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Summary Sheet

Water Situation Evaluation System

Executive Summary

In this paper, we build an evaluation system based on **Supply-Demand Model (SD Model)** to measure a region's water situation. We select **water shortage coefficient** as the basis of water measure by using the quantized relation between supply and demand of water resource.

Firstly, the framework we build composed of two mutual independent parts called the supplement of water and the demand of water. After quantizing those two parts separately by using the quota method, the difference between supplement and demand can be obtained to serves as a criterion to measure the current situation of water resource.

Considering that the D-value of supply and demand will have an effect on each portion, the **feedback mechanism** is added to reflect the impact. Through determining the degree of the feedback mechanisms effect on the supply and demand of water by using **correlation analysis**, the **correlation coefficient** and the variation quantity of two parts can be obtained to describe the dynamic change.

Then **grey prediction** is used to do a fifth-year forecast on Northern Sri Lanka and the result shows that the water shortage coefficient will increase rapidly and the water situation will become more serious due to the sharply decrease of water supplement. In addition, we can get the conclusion that the scarcity will occur in 2027 in Northern Sri Lanka.

After that, a brand new forecast on Northern Sri Lanka in 15 years can be obtained by adding the intervention plan, the result shows that the value of water shortage coefficient declined to some extent and Northern Sri Lanka will become less susceptible to water scarcity.

Finally, we conduct a sensitivity analysis on water shortage coefficient by changing the correlation coefficient and we can know that the value of water shortage coefficient has low sensitive to the industrial water, while it has high sensitive to the agriculture water.

Key words: SD Model; Water shortage coefficient; Feedback mechanism; Correlation coefficient; Grey prediction

Contents

1 Introduction

1.1 Background

The scarcity of water is a huge problem that human is facing in the world. With the development of the economy and increment of population as well as the accelerated process of industrialization and the enlargement of agricultural production scale, the demand of water resource is constantly growing, and coupled with the unreasonable exploitation and utilization of water, it is insufficient for some regions with the vast populations. In addition to the physical scarcity describe above, economic scarcity is also a primary cause for water scarcity due to the lack of infrastructures to get access to the water resource.

With the development of science and technology and the improvement of mechanization, mankind has taken some measures to alleviate the problem of water scarcity, like seawater desalination technology, sewage disposal technology, rainwater harvesting technology and so on. However, there exist several uncontrollable natural factors like global warming, seasonal rainfall and extreme rainfall that lead the water resource become so serious.

As a result, we need urgently to analyze the reasons why water is scarce in those regions on both physical and economy aspects, and some feasible and effective measures are ought to be put forward to improve the allocation and strengthen the management of water resource to keep a delicate balance between human needs and the supplement of water.

1.2 Our work

Firstly, combining with the given five issues, writers are required to set up our proposed Supply-Demand Model (SD Model) with bold assumptions to measure the water situation in an area, then the problem is transferred into constructing an evaluation system. With referring to some discovers on water resource, a water shortage coefficient is put forward to describe the connections between the supplement and demand of water. Through detailing those two parts, the supplement of the water is split into three main sections: available surface water, exploitable ground water and social water. The demand of water can be classified into four parts: domestic water consumption, industrial water consumption, agricultural water consumption and ecological water consumption.

Secondly, the model should reflect the dynamic process of the water resource. To meet such requirement, a feedback mechanism[1] is imposed to SD Model, and thus we can obtain the variation quantity of the supplement and demand of water. Therefore, we can make a prediction of the water condition for the coming year based on the variation combined with grey prediction[2].

Finally, writers are asked to evaluate sensitivity and robustness of the model by changing the correlation coefficient.

Having considered all the requirements above, in this paper, our goal is to construct a Supply-Demand model to simulate the water condition and gain further analysis.

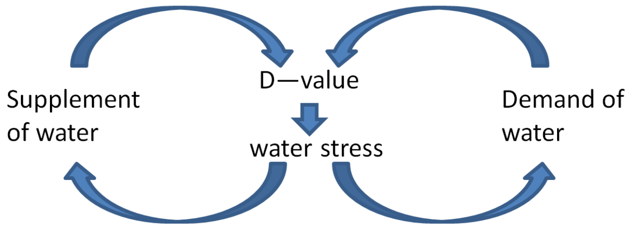

Figure 1: The basic structure of Supply-Demand Model (SD Model)

2 Basic Assumptions

- No war in the region.
- No extreme drought in the region.
- The loss of water in transportation is omitted.
- No extreme consumption of water resource in selected region.
- No serious water pollution in the region, e.g. nuclear pollution and petroleum pollution.

3 Symbol Description

In the section, we use some symbols for constructing the model as follows.

Table 1: The symbol description

Symbol	Description
W	The total supplement of water
W_s^*	The quantity of available surface water
Q^*	The quantity of exploitable ground water
W^*	The total demand of water
Wh	The quantity of water deficit
ΔW	The variation quantity of the supplement
ΔW^*	The variation quantity of the demand
W_N	The prediction value of the supplement
W_N^*	The prediction value of the demand
α	The degree of the water scarcity′s impact
η	Water shortage coefficient

P.s:Other symbol instructions will be given in the text.

4 Model preparation: the quantization of evaluation index

In order to describe the condition of the water resource in a certain region, several indexes are ought to be determined. And the index of available surface water, exploitable ground water, social water, domestic water consumption, industrial water consumption, agricultural water consumption and ecological water consumption are selected.

4.1 Supplement of the water

According to the diversity of supply source, the supplement of water[3] can be divided into three categories called surface water supply, ground water supply and social water supply.

