IOP Conf. Series: Earth and Environmental Science **64** (2017) 012016 doi:10.1088/1755-1315/64/1/012016

Supply-demand 3D dynamic model in water resources evaluation: taking Lebanon as an example

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Abstract. In this paper, supply-demand 3D dynamic model is adopted to create a measurement of a region's capacity to provide available water to meet the needs of its population. First of all, we draw a diagram between supply and demand. Then taking the main dynamic factors into account, we establish an index to evaluate the balance of supply and demand. The three dimension vector reflects the scarcity of industrial, agricultural and residential water. Lebanon is chosen as the object of case study, and we do quantitative analysis of its current situation. After data collecting and processing, we calculate the 3D vector in 2012, which reveals that agriculture is susceptible to water scarcity. Water resources of Lebanon are "physical rich" but "economic scarcity" according to the correlation chart and other statistical analysis.

1. Introduction

Water covers 71% of the Earth's surface and it is vital for all known forms of life. Although there is a tremendous amount of water, many observers have estimated that by 2025 more than half of the world population will be facing water-based vulnerability [1]. The reason is that a reliable supply of water for future growth must be available to local populations in sufficient quantity and quality, while not compromising local ecosystems. Because of increasing population and climate change, many countries are exposing to the risk of severe water scarcity and its subsequent challenges. According to Human Development Report, more than one out of every six people in the world is water stressed, meaning that they do not have access to potable water. Thus, it is of great significance to find a way to alleviate this water scarcity problem and reestablish a better world for today's generation.

Climate change, urbanization and water pollution cause adverse effects on water resources and rehabilitation costs may exceed the carrying capacity of countries or regions. A standardized indicator framework is necessary to assess water resources. Water Stress Index is an advanced concept (ranging from 0 to 1), serving as a characterization factor for a suggested midpoint category "water deprivation" in LCIA [2]. Afterwards, some other researchers gave a critical review of the City Blueprint Approach regarding the assessment of the sustainability of water resources [3].

2. Supply-demand 3D Dynamic Model

To simplify the problem, we make three basic assumptions, each of which is properly justified. At first, during the study periods, the population growth and water consumption per capita are independent from each other. The population growth follows its historical trend: individual's water consumption does not change because of population change. Water consumption per capita is affected by other

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dynamic factors which are explained in the following part. The next one is that the dispersal of pollution is not influenced by wind speed or water velocity. The data about these natural factors are unavailable, so we don't consider them in our model to simplify the complex problem. At last, a country's development goal is try to make balance between economies, ecology, and security and ease the water stress. A country needs to project a sustainable development plan and reestablish a better world for today's generation and next generations.

2.1. A Diagram of Water

Before analysis, we create a diagram of the main factors that influence the total demand of water and total supply of water.

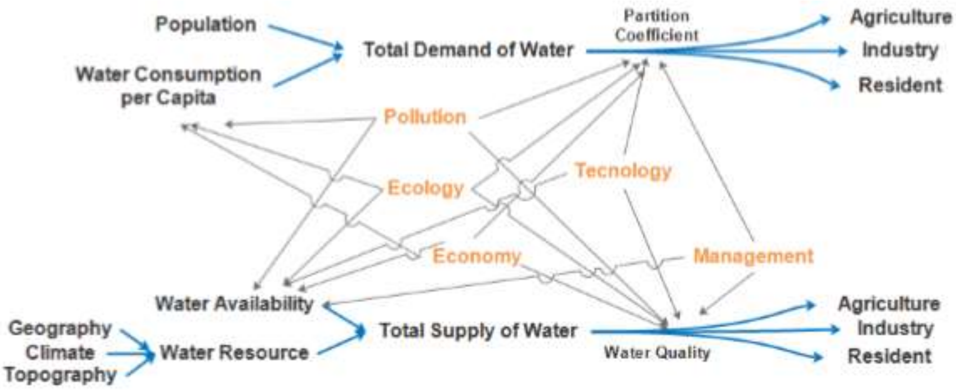

Figure 1. Supply and demand diagram of water.

In the diagram, the main factors are pollution, ecology, economy, technology and management. And all these macro factors are decomposed to micro factors. Lines link two factors which have relationship.

