Comprehensive Utilization Model of Yarlung Zangbo River Water Resources Based on Discrete Multi-objective Optimization Model

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Abstract. The Yarlung Zangbo River is rich in water resources, which is of great significance to the comprehensive utilization of water resources. The reasonable development of the hydropower resources of the Yarlung Zangbo River is realized, through the water diversion project and the establishment of the trapezoidal hydropower station. A comprehensive utilization model of hydropower resources optimized by discrete objectives is constructed, based on the discrete multi-objective optimization theory. It combined with the reading of geographic data by GPS and Matlab. The number and orientation of the optimal construction of hydropower stations and the proportion of the water transfer volume of the water diversion project are obtained, combining the cost of hydropower station construction and water diversion project implementation and the benefits brought by hydropower resources.

Keywords: Discrete Multi-objective Optimization Model; Hydropower station; Water diversion projects; Hydropower resources.

1. Introduction

1.1. Background

Hydropower is a renewable energy source with mature technology that can be developed on a large scale. The theoretical reserves of hydropower resources in the Yarlung Zangbo River Basin reach nearly 80 million kilowatts, and the runoff is second only to the Yangtze River and the Pearl River. There are currently two main viewpoints: one is to build multiple trapezoidal hydropower stations, and the other is to build water diversion projects in the northwest region, in terms of the utilization of hydropower resources of the Yarlung Zangbo River. It is necessary to formulate a reasonable resource allocation plan, in order to make full use of this precious resource.

1.2. Literature review

Hydropower is one of the oldest forms of renewable energy that has been harnessed by humans for centuries. In recent years, the significance of hydropower as a clean and sustainable source of energy has been widely recognized. This paper presents a comprehensive review of the literature on the significance, technology, environmental impact, and sustainability of hydropower and water diversion projects.

Darmawi et al [1] studiesd the significance of small hydropower as a clean energy source. The authors highlighted the importance of small hydropower in electrification and its potential to contribute to sustainable development. Pal N et al [2] discussed the technology used in hydroelectric power plants and the structural details of the turbines and dams used order. Singh V K et al [3] studied hydroelectric power plants that generate electricity with minimal operating costs and minimal environmental impact. Von Sperling E et al [4] studied how to balance the positive and negative environmental aspects of hydropower construction and operation. Yu L et al [5] discussed the variation of power generation of hydropower stations under different ecological flows. Xiao-zhu Li et al [6] gave an overview of the present situation of hydropower in China.

Zhao Z Y et al [7] took the South-to-North Water Diversion Project as an example to study the importance of water diversion projects and how to implement them. Yu M et al [8] proposed four measures to realize the sustainability of large-scale water diversion projects. Zhang M et al [9] studied the ecological effect of the water diversion project in the Heihe River Basin. Zhang M et al [10] studied the positive and negative effects of the cross-basin water diversion project on the ecological environment.

This study aims to study how to make full use of hydropower resources. More precisely, this study aims to address the following questions:

1. How to calculate the income brought by the water diversion project?
2. How to get the optimal number and location of trapezoidal hydropower stations?

1.3. Our work

First, we deduce the calculation formula of hydroelectric power from the principle of power supply. Then, we calculated the construction, transmission and 50-year operation and maintenance costs of the hydropower station.

We calculate the effective water diversion of the Hongqi River project, considering evaporation and seepage. Subsequently, we calculate the income of farmland and oasis in 50 years by calculating the actual amount of irrigated farmland and oasis. Finally, a discrete multi-objective optimization model for the comprehensive utilization of water energy resources is constructed, by analyzing the impact of water resources on the power station.

1.4. Arrangement

The rest of this article is organized as follows. Section II gives the definitions of the symbols used in the paper and the assumptions used. Section III establishes the optimization model of comprehensive utilization of water resources by giving the benefits of hydropower stations and water diversion projects. Section IV obtains the optimal allocation scheme by solving the model. Finally Section V concludes this article.

2. Preliminary

2.1. Assumptions

We propose the following rea-sonable assumptions, in order to make better use of data related to the establishment of hydropower stations and water diversion projects, and improve the validity of the model.

Assumption 1: Dams can be built anywhere on the river. Considering the construction site in actual engineering is a very complicated technical issue, it is not the focus of our research. Besides, the geological environment of the Yarlung Zangbo River Basin is not much different.