From the view of the utilization of water, the main components of water resources formed from precipitation can be divided into three parts: the amount of water which is hard to use due to the limit of technical and economic conditions like the flood, the certain quantity of water which is needed to maintain the ecological support like the instream flow quantity, and the amount usable of water resource.

Considering the water that can be obtained is not equal to the total amount of the water that nature offers to us, the actual supplement of the water is split into three main sections: available surface water, exploitable ground water and social water.

4.1.1 Available surface water

(i)The concept of available surface water

The amount of regional surface water contain the part of the water that can not be used and a portion of water which is difficult to control. The former refers to the unusable water resource which is used to safeguard the positive operation of ecological system. In this paper, this part of water is only used to maintain the instream flow quantity. The latter means to the amount of water which is useful but can not be accessed owing to the conditional limitation, and we assume that it only relates to the floods in the flooding season which exceeds the maximum bounds of regulation and storage capacity of the project. Therefore, the available surface water is the rest part of the total surface water supplement, and it can be defined as follows:

Definition1: Available surface water is the water that people have the ability to use but not destroy the ecological demand.

(ii)The calculation of available surface water

step 1 The total amount of regional surface water W_s is known.

step 2 According to the concept and definition of available surface water describe above, the quantity of available surface waterW_s^*can be expressed as below:

$$W_s^* = W_s - W_i - W_f \tag{1}$$

Where W_i represents the minimum value of instream flow quantity and W_f shows the amount of flooding in the flood season.

step 3 In order to simplify the expression, we introduce a parameterρ called availability coefficient, and it defined as follows:

$$\rho = \frac{W_s^*}{W_s} \tag{2}$$

Substituting equation (1) into equation (2), then we can obtain:

$$\rho = 1 - \frac{W_i + W_f}{W_s} \tag{3}$$

step 4 Eventually, the final expression of available surface water is:

$$W_s^* = \rho \cdot W_s \tag{4}$$

Where ρ is the availability coefficient and W_s reflects the total amount of regional surface water

4.1.2 Exploitable ground water

(i)The concept of exploitable ground water

The exploitable ground water is a part of the total amount of groundwater recharge, and the quantity of groundwater recharge mainly includes two parts: the infiltration amount of precipitation and phreatic evaporation.

(ii)The calculation of exploitable ground water

step 1 According to the concept of exploitable ground water describe above, the quantity of ground recharge Q can be defined as:

$$Q = I_p - P_e \tag{5}$$

Where I_p represents the infiltration amount of precipitation and P_e reflects the quantity of phreatic evaporation.

step 2 Precipitation infiltration I_p refers to the amount of water which seeps into the soil under the effect of gravity during and after rainfall, its calculating formulae is:

$$I_p = \alpha \cdot P \cdot A \tag{6}$$

Where α is defined as the precipitation infiltration coefficient, P represents annual average precipitation in a certain region and A shows the area of the region. Among them, the parameter α can be calculated by the formula:

$$\alpha = 1 - \frac{D}{X} \tag{7}$$

Where D is the surface runoff and X is the annual total precipitation.

step 3 The formula of annual phreatic evaporation P_e can be described as:

$$P_e = A \cdot E_n \cdot \exp(-1.1H) \tag{8}$$

Where A shows the area of the region, E_n represents the evaporation from water and H reflects the burial depth.

step 4 The quantity of exploitable ground water Q^* then can be calculated:

$$Q^* = P^* \cdot Q \tag{9}$$

Where P^* is defined as the exploit coefficient and it can be determined. As for the regions with great exploitation condition (water yield of well is over 20 $m^3/(h.m)$, the value range of P^* is [0.875, 1.0]; if the region has a moderate exploitation condition (water yield of well is between 5 10 $m^3/(h.m)$, the value range is [0.75, 0.875]; In terms of those regions whose exploitation condition is poor (water yield of well is under 2.5 $m^3/(h.m)$), then the value range is [0.6, 0.75].

4.1.3 Social water supplement

Addition to the water supplied by the nature, human attempt spontaneously to find another way to get water source with the development of technology. For example, Israel is in extreme lack of water resources, three-fifths of the area is arid, however, Israel ensures the country a sustainable and steady development with the support of high-tech water supplement.

Nowadays, there are three primary ways to supply water sources by the society: water imports, sewage treatment and seawater desalination.

• **desalination**:

A region invests capital for the purchase of water resource from other areas to relax the contradiction between the supply and demand of water resource, this phenomenon is called water imports. And we use W_1 to represent the annual import of water.

• **desalination**:

Sewage treatment means managing the sewage of a given region to an expected value to meet the demand of the quantity of usable water resource. And W_2 is introduced to show the value of the annual volume of sewage treatment.

• **desalination**:

Seawater desalination means removing salt from water to produce fresh water. Seawater desalination can increase the amount of the total fresh water without the confines of climate. We use W_3 to reflect the annual quantity of water managed by seawater desalination.

4.1.4 The calculation of total supplement of water

The total supplement of water is the sum of the quantity of available surface water, exploitable ground water and the water supplied by society. Therefore, the formula of total supplement of water W is:

$$W = W_s^* + Q^* + W_1 + W_2 + W_3 \tag{10}$$

Where W_S^* represents the available surface water,Q^* represents the quantity of exploitable ground water,W_1 is the annual import of water,W_2 is the value of the annual volume of sewage treatment and W_3 represents the annual quantity of water managed by seawater desalination.

4.2 Demand of the water

The demand of water[4] can be classified into four parts: domestic water consumption, industrial water consumption, agricultural water consumption and ecological water consumption.

4.2.1 The demand of domestic water

The domestic water refers to the amount of water used to maintain a normal life and ensure the society functioning properly on a daily basis. Domestic water consumption W_l is mainly related to the population size, and the annual demand of domestic water can be calculated based on the quota method[5] by the formula as below:

$$W_l = P' \cdot K_1 \tag{11}$$

Where $P^{'}$ shows the population of a certain year and K_1 represents the comprehensive fixed quantity of domestic water in a certain year.

