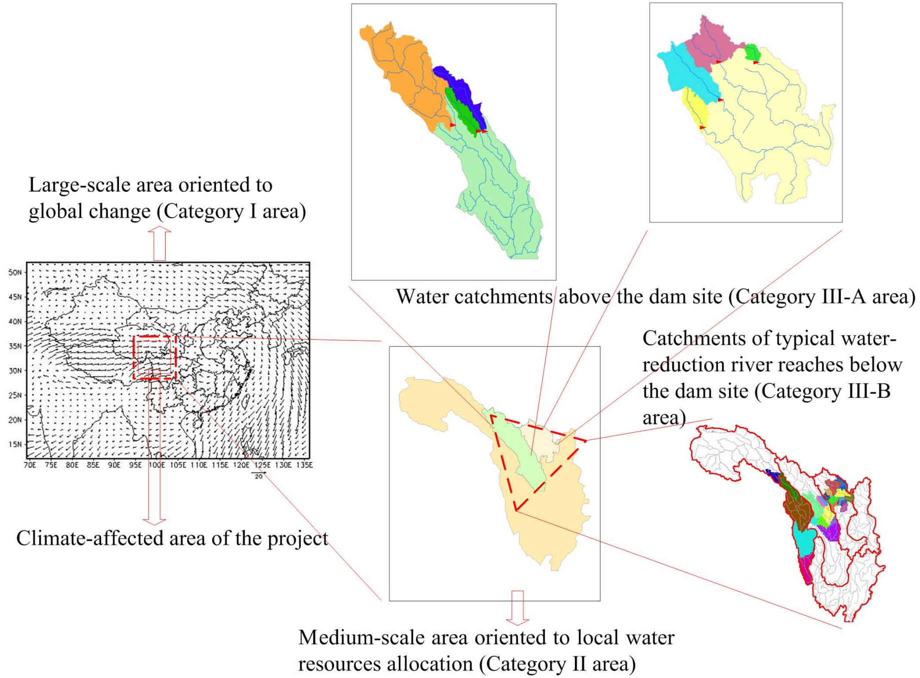

Fig. 3. The evaluation scope.

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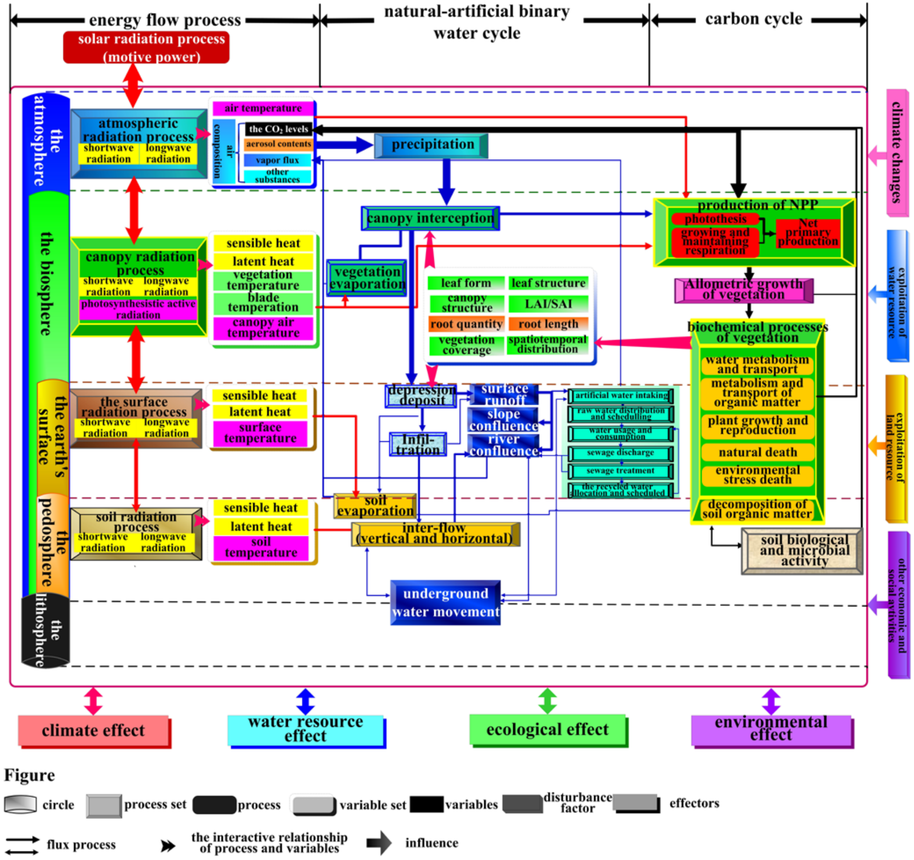

Fig. 4. Framework of climate-hydrology-ecology coupled simulation model.