Assumption 2: Do not consider the extremely harmful natural disasters such as earth-quakes and floods. Natural disasters such as earthquakes and floods are unpredictable and extremely harmful. This is not the focus of our research. In addition, the utilization of hydro-power resources is a project with a large time span, so we ignore these factors.

Assumption 3: In the next 50 years, the climate, geology and hydrological conditions of the Yarlung Zangbo River will not change significantly. Natural geographical features such as climate, geology, and hydrology are the result of the natural evolution of the earth over tens of thousands of years, so these geographical features will not change significantly in 50 years.

2.2. Notations

The key mathematical notations used in this paper are listed in Table 1.

Table 1. Notations used in this paper.

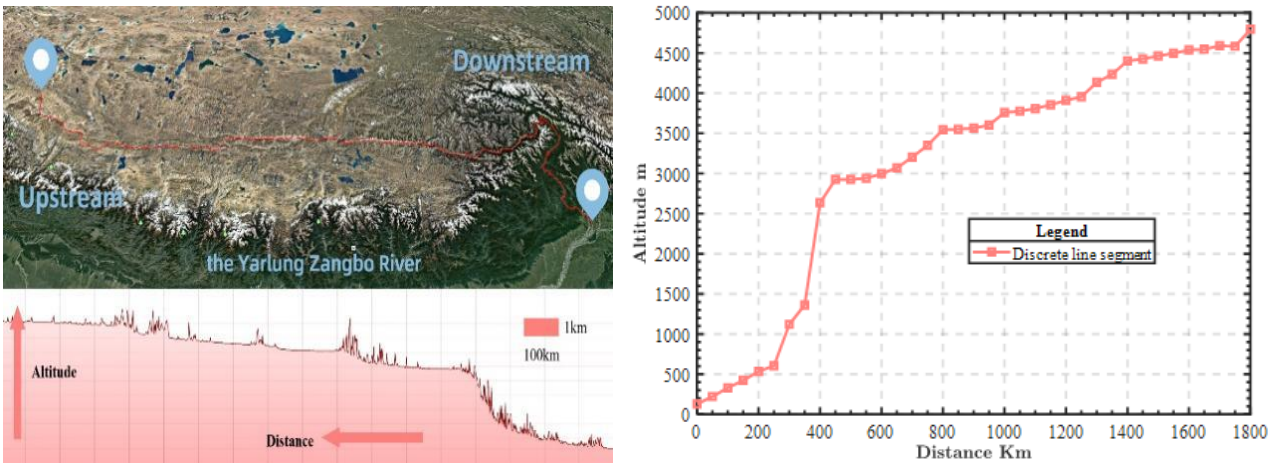
Symbol	Description
W	The annual average output electricity of the hydropower station
M_{erect}	Construction cost of hydropower station
M_{om}	Fifty-year operating and maintenance costs of hydropower plants
D_i	The sum of the distances from the *i-th* hydropower station to the six cities
g_s	Evaporation of water per hour

3. Model establishment

A hydropower station is a facility that generates electricity from water, usually built on a river or reservoir, and uses water flow to drive a turbine generator to convert mechanical energy into electrical energy. We specifically research the benefits and costs of generating electricity from hydropower plants.

Water diversion projects refer to the introduction of water sources from a certain area to areas that need water resources through the construction of water conservancy projects to meet the needs of human production and life. We specifically explore the Hongqi River water diversion project

We obtain the geographical information of the Yarlung Zangbo River through Google Maps. The result is shown in Figure 1(a).Then we discretize the Yarlung Zangbo River into several points and obtain the distance, height and slope between two points through the conversion of longitude and latitude to straight-line distance. The final result is shown in Figure 1(b).



(a). (b).

Figure 1. (a)Geographic Information Panorama.(b) Discretization infographic.

We obtain the data of the flow rate information of different places on the Yarlung Zangbo River through [11].

We use the average water flow velocity of the upper, middle and lower reaches, and use the method of linear weighting to obtain the water flow velocity between different sections based on discrete geographic information. The mentioned information is presented in Figure 2.

