Study on the Impact of Human Activities on Water Resources Assessment Process in the Yalong River Basin

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Abstract. As human activities intensify the development and utilization of water resources, significant changes occur in the hydrological cycle and underlying surface conditions of the basin, leading to potential errors in traditional water resources assessment methods. Based on the distributed hydrological model Wetspa, this study analyzes the basic characteristics and main components of the social water cycle process. It considers the influence of human water consumption and reservoir storage variability on the runoff simulation process. A coupled natural-social water cycle model is constructed for the Yalong River Basin to evaluate the quantity of water resources. By adding reservoir storage variability and water consumption to the model and analyzing the changes in water yield, the study aims to demonstrate the impact of neglecting reservoir regulation and the social water cycle process on water resources assessment when using distributed hydrological models. The results indicate that neglecting reservoir regulation and the social water cycle process in water resources assessment using distributed hydrological models leads to an overall decrease in water yield, with a more pronounced decrease in groundwater yield.

Keywords: Water Resources Assessment, Human Activities,Wetspa.

1 Introduction

With the rapid development of computer technology and the continuous advancement of hydrological models, precipitation-runoff models, water balance models, and distributed hydrological models have been widely used in water resources assessment. In addition, technologies such as artificial neural networks, 3S (Remote Sensing, Geographic Information Systems, and Global Positioning Systems), finite element method, etc., have also been widely applied in water resources assessment, improving the accuracy of water resources evaluation to a certain extent. Liang Li et al. [1] took the mountainous areas of the Manas River Basin in northwest inland river basin as an example, applied the SWAT model to the water resources assessment in data-scarce areas, and compared the results with those of traditional water resources assessment methods, suggesting that distributed hydrological models are expected to achieve dynamic, efficient, and rapid evaluation of water resources. Zhou Xingquan et al. [2] took Deyang City as an example to illustrate the application of GIS in water resources

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took Deyang City as an example to illustrate the application of GIS in water resources assessment, including extracting characteristic information such as watershed and river length in the evaluation area, as well as drawing contour lines of regional runoff depth and calculating water resources in data-scarce areas. Wang Jinli et al. [3] constructed a combined assessment model of water quantity and water quality for the Four Waters Basin in Hunan Province, and used index analysis method to predict the available water resources under different assurance rates in 2020 and 2030, analyzing the reasons for basin water shortage from the perspectives of water quantity, water quality, and ecological water demand, and proposing corresponding prevention and control measures.

Currently, research on distributed hydrological models and the evaluation of water resources using distributed hydrological models has achieved many results. However, traditional water resources assessment and existing water resources evaluation models inadequately consider the influence of human activities during the modeling process, failing to analyze the effects of human activities such as reservoir storage variability and water withdrawals on basin runoff generation. This paper analyzes the basic characteristics and main components of the social water cycle process by dissecting various elements of the natural water cycle process, such as rainfall, evaporation, infiltration, and runoff. Through studying the runoff generation mechanism of the distributed hydrological model Wetspa and introducing the concept of water yield, the paper analyzes the impact of reservoir regulation on water resources assessment by selecting the Er' tan Reservoir and the impact of increased water withdrawals by selecting the Tongzilin Hydrological Station.

2 Study Area Overview

The Yalong River Basin is located in the eastern part of the Qinghai-Tibet Plateau and is the largest tributary of the Jinsha River, stretching from northwest to southeast. The terrain in the basin is complex, surrounded by mountains on the east, west, and north sides, with elevations exceeding 4000 meters. Most areas in the basin have elevations of over 1500 meters, with drastic changes in terrain and significant drops in river elevation. The natural drop of the main stream is approximately 4400 meters. The total length of the main stream of the Yalong River Basin is over 1300 kilometers, with a drainage area of about 130,000 square kilometers. The basin has abundant runoff and rich water resources. The main source of runoff is precipitation, so the interannual and intra-annual variations in runoff and their regional distribution characteristics are basically consistent with the characteristics of precipitation changes[3-6]. The figure below shows the distribution of station locations in the Yalong River Basin.

