Blue and green water security assessment of Karuvannur watershed

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Abstract. Water security is referred as the availability of sufficient amount of good quality water to cater all ecosystem services with a tolerable level of water related risks; whereas water scarcity is defined as the ratio of water demand over water availability which is an indirect indicator of water security [1]. In order to assess the water security in terms of its specific use and availability, it is classified in to blue and green water. For this, the various components of blue and green water are calculated and water security in terms of blue and green water is assessed separately using ArcSWAT software. The crop water requirement is assessed using CROPWAT model. It is observed that in the study area, both blue and green water is secure in the current scenario but green water is less secure when compared to blue water. Therefore more attention is to be given for the conservation of green water in the study area. Since the scarcity value shows an increasing trend, stringent measures are to be initiated for water conservation henceforth, in order to assure a sustainable water security in the coming future.

1. Introduction
Availability of freshwater is fundamental for the survival of life on earth. Climatic and landuse changes, along with increased human demand put a constraint on water security worldwide. So water scarcity occurs when the amount of water available is no longer adequate to meet the requirements of the ecosystem.

Water scarcity is defined as the ratio of water demand over water availability and it is used as an indicator of water security prevailing in any watershed [1]. Water security is referred as the availability of sufficient amount of water of good quality to boost all ecosystem services with a tolerable level of water related risks [2]. Assessment of water security is important since it enables us to take proper remedies before the situation gets worsened.

Water available can be classified into blue and green water depending on its mode of availability. Blue water is found above or below the earth’s surface and is generally stored in rivers, lakes, aquifers, dams etc. Green water is the portion of precipitation which is retained in the upper layers of soil and returns to atmosphere through evapo-transpiration. Green water is again classified into green water flow which is the actual evapo-transpiration and green water storage which is the amount of soil moisture [1].
In most of the studies on water security, only blue water was taken into account since it is directly linked to human consumption whereas green water which is indirectly linked to human consumption was ignored. Green water resources are substantial for agricultural production. Therefore an assessment without green water is incomplete. Water security assessment using blue and green water concept gives a more precise idea on the water security of the study area and also helps in identifying the areas with limited freshwater availability in a given watershed. This concept helps in estimating the site-specific water demand of agriculture and also gives a clear picture about the effects of human intervention on freshwater resources. It also enables water resource engineers and other stakeholders to get a better understanding on the remedial measures to be taken to fight water stress.

In this study, water available is found out using ArcSWAT and is classified into blue and green water. Knowing the water demand for various uses, water security in terms of blue and green water available in the region is quantified (i.e., water security is assessed separately for both blue and green water in terms of their scarcity values).

2. Literature review
The purpose of this study is to analyze the water security of Karuvannur watershed independently for both blue and green water. In order to set the objectives and to formulate the methodology, various research papers on hydrologic models, assessment of water security based on blue and green water concepts and crop water requirement/estimation methods have been referred.

Fadil et al. (2011) simulated the stream flow and estimated the water balance for the Bouregreg basin using ArcSWAT model. The monthly inflow to a dam located at the basin outlet was also calculated. It was observed that a good correlation between the observed and simulated monthly average river discharges could be obtained using this model [3].

The concept of classifying water into blue and green water was put forward by Falkenmark (1995). He described green water as the portion of rainfall that infiltrates into the root zone of plants which is used for biomass production and blue water is that which is stored in lakes, aquifers etc [4]. He has also explained the importance of considering green water in water resources management which was often ignored in the earlier studies [5].

Giri et al. (2018) used a combined modelling framework consisting of ArcSWAT, which was loosely coupled with an agent based probabilistic land use conversion model. They have analyzed how the factors affecting blue versus green water security vary both spatially and temporally. They were able to develop a better knowledge about the interaction or change of various factors in the watershed as well as the time period of a year in which water scarcity occurs [2].

Gangwar et al. (2017) have estimated the reference evapo-transpiration, crop water requirement and irrigation water requirement for the major rabi crops (wheat, pulses and mustard) for Bina Command in the Sagar district of Madhya Pradesh using the software CROPWAT 8.0 which was developed by FAO (Food and Agriculture Organization). The study was found to be efficient in estimating the actual amount of irrigation water that is required by any crop and hence it is a helpful in the assessment of irrigation water requirement and for the efficient management of irrigation process both qualitatively and quantitatively [6].

3. Study area
The purpose of this study is to analyze the water security of Karuvannur watershed in Kerala State for both blue and green water separately. It is located in Thrissur district and is bounded at North by Thrissur and Chavakkad taluks of Thrissur district, South by Mukundapuram and Kodungallur taluks of Thrissur district, East by Alathur and Chittur taluks of Palakkad district and West by Arabian Sea. It lies between the latitude of 10° 15’ to 10° 40’ North and longitude of 76° 00’ to 76° 35’ East. The location map of the study area is shown in Figure 1.
The length of the main stream is forty eight kilometers and it drains an area of 1,054 square kilometer. The river originates from the Western Ghats (Pumalai Hills). The two main tributaries of the river are Manali and Kurumali. The Manali River originates from Ponmudi in the boundary of Thrissur and Palakkad districts at an elevation of +928 m. The Chimony and Muply, the two sub tributaries of the Kurumali originate from Pundimudi at an elevation of + 1116 m. It provides potable water to numerous Panchayats in Thrissur District. It has an actual utilizable water resource of 623 Mm$^3$, of which the net utilizable surface and ground water resources are 519.8 Mm$^3$ and 103.2 Mm$^3$ respectively. The average annual precipitation in the low land, midland and highland of the river basin is calculated to be 2858 mm, 3011 mm and 2851 mm respectively.