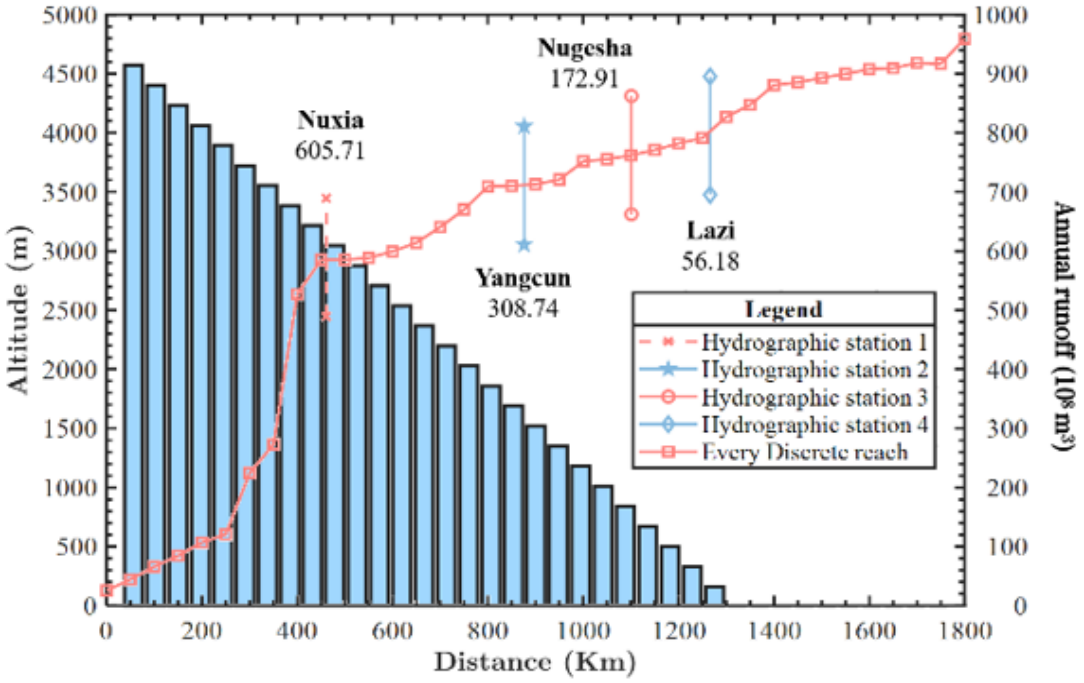


Figure 2. Velocity of major cities.

3.1. Hydropower Stations

The power generation principle of a hydropower station is to convert the potential energy of water into electrical energy. The dam creates a height from which water flows. A pipe (penstock) carries the water from the reservoir to the turbine. The fast-moving water pushes the turbine blades. The waters force on the turbine blades turns the rotor, the moving part of the electric generator. Electricity is produced, when coils of wire on the rotor sweep past the generator's stationary coil (stator) [12].

3.1.1. Power generation income

Maximum hydroelectric power output is entirely dependent on available head and flow on site, the equation for hydropower [13] is:

$$W = m \times g \times H_{net} \times \eta \times 365 \times 24 \tag{1}$$

Where W is the total annual output electricity, m is the annual avarges flow, H_{net} is the total head actually measured on site, minus any head loss. For simplicity, we assume a head loss of 10%, so

$$H_{net} = H_{gross} \times 0.9 \tag{2}$$

η is the product of all of the component efficiencies, which are normally the turbine, drive system and generator. The turbine efficiency would be 85%, drive efficiency 95% and generator efficiency 93% for a typical hydro system.So the overall system efficiency would be:

$$\eta = 0.85 \times 0.95 \times 0.93 \tag{3}$$

The cost of electricity per kilowatt-hour in China is about 0.6 *¥/kWh*. The 50-year electricity production income of the hydropower station is:

$$M_r = W \times 50 \times 0.6 \tag{4}$$

3.1.2. Construction cost

The construction cost of a hydropower station consists of a series of expenses: construction costs, equipment costs, excavation costs, installation costs, etc. It is difficult to calculate accurately. Research shows that there is a relationship between the construction cost of a hydropower station and the maximum output power [14].