For the sake of measuring a region's capacity to provide clean water to meet the needs of its population, we consider the demand and supply factors respectively. Then we define and establish a Supply-Demand Index (SDI) which reflects the balance level between water supply and water demand. Through this index, we will judge whether a region is suffering from water scarcity or not.

2.2. Water Supply

To measure the sustainable water supply, we need to take both physical factors and socio-economic factors into account. Our water supply model is shown as below:

$$TS(t) = WR(w_t^1, w_t^2, \cdots, w_t^n) \cdot \eta(t),$$

where TS(t) is the total supply of water, WR is the quantity of water resources, $w_t^1, w_t^2, \cdots, w_t^n$ are different types of water resources: surface water, ground water, seawater desalination, etc. $\eta(t)$ is the conversion coefficient from water resources to available water.

Then, we allocate the total supply to three applied aspects: industrial water, agricultural water and residential water:

$$[S_t^i \; S_t^\alpha \; S_t^\gamma] = TS(t) \cdot [\sigma_t^i \; \sigma_t^\alpha \; \sigma_t^\gamma],$$

where $[S_t^i \; S_t^\alpha \; S_t^\gamma]$ is a matrix revealing the water supply for industrial, agricultural and residential purposes, $[\sigma_t^i \; \sigma_t^\alpha \; \sigma_t^\gamma]$ is the transfer matrix from total supply to three sectors.

2.3. Water Demand

As for water demand, we consider two factors: population and water consumption per capita.

About population, logistic model is a common model to simulate population growth [4]. This model is based on the assumption that there is a maximum of population named Environmental Capacity, constraint by environmental conditions. When the population reaches Environmental Capacity, it won't increase any more. Given the hypothesis that environmental conditions have negative impacts on the population, the impact is scale up as the population density. The logistic model is shown as following:

$$\begin{cases} \dfrac{dN(t)}{dt} = [\alpha - \beta N(t)] \cdot N(t) \\ N(t_0) = N_0 \end{cases}, \tag{1}$$

where $P(t) = \alpha - \beta N(t)$ is the net growth rate of population, α is the natural growth rate of population, β is the coefficient of life, $N(t)$ is the population at time t, and $N(t_0)$ is the population at initial time t_0.

Equation (1) is a Bernoulli Equation. However, parameter α and β are difficult to determine as they may influence the accuracy of predicted results. For this reason, we introduce a net growth rate model:

$$P(t) = at + b \quad (ab < 0).$$

In this case, solving the equation, we get:

$$N(t) = N_0 \cdot \exp[-(bt_0 + at_0^2 / 2)] \cdot \exp(bt + at^2 / 2).$$

Then, we begin to consider the water consumption per capita. A person's demand of water depends on many dynamic factors. According to previous studies [5, 6], water price and pricing manner can affect people's water consumption. Water saving technology and apparatus also greatly influence the amount of water demand per person. In addition, personal life style, social culture and some other elements do have relationships with people's demand of water.

Considering the features of these factors, we divide them into three kinds: trend-cycle factors, seasonal factors and random factors. Referring to Park's method [7], water consumption per capita can be decomposed as follows:

$$Y(t) = TC(t) \cdot [S(t) + R(t) - 1],$$

Where $Y(t)$ the water consumption is per capita, $TC(t)$ is trend-cycle factors, $S(t)$ is seasonal factors, and $R(t)$ is random factors.

Accordingly, we can calculate the total demand of water:

$$TD(t) = N(t) \cdot Y(t).$$

Also, we allocate the total demand to three applied aspects: industrial water, agricultural water and residential water:

$$[D_t^i \ D_t^\alpha \ D_t^\gamma] = TD(t) \cdot [\rho_t^i \ \rho_t^\alpha \ \rho_t^\gamma],$$

Where $[D_t^i\ D_t^\alpha\ D_t^\gamma]$ is a matrix revealing the water demand for industrial, agricultural and residential purposes? And $[\rho_t^i\ \rho_t^\alpha\ \rho_t^\gamma]$ is the transfer matrix from total demand to three sectors, it relied on the proportion of a region's demand for three different fields.