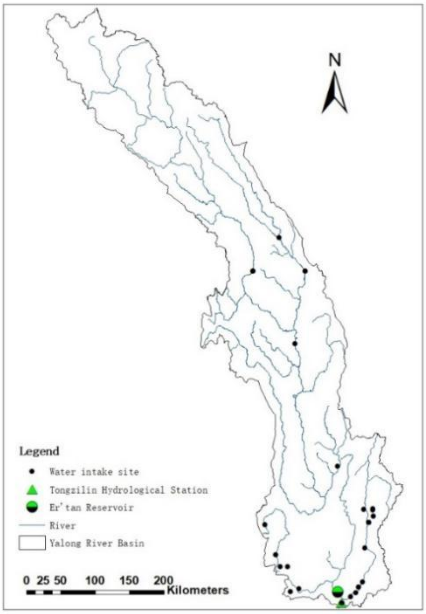

Fig. 1. Map of station locations in the Yalong River basin.

3 Data Preparation

3.1 Hydro-Meteorological Data

This study aims to establish a distributed hydrological model, Wetspa, for the Yalong River Basin. In addition to historical hydro-meteorological data, the basic data required for modeling include a digital elevation model, measured river network, land use, and soil types in the study area.

Hydrological data comprise historical daily runoff data and dispatching information for selected hydrological stations and reservoirs. Additionally, since water resources assessment involves the reconstruction of runoff data, it is necessary to collect water withdrawal data and reservoir storage variability information for the study area. The hydrological data used in this study are sourced from the Rainfall Situation Monitoring System of the Information Center of the Ministry of Water Resources. Some missing flow data are supplemented by hydrological yearbooks. Ultimately, data from the Tongzilin Hydrological Station and Er' tan Reservoir from 2015 to 2020 were collected.

Meteorological data required for modeling include precipitation, relative humidity, sunshine duration, wind speed, and maximum, minimum, and average temperatures. The meteorological data selected for this study before 2018 are sourced from the China Surface Climate Data Daily Value Dataset (Version 3.0)..

3.2 Water Withdrawal Data

The water withdrawal monitoring data used in the study are sourced from the national water resources monitoring capacity building project, specifically the nationally controlled water withdrawal monitoring points. This dataset includes surface water withdrawals and groundwater withdrawals.

4 Construction of a Binary Coupled Model for Natural-Social Water Cycle Based on Wetspa

4.1 Principles and Methods of the Wetspa Model

The Wetspa (A Distributed Model for Water and Energy Transfer Between Soil, Plants, and Atmosphere) model was proposed by Wang and Batelaan of the Vrije Universiteit Brussel, Belgium, in 1996 [7-9]. This model is a physically based distributed hydrological model, which operates at a daily time step, simulating water vapor transport and energy exchange among soil, vegetation, and atmosphere at the watershed scale[7-9].

The input data for the model include topography, land use, soil types, precipitation, and evapotranspiration capacities. If snowfall or snowmelt occurs during the simulation period, temperature data also need to be collected. All spatially distributed parameters in the model can be derived from three types of data: topography, land use, and soil types. The model calculations consider rainfall, interception, surface runoff, surface depressions, infiltration, soil interflow, and groundwater flow. In the calculation of groundwater flow, the model generalizes the aquifer as a linear reservoir, serving as one of the sources of water use or receiving percolation recharge from the soil [10-12].

4.2 Parameter Optimization Settings

In this study, to obtain intuitive parameter calibration results, the Nash-Sutcliffe coefficient is selected as the objective function for parameter optimization. Additionally, after comparative verification, when optimizing parameters using the Dynamically Dimensioned Search Algorithm (DDS), a total of 600 iterations were selected, with 100 iterations for preheating and parameter optimization.

4.3 Calibration and Validation Results

This study collected hydrological data time series from two stations over the past 20 years. However, due to the necessity of using water withdrawal data and reservoir storage data to reconstruct the measured flow, the water withdrawal data series for the Yalong River Basin collected in this study covers the years 2016-2020. Therefore, this paper selected data series from 2016 to 2019 for parameter calibration and used data from 2020 to validate the model. During the parameter optimization process, if the results of parameter optimization do not meet the requirements, parameters can be re-optimized by adjusting the parameter ranges appropriately. The adjusted parameter ranges, after parameter optimization, yielded optimal parameter results for the Ertan Reservoir and Tongzilin Hydrological Station, as shown in Table 2.