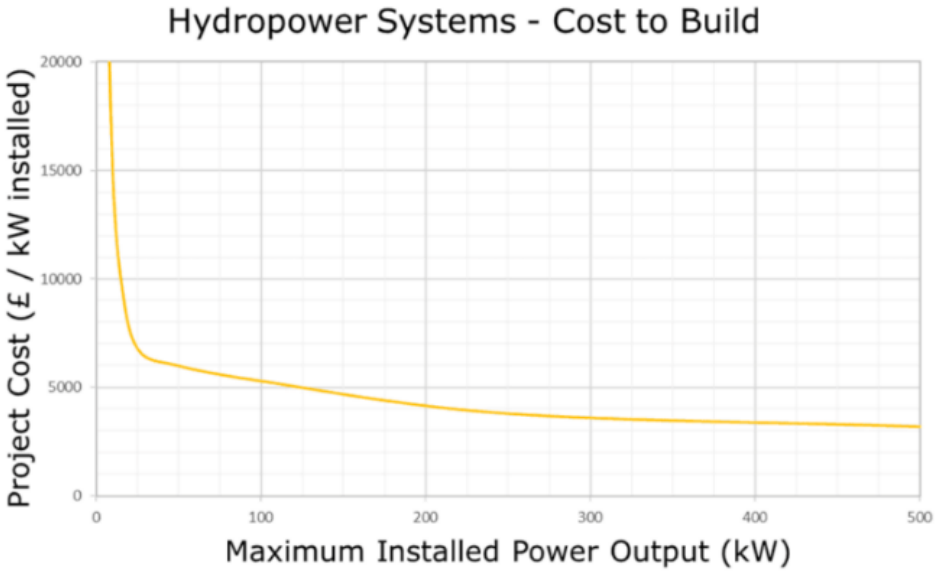


Figure 3. Hydropower system construction cost relationship diagram.

We fit the data curve in Figure 3 to get the following relationship.

$$f(w) = 49.83 \times W^{-0.636} + 1.658 \tag{5}$$

Then the construction cost can be expressed as:

$$M_{erect} = W \times f(w) \times \varepsilon \tag{6}$$

Where W is maximum output power, ε is exchange rate between pound sterling and RMB.

3.1.3. Operation and maintenance cost

Civil Engineering found that the operation and maintenance cost of hydropower stations is 3%–5% of the construction cost [15]. In the case of fifty years of use, it is obvious that the cost increases with time. Their changes satisfy the linear relationship change, where i represents the number of years.

$$M_{om} = \sum_{i=1}^{50} M_{erect}\left(\frac{0.005 - 0.003}{50} \times i + 0.003\right) \tag{7}$$

3.1.4. Transportation costs

The power generated by the hydropower station must be transported to the surrounding cities (Lhasa, Shigatse, Qamdo, Nyingchi, Shannan, Nagqu). Obviously, the distance from the hydropower station to the surrounding cities will affect the transmission cost. The longitude and latitude of the *i-th* waterway and the *j-th* city can be obtained. Based on the latitude-longitude-distance conversion formula [16].Get the distance between them.

$$D_i = \sum_{j=1}^{6} 2R \arcsin\left(\sqrt{\sin^2\left(\frac{L_a(i) - C_a(j)}{2}\right) + \cos(C_a(j))\cos(L_a(i))\frac{\sin^2(L_o(i) - C_o(j))}{2}}\right) \tag{8}$$
$$i = 1,\ 2,\ 3 \cdots 37$$

The construction cost per kilometer of transmission line is 1.3million. Total cost of transmission line laying.

$$M_t = D_i \times 1.3\,(mill/km) \tag{9}$$

3.2. Water Diversion Project

The establishment of Hongqi River is to solve the drought problem in Northwest China by irrigating farmland and building ecological green belts [17]. The specific data are presented in Table 2

Table 2. Information about the Hongqi River Project.

Total length(*km*)	Total water transfer(m^3)	Farmland (hm^2)	Oasis (km^2)	Total investment (¥)
6118	6×10^{10}	4×10^{9}	1.5×10^{6}	4×10^{13}

3.2.1. Water evaporated and leaked

The water evaporation formula is [18]:

$$g_s=(25+19v)A(x_s-x) \tag{10}$$

Where v is air velocity above water surface (m/s), A is water surface area (m^2). x_s Is the maximum humidity ratio of saturated air at the same temperature as the water surface,here take x_s=0.014.x is humidity air ratio, here take a=0.01.

The formula for calculating A is:

$$A=R_L\times R_W \tag{11}$$

Where R_L is project length of Hongqi River, which is 6118km. R_W is the width of the Hongqi River, which is 56m.