2.4. Supply-Demand 3D Dynamic Model

In this part, we measure a region's ability of providing available water to satisfy its citizens' demand. The Supply-Demand Index (SDI) can be calculated:

$$(SDI_t^i\ SDI_t^\alpha\ SDI_t^\gamma) = (\frac{S_t^i}{D_t^i}\ \frac{S_t^\alpha}{D_t^\alpha}\ \frac{S_t^\gamma}{D_t^\gamma}),$$

Where SDI_t^i, SDI_t^α and SDI_t^γ are Supply-Demand Index for industrial water agricultural water and residential water? The range of each index is (0, 1).

Therefore, the three dimension vector $(SDI_t^i\ SDI_t^\alpha\ SDI_t^\gamma)$ reflects the balance between supply and demand. We select some countries which have different levels of water scarcity to test our 3D model, and then get reasonable ranges for each level.

Table 1. Range of index.

range	0~0. 5	0. 5~0. 8	0. 8~1. 0
type	safe	warning	severe

3. A Case Study on Lebanon

Lebanon is a country in Western Asia. It is bordered by Syria to the north and east and Israel to the south. Lebanon's location at the crossroads of the Mediterranean Basin and the Arabian hinterland facilitated its rich history and shaped a cultural identity of religious and ethnic diversity.

Lebanon is referred to as the source of water in the Middle East. Its water resources are far more than its neighbors Israel and Syria. As estimated, it can obtain 4. 3 billion cubic meters of water per year,

Among which 0. 51 billion cubic meters flows to the north and 0. 44 billion cubic meters flows underground to Syria and Israel, while 0. 75 billion cubic meters inflows the sea.

3.1. Data Sources and Processing

We collect data from World Bank, NOAA Central Library, WHO and Lebanon Statistical Yearbook. The data are about Lebanon's climate, hydrology and social economy. Then we delete the indicators which are seriously lack (over 20%) and do data interpolation with the rest of indicators, in order to make data available for our study and ensure the accuracy.

3.2. Water Scarcity Analysis

Adopting supply-demand dynamic 3D model, we can calculate the 3D vector of Lebanon in 2012:

$$(SDI_t^i\ SDI_t^\alpha\ SDI_t^\gamma) = (0.51, 0.89, 0.65).$$

The result is intuitively shown in Figure 2.

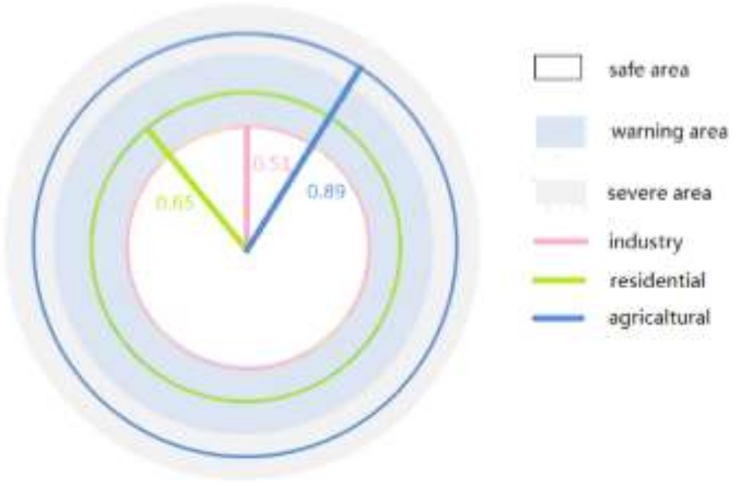

Figure 2. Result of 3D model in Lebanon.

As is shown in this figure, agricultural water is in the sever area (0. 8~1. 0); residential water is in the warning area (0. 5~0. 8); industrial water is in the safe area (0~0. 5).

Thus, we know that agricultural water in Lebanon is susceptible to water scarcity. However, Lebanon's agricultural economy occupies an important position in the domestic economy, which has a great influence on Levant area economy. Agriculture's contribution to GDP is 7%, and about 15% percent of the population is engaging in farm production. As for residential water, it's also significant for people's every life. So it's high time to change the current situation of water scarcity, especially for the need of agricultural and residential purposes.