4.2.2 The demand of industrial water

The industrial water refers to the quantity of water used in the industrial production directly and indirectly. Industrial water consumption W_d is mainly related to the industrial output, and can be obtained based on the quota method:

$$W_d = V \cdot K_2 \tag{12}$$

Where V reflects the value of industrial output in a certain year and K_2 represents the water consumption of unit output value in a certain year.

4.2.3 The demand of agricultural water

The agricultural water refers to the amount of water for irrigation use and livestock use. Agricultural water consumption W_a related to the irrigation area, irrigation quota and utilization factor of irrigation water, it can be determined using the quota method:

$$W_a = \sum_{i=1}^{n} \frac{w_i \cdot m_i}{\lambda} \tag{13}$$

Where i reflects the types of crops, n shows the kinds of crops in total, w_i is defined as the irrigation area of a certain crop, m_i represents the irrigation quota of a certain crop and λ represents the utilization factor of irrigation water.

4.2.4 The demand of ecological water

The ecological water means the quantity of water used to maintain the state needed by the development of a region with the environment without any destruction or threat to ensure the ecological system operation healthily. Ecological water consumption W_e can be defined as:

$$W_e = 2 \cdot (E_s - P) \tag{14}$$

Where E_s reflects the annual evaporation from water surface in a certain region and P shows the annual total precipitation in a certain region.

4.2.5 The calculation of total demand of water

The total demand of water is the sum of the quantity of domestic water consumption, industrial water consumption, agricultural water consumption and ecological water consumption. Therefore, the formula of total demand of water W^* is:

$$W^* = W_l + W_d + W_a + W_e \tag{15}$$

Where W_l is the domestic water consumption, W_d is the industrial water consumption, W_a is the Agricultural water consumption and W_e represents the ecological water consumption

5 An evaluation system construction based on SD model

The relationship between supply and demand of water resource should be considered, because it reflects the contradiction between the real capacity of supplement and the total demand. This relationship can be used as a criterion to measure the situation of water resource in a certain region base on Supply-Demand Model (SD Model).

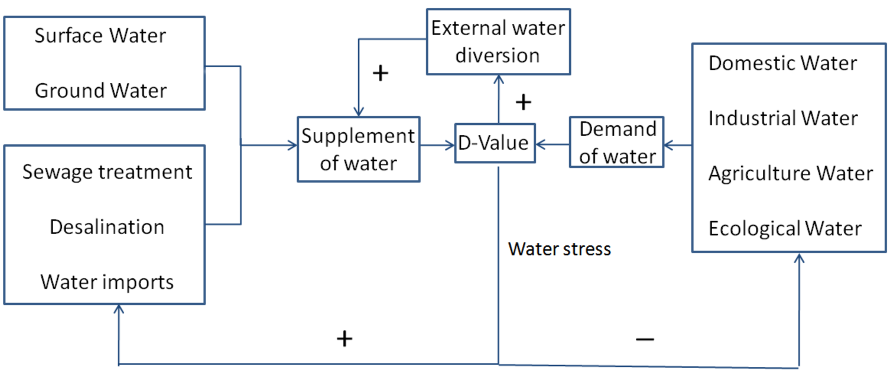

Figure 2: The feedback mechanism of SD Moedl

The main idea of the model is to measure the degree of effect by the feedback mechanism's effect on the supply and demand of water, and then to obtain the variation quantity of the supplement and demand. Meanwhile, the method of grey prediction is used to predict the quantity of supply and demand water in the next year. Finally, we can predict the water condition for the coming year based on the variation.

5.1 A forecast for the next year based on grey prediction

Considered that the water resource is an important part in ecosystem, and the world ecosystem is a grey system with multi-factors. For example, there are many factors result in water scarcity, but the known elements are too rare. Therefore, the method of prey prediction is appropriate to forecast the water resource system.

Through forecasting the change of the intercoordination among several factors in the system, we can get the prediction value of the supplement of water $W_N^{'}$,and the prediction value of the demand of water W_N^{**}.

5.2 The influence of the feedback mechanism

With the rapid growth in economy and population, human witness a much greater demand for water resource. A serious water shortage phenomenon appeared in many regions. The increase of water deficit leads some pressure on the supplement and demand of water, and this water stress is called the feedback mechanism of the system. For instance, the water price will increase if the water resource is inadequate and people are going to shorten the time of washing to save water resource.

Based on the feedback mechanism, we can calculate the variation quantity of the supplement and demand due to the water stress.

5.2.1 The water condition of current year

The quantity of water deficit W_h is defined as:

$$W_h = W^* - W \tag{16}$$

Where W^* reflects the total demand of water and W shows the total supplement of water. We call the region is well supplied with water, if ; on the contrary, we call it is hydropenic.

Then we introduce a parameter called water shortage coefficient η, and it is defined as below:

$$\eta = \frac{W_h}{W^*} \cdot 100\% \tag{17}$$

Where W_h reflects the quantity of water deficit and W^* reflects the total demand of water.

The water shortage coefficient η^* is used to measure the situation of water resource in a certain region.

5.2.2 The total variation quantity of the next year

(i)The variation quantity of the demand:

Considering that the degree of the effect by water shortage is different, we let the correlation coefficient[6] α_l to show the effect on the demand of domestic water, let α_d to reflect the effect on the demand of industrial water, let α_a to represent the effect on the demand of agriculture water and α_e to represent the effect on ecological water. Then we use correlation analysis to determine their value.