There is a certain proportional relationship between the amount of leakage water and the total amount of water, and the amount of leakage water during transportation has the following relationship.

$$V_{leak}=V_{water}\times5\% \tag{12}$$

According to the formula above, the water loss during transportation can be obtained as:

$$V_{loss}=g_s\times24\times365+V_{leak} \tag{13}$$

3.2.2. Farmland income

Due to water evaporation and leakage losses, the actual number of irrigable fields is:

$$N_{real}=2\times10^{8}\times\frac{V_{water}-V_{loss}}{V_{water}} \tag{14}$$

The income per hm^2 of farmland in Northwest China is 643¥/year, then the total farmland income created by the Hongqi River Project within 50 years is:

$$B_{farm}=N_{real}\times643\times50 \tag{15}$$

3.2.3. Oasis value

The total amount of oases that can be actually constructed is

$$G_{real}=2\times10^{5}\times\frac{V_{water}-V_{loss}}{V_{water}} \tag{16}$$

According to the survey of Mamat Sawut , Mamattursun Eziz,The ecological benefit of the 1140.7km^2 Magan-Kuqa Delta Oasis is 83.23×10^{8}¥[19].

So, the ecological benefit per km^2 of oasis is:

$$B_{per}=\frac{8.323\times10^{9}}{1.1407\times10^{4}} \tag{17}$$

The oasis benefit created by the Hongqi River project is:

$$B_{oasis}=G_{real}\times B_{per} \tag{18}$$

3.3. Water Diversion-Generate Electricity Model

3.3.1. Water diversion benefit

The economic benefits generated by transporting $1m^3$ of water resources are:

$$B_{tran-per} = \frac{B_{real}}{V_{water} - V_{loss}} \tag{19}$$

Therefore, the net economic benefit produced by diverting water $V_i m^3$ from the *i*-section of the Yarlung Zangbo River to Northwest China is:

$$B_{tran} = V_{i\times} B_{tran-per} \tag{20}$$

3.3.2. Power generation

The serial number of the known water diversion section is i ,assume that the set of serial numbers of the entire river section below the *i-th* section is $J = \{j \mid j_1, j_2, \cdots j_a\}$ a total of section a. The river section above the $i-th$ section has a total of *b* sections as $K = \{k \mid k_1, k_2, \cdots k_b\}$.

The power generation of a hydropower station in section *j* is:

$$W_j^{'} = (m_j - P_i) \times H_j \times \mathrm{g} \times \eta \times 365 \times 24 \tag{21}$$

The power generation of a hydropower station in section *k* is:

$$W_k^{'} = m_k \times H_k \times \mathrm{g} \times \eta \times 365 \times 24 \tag{22}$$

3.3.3. Economic Benefits of Hydropower Stations

According to formula (5)and(6), we can obtain the construction cost, 50-year operation and maintenance cost, and power transmission cost of all hydropower stations in the *J,K* section.

1. Construction cost

The sum of the construction cost of section *J, K* is:

$$M_{erect}^{'} = \sum_{j=1}^{N_a} W_j^{'} f(w_j^{'}) \varepsilon + \sum_{k=1}^{N_b} W_k^{'} f(w_k^{'}) \varepsilon \tag{23}$$

Where N_a N_b are respectively the number of hydropower stations that can be built in *J, K* section?

2. Operating and Maintenance Costs

The sum of the Operating and Maintenance Cost of section J, K is:

$$\begin{aligned} M_{om}^{'} = & \sum_{j=1}^{N_a} \sum_{i=1}^{50} W_j^{'} f(w_j^{'}) \varepsilon \left(\frac{0.005 - 0.003}{50} i + 0.003 \right) \\ & + \sum_{k=1}^{N_b} \sum_{i=1}^{50} W_k^{'} f(w_k^{'}) \varepsilon \left(\frac{0.005 - 0.003}{50} i + 0.003 \right) \end{aligned} \tag{24}$$

3. Transmission line cost

The sum of the Transmission line cost of section *J, K* is:

$$M_t^{'} = \sum_{j=1}^{N_a} D_j \times 1.3\,(mill/km) + \sum_{k=1}^{N_b} D_k \times 1.3\,(mill/km) \tag{25}$$

D is the sum of distances from each hydropower station to 6 major cities.