We choose both environmental and socio-economic factors to analysis their correlation with the level of water scarcity. The specific indicators are shown in Table 2.

Table 2. Indicators table.

water scarcity level	environmental factors	socio-econmic factors
industrial water(SDI1)	annual rainfall(V1)	technology investment(V4)
agricultural water(SDI2)	CO_2 emissions(V2)	population density(V5)
residential water(SDI3)	temperature(V3)	CPI(V6)
		GDP per capita(V7)
		education investment(V8)

Calculate the Pearson correlation coefficient between two factors, and the results is in Figure 3. Obviously, both the environmental factors and socio-economic factors have correlation with SDI. Technology and education investment have negative correlations with SDI, which means that if Lebanon invests more on technology or education, the water scarcity can be mitigated to some extent. Others have positive correlations with water scarcity.

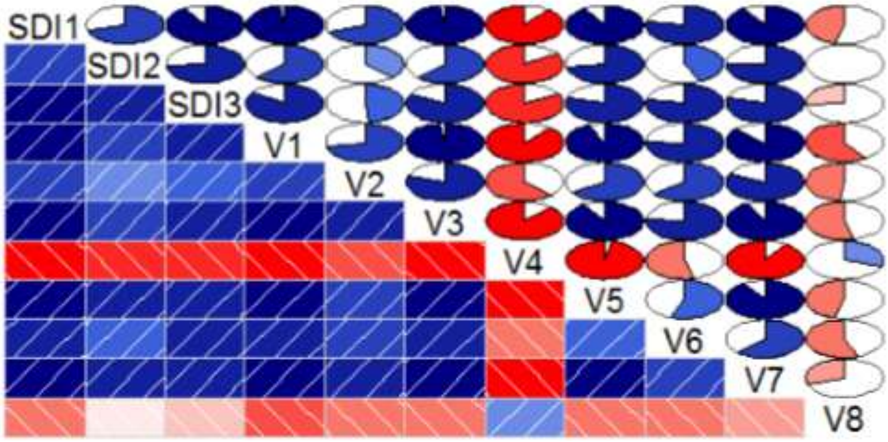

Figure 3. The correlation chart.

To interpret this graph, start with the lower triangle of cells (the cells below the principal diagonal). By default, a blue color and hashing that goes from lower left to upper right represents a positive correlation between the two variables that meet at that cell. Conversely, a red color and hashing that goes from the upper left to the lower right represents a negative correlation. The darker and more saturated the color, the greater the magnitude of the correlation. Weak correlations, near zero, will appear washed out.

4. Conclusion

In our research, we consider all the macro factors which can influence the water supply or water demand, and then divide them into micro factors. So the system is comprehensive and can describe the relationships of these factors clearly. The three dimension vector reflects the scarcity of industrial, agricultural, and residential water. Thus, we can know about the situation of each sector.

Usually, there are two primary causes for water scarcity: physical scarcity and economic scarcity. Physical scarcity is where there is inadequate water in a region to meet demand. Economic scarcity is where water exists but poor management and lack of infrastructure limits the availability of clean water. In this case, knowing about a country's main causes for water scarcity, we can find more effective ways to deal with the problem. Through our analysis, water resources of Lebanon are "Physical Rich" but "Economic Scarcity".

References

[1] Kulshreshtha, A global outlook for water resources to the year 2025, Water Resources Management. 12 (1998) 167-184.
[2] S. Pfister, A. Koehler, S. Hellweg, Assessing the environmental impacts of freshwater consumption in LCA, Environmental Science&Technology. 14(2009)4098-4104.
[3] S. H. A. Koop, C. J. Van Leeuwen, Assessment of the sustainability of water resources management:a critical review of the city Blueprint Approach, Water Resources Management. 29(2015)5649-5670.
[4] G. F. Mulligan, Logistic population growth in the world's largest cities, Geographical Analysis. 38(2006)344-370.
[5] OECD, Household energy&water consumption and waste generation, Paris, 2001.
[6] OECD, Household water pricing in OECD countries, Paris, 1999.
[7] S. O. Park, Seasonal adjustment method of employment statistics:X-12_ARIMA, Journal of Korean Official Statistics. 14(2009)40-68.