Table 2: The effect on the demand of industrial, agriculture and ecological water

	Correlation
α_d	0.532
α_l	0.749
α_a	0.674
α_e	0.652
α_1	0.805
α_2	0.430
α_3	0.350

Table 3: The effect on the demand of domestic water

Correlations

		W_h	α_l
W_h	Pearson Correlation	1	.749**
	Sig. (2-tailed)		.000
	N	26	26
α_l	Pearson Correlation	.749**	1
	Sig. (2-tailed)	.000	
	N	26	26

**. Correlation is significant at the 0.01 level (2-tailed).

Then we obtain the demand water of the coming year by adding the feedback mechanism, and they can be defined as below:

$$W_l^* = W_l \cdot (1 - \alpha_l \cdot \eta^*) \tag{18}$$

Where W_l^* reflects the demand of domestic water in next year, W_l reflects the demand of domestic water in current year, α_l shows the effect on the demand of domestic water and η^* represents the water shortage coefficient in current year. Similarly, W_d^*, W_a^*, W_e^* can be determined in the same way.

After that, the variation quantity of the demand can be determined:

$$\Delta W_l^* = W_l^* - W_l \tag{19}$$

Where ΔW_l^* reflects the variation quantity of the demand of domestic water in next year, W_l^* reflects the demand of domestic water in next year and W_l reflects the demand of domestic water in current year.

Substituting equation (18) into equation (19), then we can obtain:

$$\Delta W_l^* = \alpha_l \cdot \eta^* \tag{20}$$

Where α_l shows the effect on the demand of domestic water and η^* represents the water shortage coefficient in current year. In the same way, we can get ΔW_d^*, ΔW_a^*, ΔW_e^*.

Eventually, the final expression of the variation quantity of the demand is:

$$\Delta W^* = \Delta W_l^* + \Delta W_l^* + \Delta W_a^* + \Delta W_e^* \tag{21}$$

Where ΔW^* represents the variation quantity of the demand, ΔW_l^* is the variation quantity of the demand of domestic water in next year, ΔW_d^* is the variation quantity of the demand of industrial water in the coming year, ΔW_a^* is the variation quantity of the demand of agricultural water in next year and ΔW_e^* is the variation quantity of the demand of agricultural ecological water in next year.

(ii)The variation quantity of the supplement:

The pressure of water scarcity also has an effect on the supplement of water. For instance, people are going to increase the import of water or import some equipment like sewage purifier and seawater desalting equipment to relieve the pressure. And in this paper, the way of increasing the pumping of groundwater or surface water is not take into consideration, because it does not conform to the principle of sustainable development.

Similar to the method of calculating the variation quantity of the demand, we let α_1 as the effect on the supplement of water imports, let α_2 as the effect on the supplement of sewage water and let α_3 as the effect on the supplement of seawater desalination. And their value can be determined by using correlation analysis.

Then the variation quantity of the supplement can be respectively got:

$$\Delta W_n = \alpha_n \cdot \eta^*(n = 1, 2, 3) \tag{22}$$

Eventually, the final expression of the variation quantity of the supplement is:

$$\Delta W = \Delta W_1 + \Delta W_2 + \Delta W_3 \tag{23}$$

Where ΔW_1 represents the variation quantity of the import of water, ΔW_2 is the variation quantity of sewage water, ΔW_3 reflects the variation quantity of seawater desalination.

5.3 A forecast for the next year after adding the feedback mechanism

The forecast for the coming year we did above did not consider about the influence of the feedback mechanism. After adding the feedback mechanism we can improve the integrity and accuracy of the prediction.

Therefore, the prediction of the supplement of water W_N is:

$$W_N = W_N^{'} + \Delta W \tag{24}$$

Where $W_N^{'}$ represents the prediction value of the supplement of water based on grey prediction without the feedback mechanism and ΔW represents the variation quantity of the supplement

Similarly, the prediction of the demand of water W_N^* is:

$$W_N^* = W_N^{**} - \Delta W^* \tag{25}$$

Where W_N^{**} represents the prediction value of the demand of water based on grey prediction without the feedback mechanism and W_N^* represents the variation quantity of the demand.

Finally, the water shortage coefficient η of the next year can be determined:

$$\eta = \frac{W_N^* - W_N}{W_N^*} = \frac{W_N^{**} - W_N^{'} - \Delta W^* - \Delta W}{W_N^{**} - \Delta W^*} \tag{26}$$

Where W_N^{**} and $W_N^{'}$ respectively represents the prediction value of the demand or supplement of water based on grey prediction without the feedback mechanism, ΔW^* and ΔW respectively reflects the variation quantity of the demand or supplement.

Table 4: The simple description of water shortage coefficient

	η <0	η <0
Description	There is no water shortage, and the smaller the value is, the more abundant water resources it has	Water scarcity appears in this region, and the higher the value is, the more serious the problem of water scarcity is

The simple description of η is given in Table 4.

Then we can define the degree of water shortage according to the value of :

Table 5: The level of the degree of water shortage

	$0 < \eta \leq 0.1$	$0.1 < \eta \leq 0.3$	$0.3 < \eta \leq 0.4$	$\eta > 0.4$
Level	Slight	Moderate	Heavy	over

5.4 Model verification

In order to verify the model, we select four typical countries from UN water scarcity map[7] according to the different levels of water scarcity, and then make a fifteen-year forecast for water situation from 2000 to 2015. Finally, we compare the results with the actual situation to verify the model.