Table 1. Optimal parameter results for Tongzilin and ErTan.

No.	Parameter	Meaning	Lower limit	Upper limit	Ertan	Tongzilin
1	UnitSlopeM	Slope correction coefficient	0.30	10.00	9.31	6.75
2	ConductM	Soil saturated hydraulic conductivity correction coefficient	0.50	18.00	14.18	17.61
3	PoreIndexM	Soil porosity correction coefficient	0.30	1.80	0.70	0.86
4	LaiMaxM	Maximum leaf area index correction coefficient	0.50	1.50	0.86	1.28
5	DepressM	Fill-pit correction coefficient	0.30	5.00	4.53	2.21
6	RootDpthM	Root depth correction coefficient	0.30	1.50	0.65	0.69
7	ItcmaxM	Maximum canopy interception capacity correction coefficient	0.30	25.00	24.19	0.52
8	Imp_M	Impervious area ratio correction coefficient	0.00	2.00	0.01	1.89
9	petm	Evaporation correction coefficient	0.50	1.00	0.75	0.75
10	PorosityM	Soil void ratio correction coefficient	0.05	1.95	1.00	0.90
11	FieldCapM	Soil field capacity correction coefficient	0.05	1.95	11	0.90
12	CH_S2	Sub-basin main channel slope correction coefficient	0.10	3.00	1.00	0.45
13	CH_L2	Sub-basin main channel length correction coefficient	0.50	5.00	0.16	5.00
14	CH_N2	Sub-basin main channel Manning roughness coefficient correction coefficient	0.30	6.00	4.37	3.71
15	CH_K2	Sub-basin main channel bed bottom hydraulic conductivity correction coefficient	0.30	6.00	5.88	5.63

To evaluate the Wetspa model, this study employs three metrics: the Nash-Sutcliffe Efficiency (NSE), the Relative Error (RE), and the Monthly Nash-Sutcliffe

Efficiency. The calculation method for the Monthly Nash-Sutcliffe Efficiency involves first computing the monthly averages of the model results and observed values, followed by the calculation of the Nash-Sutcliffe Efficiency and Relative Error for the obtained monthly average series.

The NSE ranges from [-∞, 1], where values closer to 1 indicate a higher degree of fit between simulated and observed values. The RE ranges from [-∞, +∞], and smaller absolute values indicate higher simulation accuracy. The formulas for calculating the Nash-Sutcliffe Efficiency and Relative Error are as follows:

$$NSE = 1 - \frac{\sum_{i=1}^{N} (y_i - y_i)^2}{\sum_{i=1}^{N} (y_i - y)^2} \tag{1}$$

$$RE = \frac{\sum_{i=1}^{N} (y - y)}{\sum_{i=1}^{N} y} \times 100\% \tag{2}$$

Where: i represents the ith time step; N represents the total number of time steps; y-hat represents the simulated value; y represents the observed value; y-bar represents the mean of the observed data.

The model application results statistics for Ertan Reservoir and the Tongzilin Hydrological Station are summarized in the following table:

Table 2. The model application results for Ertan and Tongzilin.

Station	Calibration results			Verification results		
	NSE	Monthly NSE	RE (%)	NSE	Monthly NSE	RE (%)
Ertan	0.87	0.95	-0.10	0.90	0.93	9.77
Tongzilin	0.90	0.95	-0.97	0.96	0.98	1.41

According to the table above, it can be observed that both the Ertan Reservoir and the Tongzilin Hydrological Station have Nash-Sutcliffe Efficiency (NSE) values exceeding 0.8 and absolute Relative Error (RE) values less than 10%. Furthermore, the Monthly Nash-Sutcliffe Efficiency values are all greater than 0.9, indicating good simulation results. This suggests that the application of the Wetspa model in the Yalong River Basin is suitable, and this study can utilize the Wetspa model for assessing the impacts of human activities on water resources.

