Assessment and Projection of Water Demand in Changing Scenarios for India

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Abstract

Water sustainability measures in terms of water availability and water demand; any significant change in water availability impacts the water sustainability and thus food sustainability. Declining water resources, changing climate and rainfall pattern, increasing water demand for agricultural, domestic and industrial purposes creates the pressure on water sustainability. A quantitative analysis of water sustainability is essential for populous and water scarce country like India for long term policy planning. Crop-wise analysis of water demand gives the accurate estimate of total water demand for agriculture purpose. In the present study, we develop a mathematical model to estimate the crop-wise water demand and projected water sustainability in different scenarios of population growth, consumption pattern and climate change.

Key Words: Water Sustainability, Water Footprint, Virtual Water Trade, Loss of Water Sustainability, Climate Change, Socio-Economic Change

1. INTRODUCTION

Water sustainability is defined as a ratio of total renewable water available to the total water demand. The water sustainability is limited by the constraints like declining available water resources, increasing water demand due to population growth and consumption pattern, and changing climate [1-4]. Virtual water trade also creates additional pressure on water sustainability [5]. Agricultural production depends on availability of water resources [6, 7]; any significant change in water resources may cause for loss of water sustainability and thus food sustainability [2, 8, 9]. Similarly, the water demand depends on population growth, changing consumption pattern, increasing food demand and industrial developments. Several studies have shown the large impact of these factors on water resources [8].

Climate change is one of the most affecting constraints for water resource availability; it has the potential to later the hydrological cycle, water availability, water quality and rainfall pattern from regional scale [10-13] to global scale [1-3].

Increasing demand and declining water resources, a quantitative analysis of water sustainability with constraints is required for water scarce and populous country like India. Crop-wise analysis of water requirement can give the accurate estimate of total water demand for agricultural purposes. Several studies have estimated the crop-wise water requirement [5, 14]; the projection of water demand as function of population, consumption pattern and climate change is missing. Therefore, a crop-wise quantitative analysis and projection of water demand is required to maintain water sustainability and making long term policies.

The main objective of the present study is the analysis of crop-wise water requirement to estimate the total water demand for agricultural purposes and to develop mathematical model to estimate the current state of water sustainability and project the water sustainability in different scenarios of population growth, consumption pattern, climate change and water demand.

2. FORMULATION

2.1 Total precipitated water

Total precipitated water, the total water volume available in the given region, is defined as

\[ W_T(t) = R(t) \cdot \text{Area} \]

(1)

Where \( W_T(t) \) represents the total water precipitated in the region for the year \( t \), \( R(t) \) and \( \text{Area} \), respectively, represent the total area-averaged annual rainfall (in mm) and the total area of the given region.

2.2 Total utilisable water available

The total available water for a country in a year is taken as the sum of ground water and surface water available through annual rainfall; for quantitative assessment, we define the total water available in a year \( t \), \( W_A(t) \), as

\[ W_A(t) = \alpha \cdot R(t) \cdot \text{Area} + W_G \]

(2)

where \( R(t) \), \( \text{Area} \) and \( W_G \), respectively, represent area-averaged annual rainfall (precipitation depth in mm) for the year \( t \), total land area and ground water. In general, only a fraction of the annual rainfall water will be available for utilization due to runoff and evapotranspiration; the value of \( \alpha \) is 0.54 for India. The first term represents the total surface water available and the second term of the right hand side represents the potential ground water resource for India. The total utilisable water in India is about 1869 billion m³ of India (AQUASTAT).
2.3 Total Water demand
The available water is used for the agricultural, domestic and industrial purposes.

\[ W_T(t) = W_{DA}(t) + W_{DD}(t) + W_{DI}(t) \]  

Here \( W_{DA}(t) \), \( W_{DD}(t) \) and \( W_{DI}(t) \) represent respectively the water demand for agriculture, domestic and industrial purposes. Agriculture sector is the main consumer of total available water resources; about 90 percent of total utilisable water is used for agricultural purposes and 10 percent is used for non-agricultural purposes like domestic and industrial purposes. We have not considered water demand for domestic and industrial sector.

2.4 Water demand for agricultural practices
Water demand for agricultural practices depends on the agricultural production and water footprints of the crops. Therefore, the water required for agricultural purposes in terms of agricultural production is defined as

\[ W_{DA}(t) = \sum_{i=1}^{N} F_{PC}(i,t) \cdot W_{FP}(i) \cdot N(t) \]  

Where \( F_{PC}(i,t) \) represents the per capita food production of \( i \) th crop for the year \( t \), \( W_{FP}(i) \) represents the water footprint of the crop \( i \) and \( N(t) \) represents the population of the country for the year \( t \). The water footprint of the crop is adopted from the study [14].

Similarly, the total water demand in terms of food consumption is defined as

\[ W_{DA}(t) = \sum_{i=1}^{N} F_{CP}(i,t) \cdot W_{FP}(i) \cdot N(t) \]  

\( F_{CP}(i,t) \) represents the food consumption per capita of \( i \) th crop for the year \( t \).