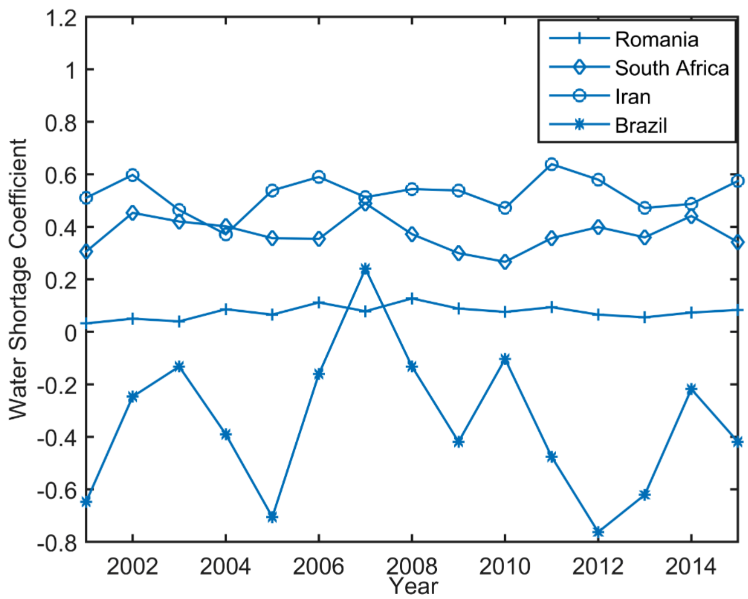

Figure 3: A 15-year forecast of water shortage coefficient of four countries

From Figure 3, after comparing with the actual situation, we can see that the results obtained by the model accord with the reality, it means that our model has its rationality and is suitable to predict the water conditions in the future within fifteen years.

6 A case study on Northern Sri Lanka

The reason why we select Northern Sri Lanka is that we notice that it has a rich freshwater endowment. In fact, Sir Lanka is blessed with 103 small and medium rivers, collecting about 52 billion cubic meters of annual surface runoff in a geographic area of 65,000km[8] . However, Sri Lanka is subsumed into the country where water is either heavily or moderately overloaded, especially the Northern Lanka. Therefore, it is necessary to analysis why and how water is scarce in Northern Sir Lanka.

• **Environmental drivers**:

Table 6: The conditions of water supply in Northern Sri Lanka in 2014

	Surface water((10^9m^3)	Groundwater(10^9m^3)	Reused water(10^9m^3)
Quantity	52	8	53

From Table 6, we can see that the surface runoff is plenty in Northern Sri Lanka, but the spatial distribution is not balanced, the wet-zone with only 23% of the land area account for 51% of the annual surface runoff, leaving large parts with sever water shortage (physical scarcity). At the mean time, the projects used to transport the water resource from wet-zone to dry-zone is too rare, thus leading the conditions of water scarcity does not get any improvement (economic scarcity).

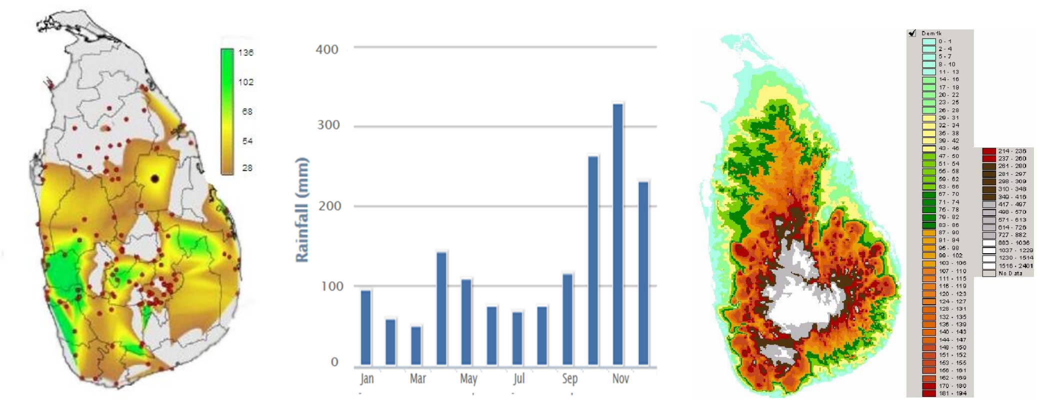

Figure 4: From left to right: The spatial distribution of precipitation, the temporal distribution of precipitation, the terrain of Sri Lanka

From Figure 4, it is noticed that the spatial and temporal variation of precipitation is also not in balance due to the influence of monsoonal weather patterns, and it leads to an extreme phenomenon: a large part of water is wasted in the rainy season, while the water is not enough for use in the dry season, in addition, the unique terrain: high in the middle and low on all sides, is easy to cause the flood and the flood water is difficult to control and use (physical scarcity). Meanwhile, the equipment like dam and reservoir is not consummate to store the excessive quantities of water, thus leading a low availability of water use (economic scarcity).

• **Social drivers**:

Table 7: The conditions of water use in Northern Sri Lanka in 2014

	Agriculture use($10^9 m^3$)	Industrial use($10^9 m^3$)	City use($10^9 m^3$)
Quantity	11.31	0.83	0.81

From Table 7, we can see that in addition to the low availability, water-use patterns in agriculture also aggravate water stress. Irrigation is by far the highest water use sector in Sri Lanka, accounting for over 90% of the water use, and the dry-zone districts account for 91% of the irrigated area (physical scarcity). Besides, although Sri Lanka had developed about 6bcm of storage capacity, this capacity is very low (per capita storage of only 291 m^3 compared to 5,961 m^3 in the U.S.A), therefore, the low storage capacity leads the economic water scarcity (economic scarcity).