5 Study on the Impact of Human Activities on Water Resources Assessment

Parameter partitioning can describe the entire set of grids and sub-basins from a measurement station to upstream measurement stations. Once the parameter partitioning is defined, calculations can be performed for the sub-basins within this parameter partition based on the watershed conditions and requirements, or for all upstream sub-basins. When performing partitioned calculations for measurement stations with control stations upstream, the calculation results of the upstream measurement stations can be automatically retrieved based on the upstream-downstream relationship. This facilitates the simulation of runoff processes and parameter calibration for the sub-basins within the parameter partition of the measurement station. This approach not only reduces the generalization and homogenization of runoff capabilities for different regional sub-basins but also accurately captures the runoff capabilities of sub-basins within the parameter partition, greatly improving the efficiency of parameter sensitivity analysis and calibration.

In this study, a grid size of 1 km × 1 km was used for modeling. After calculating the runoff for each grid in the model, appropriate statistical partitioning can be selected to statistically analyze the surface runoff of the model as needed. This paper takes the Ertan Reservoir and the Tongzilin Hydrological Station as examples to investigate the influence of reservoir regulation and water withdrawal data on runoff calculation in the model. Therefore, the runoff from the parameter-controlled partitions of the Ertan Reservoir and the Tongzilin Hydrological Station is statistically analyzed to study the impact of human activities on the assessment of water resources. The following figure shows the parameter partitions for the Ertan Reservoir and the Tongzilin Hydrological Station.

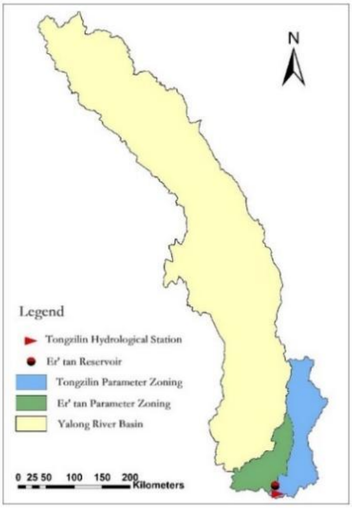

Fig. 2. The parameter partitions for the Ertan Reservoir and the Tongzilin Hydrological Station.

5.1 Evaluation Indicators and Methods

This study evaluates and predicts the quantity of surface water resources in the Yalong River Basin using the following evaluation indicators:

(1)Groundwater Yield

Groundwater yield refers to the amount of water infiltrated by precipitation at a stable infiltration rate, forming groundwater runoff. The calculation formula is as follows:

$$RG = Rg \quad (3)$$

Where: RG represents groundwater yield, and Rg represents net groundwater flow.

(2)Surface Runoff

Surface runoff refers to the portion of precipitation exceeding the stable infiltration rate, forming surface runoff, including soil water runoff and surface water runoff. The formula is as follows:

$$RS = Ri + Rs \quad (4)$$

Where: RS represents surface runoff, Ri represents soil water runoff, and Rs represents surface water runoff.

(3) Total Runoff

Total runoff refers to the portion of precipitation remaining after deducting various losses, which forms runoff. It is the sum of surface runoff and groundwater yield. The formula is as follows:

$$R = RS + RG \quad (5)$$

Where: R represents total runoff, RS represents surface runoff, and RG represents groundwater yield.

5.2 Considering the impact of reservoir storage on runoff calculation results

This study analyzes the influence of reservoir regulation on water resources assessment using the Ertan Reservoir as a case study. Two scenarios were considered: with reservoir regulation (regulated) and without reservoir regulation (unregulated). The control area of the Ertan Reservoir, i.e., the runoff within its parameter-controlled partition, was statistically analyzed under both scenarios. The results are presented in the table below.

Table 3. The calculation results of water resources with reservoir regulation and without reservoir regulation. ($10^8 m^3$)

Mo.	With reservoir regulation			Without reservoir regulation		
	R	*RS*	*RG*	*R*	*RS*	*RG*
1	1.80	0.56	1.24	1.15	0.66	0.49
2	0.49	0.01	0.48	0.21	0.01	0.20
3	0.10	0.00	0.10	0.04	0.00	0.04
4	0.04	0.01	0.04	0.02	0.01	0.02
5	1.15	1.10	0.05	1.00	0.99	0.01
6	4.47	3.59	0.88	2.97	2.96	0.01
7	9.33	6.93	2.40	6.22	5.98	0.24
8	10.91	6.88	4.03	7.06	6.45	0.62
9	8.57	4.74	3.83	4.80	4.27	0.53
10	2.34	0.76	1.58	0.60	0.58	0.01
11	1.24	0.01	1.23	0.01	0.00	0.01
12	0.53	0.00	0.53	0.00	0.00	0.00