4. Potential yield gain

We can get the potential power generation income:

$$M_r^{'} = \sum_{j=1}^{N_a} W_j^{'} \times 50 \times 0.6 + \sum_{k=1}^{N_b} W_k^{'} \times 50 \times 0.6 \tag{26}$$

Finally, the net income of potential power generation for the next 50 years can be ob tained as:

$$M_{total}^{'} = M_r^{'} - M_{erect}^{'} - M_{op}^{'} - M_t^{'} \tag{27}$$

3.3.4. Water diversion distance

We need to lead the water to the starting point of the planned water transfer project, considering the actual water transfer distance transportation. It is the starting point of the Hongqi River Project.

We can get the longitude and latitude ($L_o^{'}, L_a^{'}$) of the starting point of the water diversion project, based on the Hongqi River Project and Google Maps. Then the distance between the two can be obtained on the basis of the known longitude and latitude ($L_{io}^{'}, L_{ia}^{'}$) of the river section of the water diversion project.

$$D^{'} = 2R \arcsin\left(\sqrt{\sin^2\left(\frac{L_a^{'} - L_{ia}^{'}}{2}\right) + \cos(L_{ia}^{'})\cos(L_a^{'})\frac{\sin^2(L_o^{'} - L_{io}^{'})}{2}}\right) \tag{28}$$

3.4. Discrete Multi-objective Optimization Model

The Yarlung Zangbo River water resources comprehensive utilization plan is to coordinate the potential power generation and water diversion of multi-level hydropower stations to maximize economic benefits. Therefore, we build a multi-objective optimization model with potential power generation and water diversion benefits as the objective function.

1. Decision Variable

The ordinal number of the river section of water diversion i and the adjusted water vol ume V_i .

2. Constraints

The amount of water transferred cannot exceed the flow rate of the corresponding section of the river, that is,

$$0 \ll V_i \ll m_i \ , \ i = 1, 2 \cdots 37 \tag{29}$$

At the same time, it must meet the constraints of the drop and flow that can generate electricity.

$$\begin{cases} H_i \geqslant 150m \\ m_i \geqslant 250 \times 10^8 m^3 \ , \ i = 1, 2 \cdots 37 \end{cases} \tag{30}$$

3. Objective Function

It is defined as maximizing the sum of the net economic benefits of hydropower stations within 50 years of the Yarlung Zangbo River after diverting water resources, the total benefit of Northwest China after water diversion, and the distance between water diversion section and the starting point of the Hongqi River project.

$$\max f(i) = \frac{M_{total-\max}^{'} - M_{total}^{'}}{M_{total-\max}^{'} - M_{total-\min}^{'}} + \frac{B_{tran-\max} - B_{tran}}{B_{total-\max} - B_{total-\min}} + \frac{D_{\max}^{'} - D^{'}}{D_{\max}^{'} - D_{\min}^{'}} \tag{31}$$

Where$W_{total-\max}^{'} - W_{total-\min}^{'}$, $B_{total-\max} - B_{total-\min}$ is to standardize the objective func tion.

Finally, the multi-objective optimization function can be obtained as follows:

$$\begin{cases} \max\ f(i) = \dfrac{W'_{total-\max} - W'_{total}}{W'_{total-\max} - W'_{total-\min}} + \dfrac{B_{tran-\max} - B_{tran}}{B_{total-\max} - B_{total-\min}} + \dfrac{D'_{\max} - D'}{D'_{\max} - D'_{\min}} \\ s.t \begin{cases} 0 \ll V_i \ll m_i \\ H_i \geqslant 150m \\ m_i \geqslant 250m^3\ ,\ i = 1, 2 \cdots 37 \end{cases} \end{cases} \tag{32}$$