7 Prediction for water situation of Northern Sri Lanka in the next 15 years

• Prediction of the water demand in the next 15 years:

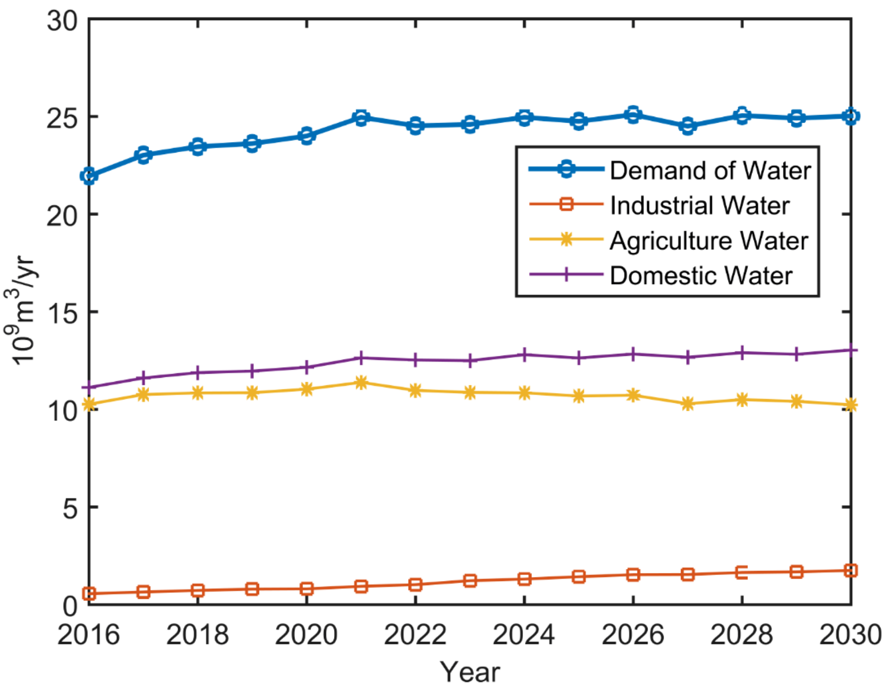

Figure 5: 15-year forecast of water demand in Northern Sri Lanka

From Figure 5, we notice that the total demand of water will maintain a steady level in the next fifteen years, and trend of the industrial water consumption, agriculture water consumption and domestic water consumption is also tends to be stable.

This situation is possible because the citizen of Northern Sri Lanka have already try their best to maintain the minimal amount of water usage due to the lack of water resource for a long time, and the ecological system also maintains its social function by using the minimum amount of the water resource.

• Prediction for the water supplement in the next 15 years:

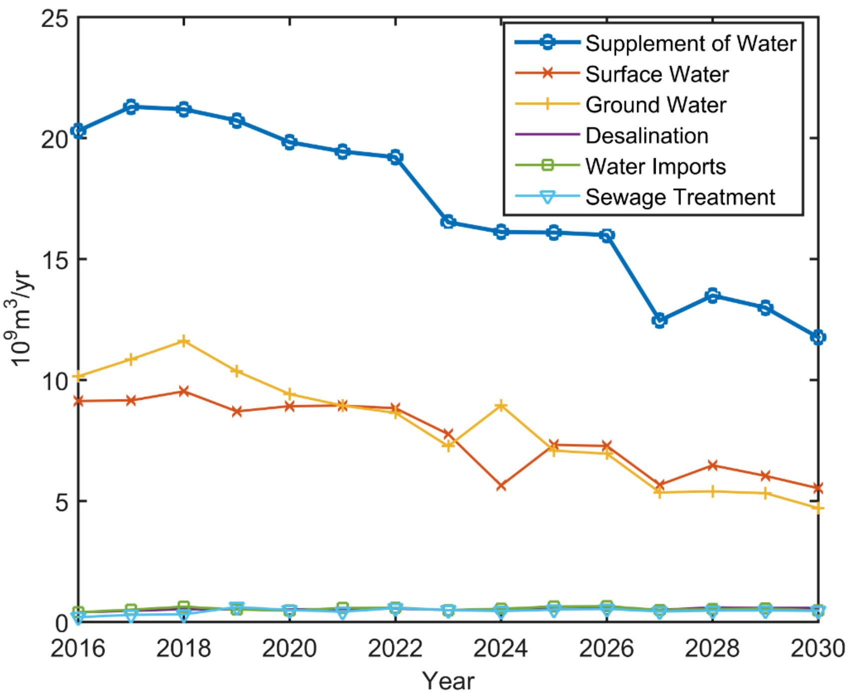

Figure 6: A 15-year forecast of water supplement in Northern Sri Lanka

From Figure 6,it is noticed that from an overall perspective, the supplement of water is going down sharply with surface water and ground water decrease rapidly. We can get the information that the source of the water supply is mainly derived from the surface water and ground water, the man-made supplement of water is only contribute a small amount of water.

The possible reason why the supplement of water decreased so quickly is that the water resource is confronted with being exhausted because of human overexploitation due to the lack of water resource.

• Prediction for the water shortage coefficient in the next 15 years:

From Figure 7,we can see that from an overall perspective, the water shortage coefficient is going up steadily and rapidly. According to the criterion of the level of water scarcity, the water situation in Northern Sri Lanka is excepted to remain a state of slight water deficit within in the next two years, and will reach the level of moderate water deficit in the third year in the future, then a mutation appears in 2023 due to the decrease