To visually demonstrate the variation of reservoir regulation on runoff, the corresponding data from the table will be plotted as a bar chart, as shown below. Here, *RS*+ and *RG*+ represent surface runoff and groundwater yield, respectively, under the increased reservoir regulation mode. *RS* and *RG* represent surface runoff and groundwater yield, respectively, under the unregulated reservoir mode. *RS*+*RG* represents total runoff.

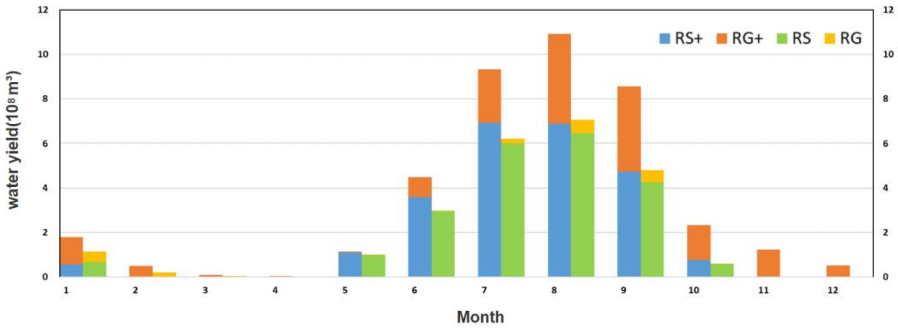

Fig. 3. The calculation results of water resources with reservoir regulation and without reservoir regulation.

From the graph, it can be observed that under the unregulated reservoir mode, the total runoff is significantly lower compared to the runoff under the increased reservoir regulation mode. Additionally, groundwater yield shows a more pronounced decreasing trend compared to surface runoff.

5.3 Considering the impact of water withdrawal on runoff calculation results

This study analyzes the influence of increased water withdrawal on water resources assessment using the Tongzilin Hydrological Station as a case study. Two scenarios were considered: with water withdrawal (withdrawal) and without water withdrawal (no withdrawal). The control area of the Tongzilin Hydrological Station, i.e., the runoff within its parameter-controlled partition, was statistically analyzed under both scenarios. The results are presented in the table below.

Table 4. The calculation results of water resources with water withdrawal and without water withdrawal. ($10^8 m^3$)

Mo.	With water withdrawal			Without water withdrawal		
	R	*RS*	*RG*	*R*	*RS*	*RG*
1	5.03	3.77	1.26	5.02	3.92	1.10
2	2.87	2.39	0.48	2.90	2.48	0.42
3	0.26	0.16	0.10	0.26	0.18	0.09
4	1.67	1.63	0.04	1.72	1.69	0.03
5	4.63	4.15	0.48	4.02	4.01	0.01
6	15.57	12.16	3.42	14.20	12.77	1.42

7	20.83	13.41	7.42	19.40	13.49	5.92
8	17.27	11.90	5.37	16.31	11.97	4.33
9	16.53	11.19	5.34	15.60	11.36	4.24
10	11.92	5.73	6.19	8.14	5.85	2.29
11	5.70	0.15	5.54	2.45	0.18	2.26
12	3.08	0.85	2.23	1.85	0.93	0.92

To visually demonstrate the variation of water withdrawal on runoff, the corresponding data from the table will be plotted as a bar chart, as shown below. Here, *RSu* and *RGu* represent surface runoff and groundwater yield, respectively, under the increased water withdrawal mode. *RS* and *RG* represent surface runoff and groundwater yield, respectively, under the no water withdrawal mode. *RS+RG* represents total runoff.