4. Experment

4.1. Algorithm

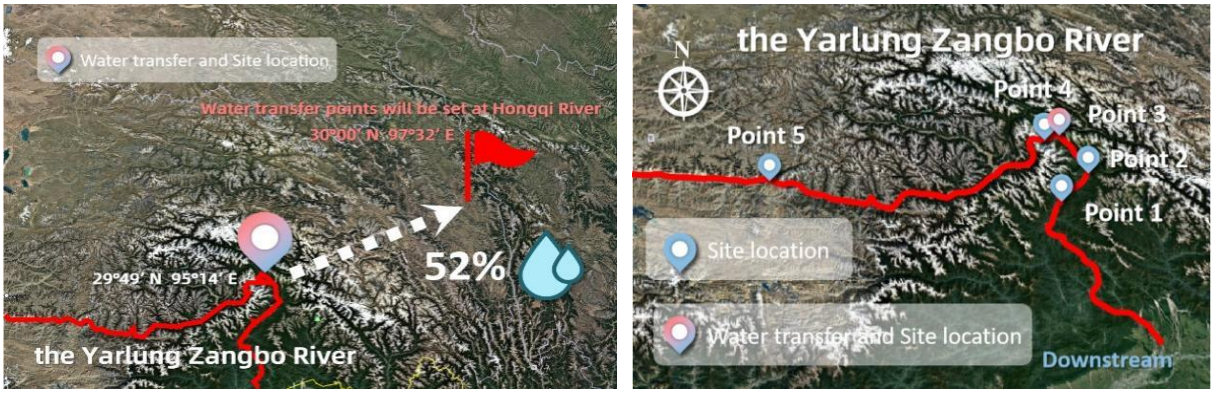
We gradually increase the water diversion ratio from 1% to 99% in steps of 1%, and calculate the water diversion benefit, the net income of the hydropower station, and the distance from the starting point of the Hongqi River project, find the best ratio of the *i-th* water adjustment point, and calculate the remaining points according to this method. Specific thought exhibition is in Table 3 below.

Table 3. Specific algorithm.

Algorithm 1 Draw an optimized contour map	
	Input: *flow* , *place* , h_{delta}
	Output: the Objective function numerical matrix
1:	f_{aim} = []
2:	*Per* = 1%:99%
3:	**for** *index*_1 = 1:*length*(*flow*)
4:	**for** *index*_2 = 1:*length*(*Per*)
5:	$flow_{temp}$ = *flow*
6:	$flow_{temp}$(*index*_1:*end*) = *flow*(*index*_1:*end*).**Per*(*index*_1)
7:	**if** h_{delta}>150
8:	update the value of $\boldsymbol{W_{income\ from\ power\ generation}}$
9:	update the value of ***Distance***
10:	update the value of $\boldsymbol{B_{income\ from\ water\ transfer\ projects}}$
11:	update the value of $\boldsymbol{f_{aim}}$(*index*_1,*index*_2)
12:	**else**
13:	f_{aim}(*index*_1,*index*_2) = 0
14:	**end**
15:	**end**
16:	**end**
17:	surf(f_{aim})

4.2. Results

We get the final result in the figure below.



(a) (b)

Figure 4. (a) Starting position and water diversion ratio of water diversion project. (b) The location of the hydropower stations.

1. From Figure 4(a), it can be seen that the water diversion project diverts water from the position (30°00'N 97°32'E) to Northwest China every year, accounting for 52% of the annual flow of the river in this section, in order to maximize the utilization value of the Yarlung Zangbo River's water resources.

2. From Figure 4(b), a total of 5 hydropower stations can be built. In addition to the hydropower stations that can be built at the water transfer office, hydropower stations can also be built in the other 4 places. The specific positions are shown in Table 4.

Table 4. The specific location of the hydropower station.

Point 1	Point 2	Point 3	Point 4	Point 5
(29°11'N,95°06'E)	(29°28'N,95°24'E)	(29°49'N,95°14'E)	(29°45'N,95°03'E)	(29°16'N,91°29'E)

We can see from Table 5 that we can still build hydropower to supply power to surrounding cities under the condition of meeting the water diversion demand of the Hongqi River Project, so the full utilization of water resources can bring huge economic benefits.

Table 5. Specific results.

Total annual output	Power production efficiency	Total water transfer	Water diversion income
$2.083\times10^{11}(kwh)$	6.249×10^{12}(¥)	35.19bill(m^3)	1.2354×10^{12}(¥)

5. Conclusion

In this paper, we constructed an optimal utilization model of water resources, taking the economic benefits of water transfer, the economic benefits of power generation, and the distance from the water transfer point to the starting point of the project as the optimization objectives, taking the location of the water transfer point and the amount of water transfer as the decision variables, and consider the limitations of drop, flow, and water transfer volume. We got the utilization plan: 35.19 billion m^3 of water is transferred from (29°49'N, 95°14'E) to the western region every year, and hydropower stations can be built in five locations. It is worth exploring further in terms of how hydropower plants interact with the environment and research on other ways in which water diversion projects can bring benefits. In addition, the modeling process requires a lot of data, many of our data are replaced by average values, due to the limitation of time and computing power. And in the modeling process, we have carried out detailed calculations without simplifying from a mathematical point of view, which makes our model have many calculation formulas and calculation steps.

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