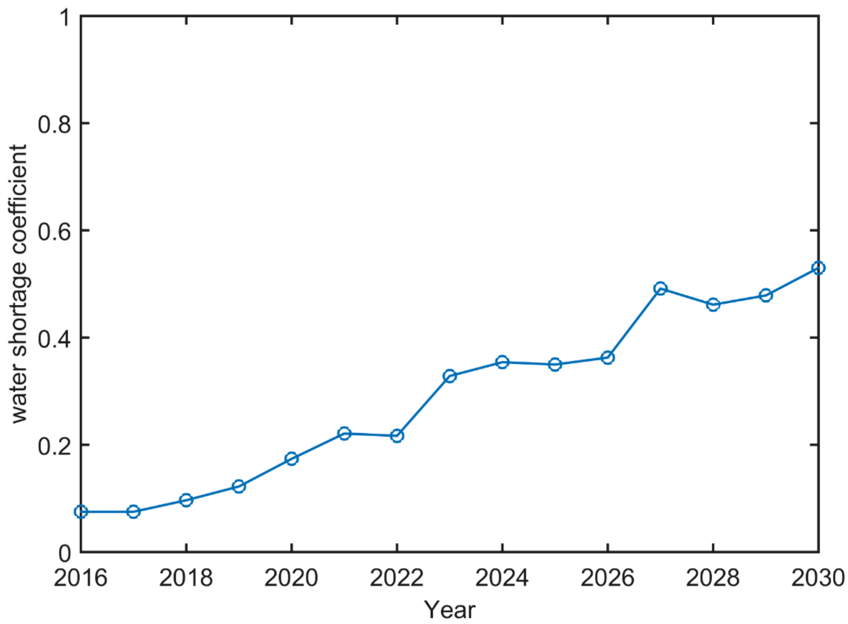

Figure 7: A 15-year forecast of water shortage coefficient in Northern Sri Lanka

of the supplement and the level of water shortage will reach the value of about 0.4, that is, the condition of water shortage will become serious and reach the level of severe water deficit. Then after a smooth period about three years, a greater mutation will appear in 2027 because of the mutation appeared in the supplement of water and the value of water shortage coefficient will reach 0.5, but will stability control to the volatility within 0.1 degrees.

The rapid increase of water shortage coefficient is mainly caused by the decrease of water supplement, and will have a huge impact on the lives of citizens lived in Northern Sri Lanka. For instance, due to the fact that Northern Sri Lanka is a primarily agricultural region and the rice is the most important crops in this region, the increase of water deficit will become the major abiotic stress in rice production,thus leading a lower standard of living for citizens.

8 A plan for alleviating water scarcity and its impact

Considered that the spatial and temporal variation of precipitation is not in balance and a large part of water is wasted in the rainy season, while the water is not enough for use in the dry season, we hold that it is necessary to build rain-harvesting reservoirs to store the water resource supplied in rainy season. In addition, we notice that coastal erosion is mainly caused by human sand excavation which will expend the area and degree of saline-alkali soil, therefore, it is of great importance to develop a policy to prohibit illegally sand excavation.

•The alleviation mechanism of the plan:

The problem of uneven distribution of water resource can be solved by building reservoirs. Those reservoirs play an active role in emergency water supply in Northern Sri Lanka, increasing the quantity of irrigation water in irrigated area, adjusting the allocation of water by using the water stored in rainy season.

The prohibition of illegally sand excavation can reduce the loss of water through stabilizing the structure of riverbed and coast.

•The impact on the larger context of the plan:

The positive impact is that reservoirs can increase the environmental humidity of the surrounding areas due to the increase of water evaporation. In addition, the climate will become warm and wet because of the construction of reservoirs, thus improving the production capacity of ecological system with the growth and reproduction of terrestrial animal and plant. In terms of the policy of prohibiting illegally sand excavation, it can maintain the stability of the river regime through the interaction between flow and sediment movement

The negative impact is that the vegetation coverage will decrease in the process of reservoir construction, thus causing water loss and soil erosion, because the water holding ability of soil will decline due to the destroy of vegetation and soil structure. Besides, the crust of the earth will increase because of the huge load of water, thus deteriorating the stability of fault plane and will induce earthquake under a certain condition.

9 A prediction on Sri Lanka after adding the intervention

Then we make a prediction of the water situation in Northern Sri Lanka after adding the intervention plan, then a brand new forecast on Northern Sri Lanka in 15 years can be obtained, and then compare with the original forecast made above.

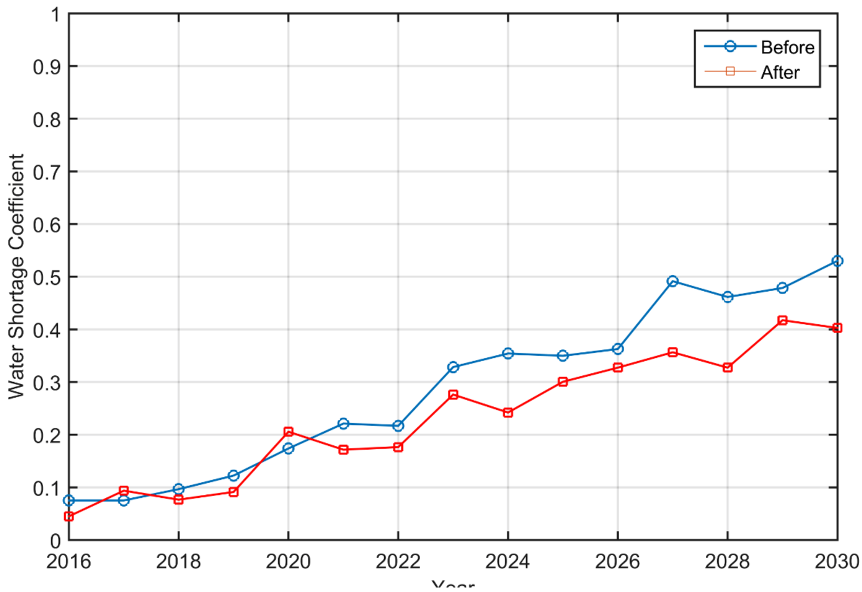

Figure 8: 15-year forecasts comparison of Northern Sri Lanka

From Figure 8,we can see that the value of water shortage coefficient declined to some extent after adding the intervention plan which shows that the intervention plan made above indeed operated on the water shortage coefficient and let it down, though the effect is not obvious and even aggravates the degree of the water deficit in the early period. But on the whole, the Northern Sri Lanka will become less susceptible to water scarcity.