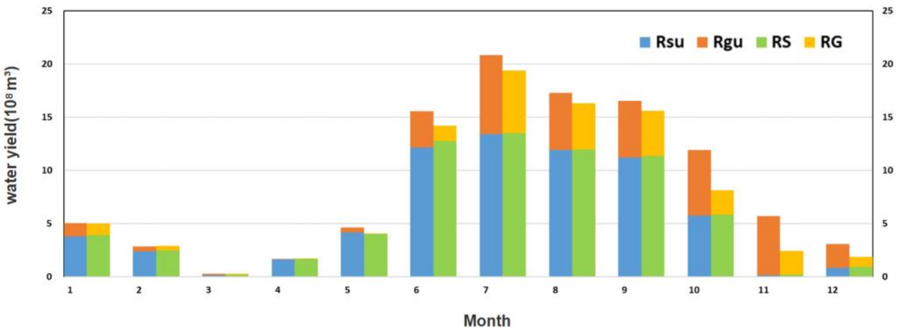

Fig. 4. The calculation results of water resources with water withdrawal and without water with-drawal.

From the graph, it is evident that under the no water withdrawal mode, the total runoff is slightly lower compared to the total runoff under the mode with water withdrawal. The surface runoff remains relatively consistent, with slight increases in some months. However, groundwater yield exhibits a clear decreasing trend.

6 Conclusion

Based on the Wetspa distributed hydrological model and utilizing monthly scale, this study analyzed the fundamental characteristics and key components of the socio-hydrological cycle. Considering human water usage and reservoir storage variation during the modeling process, a binary coupled model of natural-social water cycle was constructed. Through the coupling of these two models, simulation of reservoir regulation and the socio-hydrological cycle process was achieved. The results indicate that when employing distributed hydrological models for water resource assessment, neglecting reservoir regulation and the socio-hydrological cycle process leads to an overall reduction in runoff, with a particularly pronounced decrease in groundwater yield.

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References

1. Liang Lili, Gong Jiaguo, Ye Yuntao, et al. Evaluation method of water resources in da-ta-deficient areas based on SWAT distributed hydrological model [J]. Journal of China Institute of Water Resources and Hydropower Research, 2014, 12(01): 54-59.
2. Zhou Xingquan, Xu Huanbin, Tian Yue. Application of GIS in surface water re-sources assessment in Deyang City [J]. Sichuan Water Resources, 2016, 37(01): 46-49.
3. Mao Dehua, Wang Jinli, Song Ping, Liao Xiaohong, Li Xichun. Joint evaluation of ecological water demand in Four Rivers Basin of Hunan under binary water cycle [A]. The 15th China Water Forum [C], 2017-11-10.
4. Huang Yanyan. Study on the relationship between snow cover area change and run-off in the upper reaches of Yalong River [D]. Lanzhou Jiaotong University, 2016.
5. Li Xin. Study on flood forecasting of Litang River in Yalong River Basin based on HEC-HMS [D]. China University of Geosciences (Beijing), 2015.
6. Yang Mingxiang. Study on precipitation-runoff forecasting based on land-atmosphere coupling [D]. Tsinghua University, 2015.
7. Takanari Nakano; Yuto Kamei;. Gis-Based Flow Routing with the Distributed Hydro-logical Wetspa Model in the Ziarat River Basin - Gorgan, Iran [J]. Cercetari agronomice in Moldova, 2015, Vol.48(2): 15-28.
8. Chen Yang. Application research of distributed hydrological model EasyDHM in the receiving area of South-to-North Water Diversion Middle Route [D]. Tianjin University, 2010.
9. Li Runkui, Zhu Axing, Qin Chengzhi, et al. Influence of soil data on simulation ef-fect of distributed watershed hydrological model [J]. Advances in Water Science, 2011, 22(02): 168-174.
10. Liu, Yan. Simulation and Prediction of Hydrological Elements Based on Deep Learning [D]. Tianjin University, 2021. DOI:10.27356/d.cnki.gtjdu.2021.002293.
11. Chen, Guoyin. Runoff Simulation Study of Naoli River Basin Based on CLUE-S-WetSpa Coupled Model [D]. Northeast Agricultural University, 2023. DOI:10.27010/d.cnki.gdbnu.2023.000822.
12. Zhou, Xi. Application Research of Mechanism and Data-Driven Hydrological Forecasting Models [D]. Hebei University of Engineering, 2022. DOI:10.27104/d.cnki.ghbjy.2022.000535.