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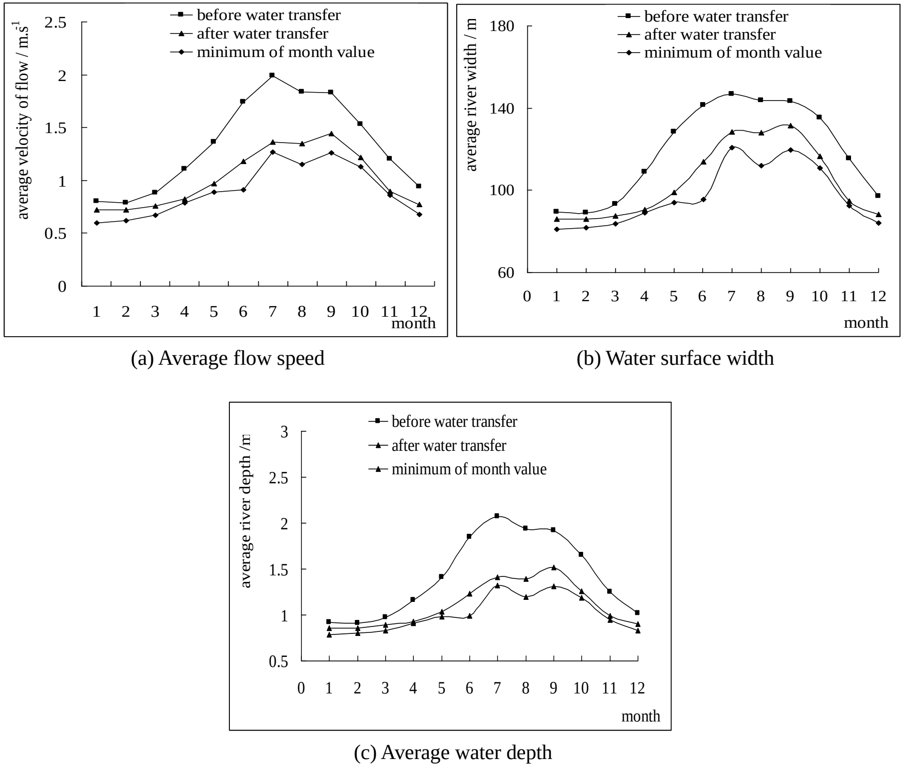

Fig. 5. Influence on the average flow speed, water surface width and water depth at the Ganzi cross-section of Yalong River. **(a)** Average flow speed, **(b)** water surface width and **(c)** average water depth.

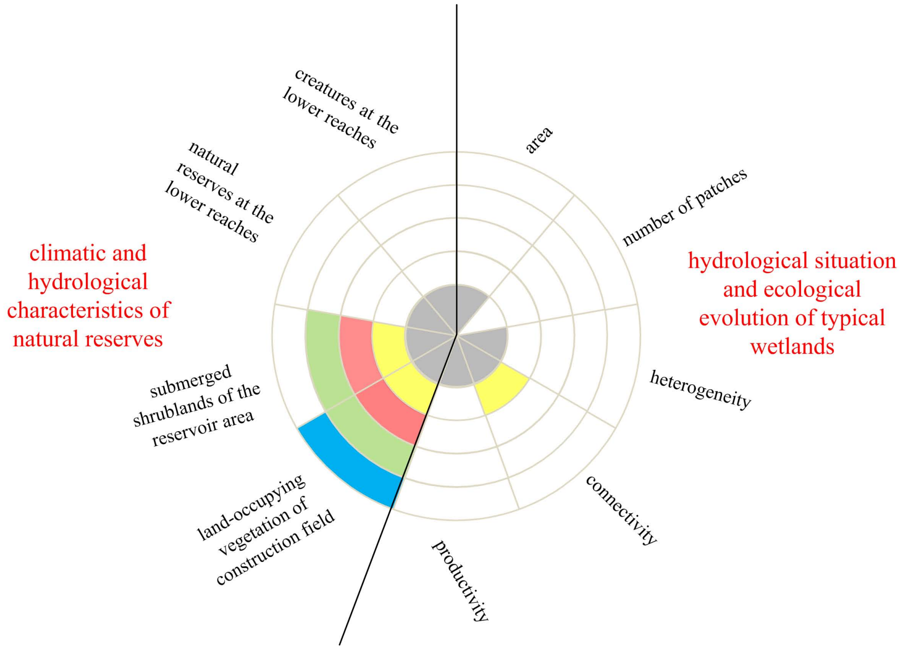

Fig. 6. Influence of the project on the ecology and environment of the water resource area (1).

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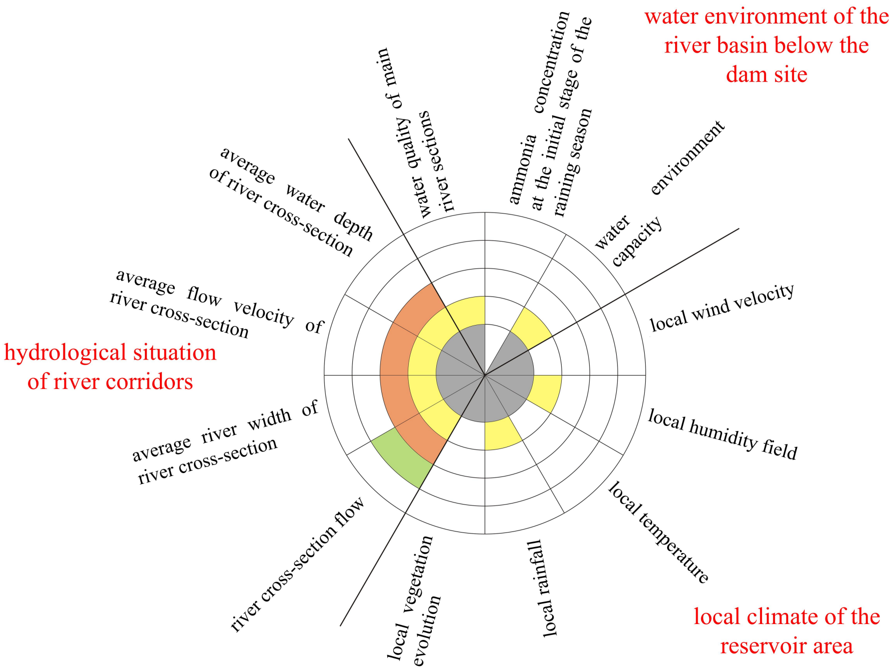

Fig. 7. Influence of the project on the ecology and environment of the water resource area (2).

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