It is noticed that the value of water shortage coefficient is about 0.4 in 2030, it means that the level of water scarcity is heavy in Northern Sri Lanka in the next fifteen years, meanwhile, considered the trend of the degree of water deficit is continues to grow, so we think that the water will become a critical issue in the future.

In terms of the prediction without adding the intervention plan, we noticed that s-carcity will occur in 2027, for the value of water shortage coefficient suddenly has a mutation in this year, and lead the Northern Sri Lanka in a condition of over exploited. However, as for the prediction with the intervention plan, the state of over exploited is not appear, but with the respect to the increase trend of water shortage coefficient, we conjecture that the scarcity will occur after the year of 2030.

10 Sensitivity analysis

This paper is required to conduct a sensitivity analysis on water shortage coefficient by changing the correlation coefficient.

• Sensitivity analysis by changing correlation coefficient of industrial water:

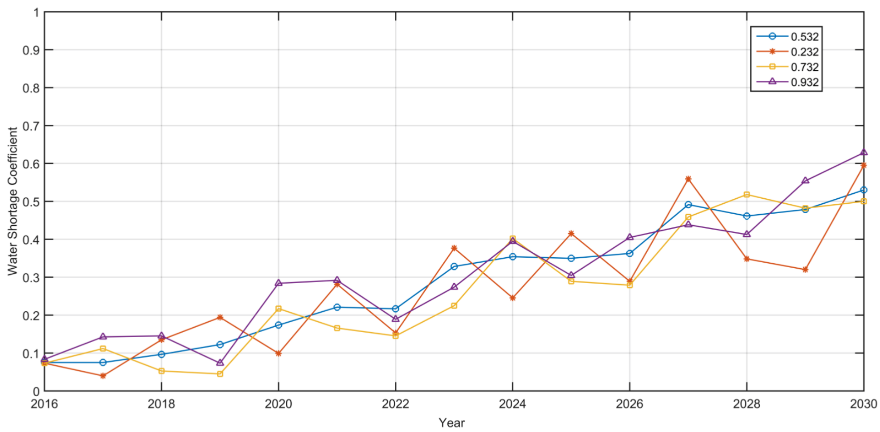

Figure 9: Sensitivity analysis by changing correlation coefficient of industrial water

Figure 9 implies that the relation between the correlation coefficient of industrial water and water shortage coefficient is not close due to the fact that the line is not changed much with the great change of the industrial water's correlation coefficient. That is, the value of water shortage coefficient has low sensitive to the industrial water.

• Sensitivity analysis by changing correlation coefficient of agriculture water:

Figure 10 implies that the higher the value of agriculture water's correlation coefficient is, the lower the water shortage coefficient is. It means that a slight change of the

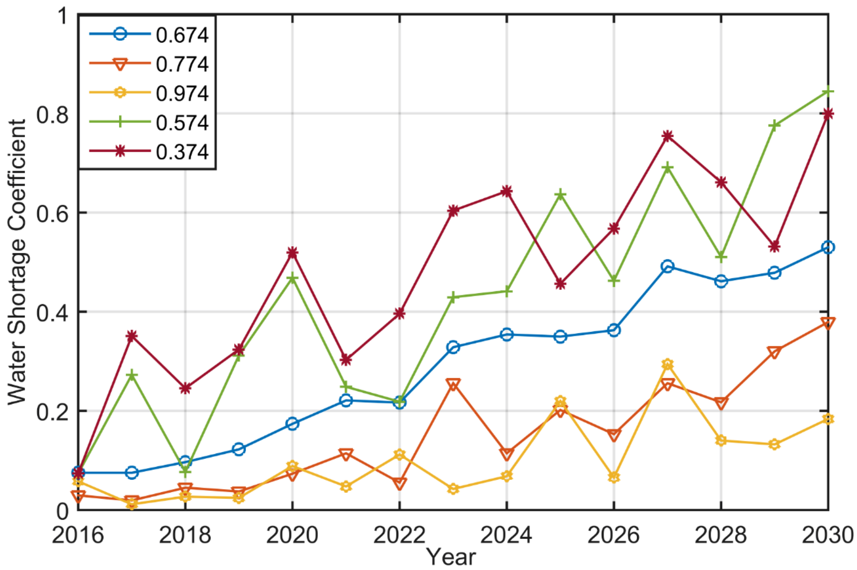

Figure 10: Sensitivity analysis by changing correlation coefficient of agriculture water

correlation coefficient of agriculture will cause a huge fluctuation of the water shortage coefficient. Therefore, we can conclude that value of water shortage coefficient has high sensitive to the agriculture water.

11 Strengths and Weaknesses

strengths:

- Our model shows a large amount of information, thus making a comprehensive analysis on the actual problem.
- Several analysis methods such as quota analysis and correlation analysis are utilized to fulfill the model, thus making the results more convincing and make the final close a lot easier.
- The consequences are easy to concluded, because the model calculation is brief and simple.

Weaknesses:

- The prediction may not accurate to some extent due to the lack of data. Because the matter is difficult to do a 15-year prediction by using limited set of data.
- The relevant factors selected are not enough due to the complexity of the system, therefore some factors were not taken into consideration.
- The elements used to make comprehensive evaluation are rare and to some extent, can not completely evaluate the level of water shortage.

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