2.7 Water surplus
Water surplus, \( W_S(t) \), is calculated as

\[ W_S(t) = W_{A}(t) - W_{D}(t) \]  

2.8 Projection of population for sustainability
For projection of water demand and sustainability, we have considered demand in terms of projection of population. We represent the population of either India as

\[ \frac{dN_T(t)}{dt} = \gamma \left( 1 - \frac{N_T(t)}{N_{PS}} \right) N_T(t) \]  

Where \( N_T(t) \) is the population for the time \( t \). \( \gamma \) and \( N_{PS} \), respectively, are the rate of growth and carrying capacity of population for India.

3. METHODOLOGY AND DATA
The observed data for agricultural production, food consumption, export and import of all crops and population has been adopted from Food and Agriculture Statistics Division (FAOSTAT). The observed data for total renewable water resources, surface water, ground water, per capita availability of water resources, total water used for agricultural purposes have been adopted from AQUASTAT. The water footprints of crops, as sum of green and blue water footprint, have adopted [14]. The all India average annual rainfall is adopted from Rajeevan et al. [15] for the year 1961-2010.

4. RESULTS AND DISCUSSION
4.1 Total water available and per capita water availability
Water sustainability depends on available water resources. The total utilisable water (BCM, billion m\(^3\)) is given in Fig. 1 (solid line; left y axis), the average water available is about 1870 (billion m\(^3\)). A sharp decline have shown in the total water available in the period 1990 to 2010 (Fig. 1, solid line, left y axis). Similarly, the per capita water availability also have shown the declining trend (Fig. 1, dotted line); per capita water availability decreases from 5700 m\(^3\)/per capita/year to 1800 m\(^3\)/per capita/year in the last 50 years (figure 1, dash line, and right y axis).

4.2 Water demand and water surplus
Crop-wise water requirement has shown in Fig. 2, the water demand to produce the major crops in food grains like wheat, rice, maize, millet and barley in terms of quantity (Fig. 2, top left panel) and in terms of percentage (Fig. 2, bottom left panel) are given in Fig. 2, left panel. While the group-wise water required to produce the crops are given in terms of quantity (Fig. 2, right top panel) and in terms of percentage (Fig. 2, right bottom panel) are given in the Fig. 2, right panels.

The total water demand for agricultural purposes has increased from 400 billion m\(^3\) to 1000 billion m\(^3\) (Fig. 3, top panel, solid line) in the last 50 years. In terms of percentage, the water demand has increased from 20 percent to 60 percent of total water available in 50 years (Fig. 3, dash line, right y axis). On the other hand, the water surplus has decreased from 1500 billion m\(^3\) to 800 billion m\(^3\) in the last 50 years (Fig. 3, bottom panel, solid line). Current water surplus is about 40% of total water resource (Fig. 3, bottom panel, dash line).

4.3 Impact of critical population load on water demand
The crop-wise water demand as function of population based on current per capita food consumption has shown in figure (4); in terms of quantity in figure (4, top panel) and in terms of percentage in figure (4, bottom panel). Food grains and oil
crops are major water consumer crops; about 600 billion m$^3$ (≈25 percent of total water available) water required to fulfill the food demand for current population for food grains only while about 1200 billion m$^3$ (≈60 percent of total water available) water is required to fulfill the food demand for doubling population (Fig. 4). Similar conclusion also holds for other crops. In the doubling population scenarios, the total water demand is higher than total water available (Fig. 4).

4.4. Impact of consumption pattern and climate change on water surplus

The impact of climate change and changing consumption pattern on water surplus has shown in Fig. 5 for current population (top panel) and doubling population (bottom panel). The water surplus is higher for excess in rainfall with lower per capita consumption than the deficit in rainfall and higher per capita food consumption. The sustainable situation of water surplus is for the per capita food consumption in the rage 50-100 percent (current) and rainfall 100-140 percent of average rainfall. While for deficit in rainfall and higher per capita food consumption put the pressure on water surplus (Fig. 5, top panel). Similarly, for doubling population scenarios, the ideal situation for survival in lowest per capita food consumption and excess in rainfall (Fig. 5, bottom panel).
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domestic and industrial purposes is in increasing trend and the
are in declining trend
population in doubling population scenario.
The projection of water demand shows that the total water
available
is required to fulfil the food needs of growing
-estimation of
climate change and consumption per
capita (as percentage of current consumption of water) for
current population (top panel) and doubling population (bottom panel). The horizontal line represents the current
rainfall and the vertical solid line represents the current
per capita food consumption.

5. CONCLUSION

Our basic objective of the present study is the assessment of the
water resources, estimation of the water requirement for
agriculture and crop-wise projection of water requirement in
different scenarios of population, per capita food consumption and changing climate. In the present study, we have found that
there is large impact of population growth, consumption pattern and climate change on available water resources.

The projection of water demand shows that the total water
available is required to fulfil the food needs of growing
population in doubling population scenario. The main
conclusion of the present study is the available water resources
are in declining trend while the water demand for agriculture, domestic and industrial purposes is in increasing trend and the
water demand will be double in the future. The other
conclusion of our study is that the large impact of climate
change, consumption pattern and population growth on water
resources.

We have considered green water and blue water footprints of
the crops while the water polluted due to agriculture (grey water) is excluded from the present study. We have also
excluded the industrial water demand due to unavailability of
data for industrial products and water footprint.

We have considered the water demand for agriculture purposes
in terms of agricultural production only. The methodology is
quite generic and applicable for other regions.

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