4. Methodology

The study area is modelled using ArcSWAT (Soil and Water Assessment Tool) for three different decades (1990s, 2000s and 2010s) in order to simulate its hydrological processes. The input data for SWAT can be widely classified into spatial data and temporal data. The spatial data includes Digital Elevation Model (DEM), land use map and soil map whereas temporal data include meteorological parameters like daily precipitation, maximum and minimum air temperature, river discharge, relative humidity, wind speed and solar radiation along with the prevailing agricultural management practices. Sensitivity analysis, calibration and validation of the model are performed using SWAT-CUP model. Model is calibrated for a period from 2006 to 2008 and validated for a period from 2009- 2011.

The components of blue and green water available are obtained from the output of the calibrated ArcSWAT model of the study area. Blue water is computed as the summation of water yield and groundwater storage. Green water is estimated as the summation of soil moisture and evapo-transpiration.

Blue and green water demand for the study area is computed using the irrigation water requirement obtained from CROPWAT and also from the evapo-transpiration obtained from ArcSWAT. Data
required in CROPWAT includes soil map, maximum and minimum temperature, wind speed, relative humidity and sunshine, crop data and soil data. The estimated irrigation water requirement is compared with the blue water available. Population data of the study area is also used for estimating the domestic water requirement. Water security is assessed in terms of water scarcity separately for blue and green water components. Blue Water Scarcity is calculated as the ratio of demand and availability of blue water and similarly estimated green water security too.

Water is secure, if the scarcity value is less than one. While calculating the blue water availability, environmental flow requirement is considered. Environmental flow is the least possible amount of stream flow that is essential to preserve the downstream ecological integrity of the river. It is obtained from Global Environmental Flow Information System, IWMI. Similarly for groundwater also, environmental flow requirement concept is applied in order to prevent the over exploitation of groundwater.

Similarly, green water scarcity is calculated as the ratio of demand and availability of green water. Blue and green water securities in the study area are obtained for the last 3 decades and are compared. In order to understand the significance of blue and green water security, the total water security is also assessed along with them. As the total water scarcity is reckoned simply as the ratio of total water demand to total water availability, there is a possibility that surplus in one component may compensate for the insufficiency of the other, showing the total as agreeable, thus masking the reality.

5. Results and discussions

The irrigation water demand for the major crops in the study area is calculated using CROPWAT for the last three decades. The major crops considered are paddy and banana. This irrigation water requirement is used for calculation of blue water demand. On comparison, it is observed that there is a rising trend in the irrigation water requirement and is shown in Figure 2 below.

![Figure 2. Comparison of irrigation water requirement over the past 3 decades](image)

Hydrologic modelling of the study area is done in ArcSWAT and is calibrated in SWATCUP for a period from 2006 to 2008. The calibrated model is validated for a period from 2009-2011. The coefficient of determination (R²) obtained for calibration and validation are 0.843 and 0.810 respectively. Figure 3 shows the comparison of observed and simulated discharge after calibration and validation. The NSE value obtained for the calibrated and validated model are 0.62 and 0.55 respectively.
After performing calibration and validation, the model is made to suit the conditions of the study area. Blue and green water available is found out and is compared with blue and green water demand. Theoretically, a place is water secure when its scarcity value is less than one and is not secure when it is greater than one. Annual and seasonal variation in blue water availability and demand is determined and water security is assessed yearly. For easiness, decadal average is calculated and presented in Table 1. Similarly decadal average of green water security is also done. Both blue and green water security tend to decrease over the years.

Figure 4 shows the comparison of water security in terms of water scarcity in the past three decades; i.e., 1990s, 2000s and 2010s. It is observed that compared to blue water, green water is less secure. Also on comparing the total water security with blue and green water security, it is observed that even when the total water security shows a safer value, it is not true in the case of green water. This shows the importance of separately assessing water security in terms of blue and green water.
Table 1. Blue and green water security in terms of scarcity values over the decades

| Decade | Blue Water | | | Green Water | | | Total water scarcity |
|--------|------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|
|        | Average Annual Availability (mm) | Average Annual Demand (mm) | Scarcity | Average Annual Availability (mm) | Average Annual Demand (mm) | Scarcity | |
| 1990s  | 3274.63   | 955.69   | 0.29 | 928.76   | 843.21   | 0.91 | 0.43 |
| 2000s  | 3216.44   | 1764.22  | 0.54 | 925.567  | 902.427  | 0.975 | 0.64 |
| 2010s  | 3155.95   | 2281.60  | 0.72 | 928.73   | 822.97   | 0.89 | 0.76 |

From the table, it is clear that for all the decades, green water scarcity value is greater than blue water scarcity value. In all the three decades, even though both blue and green water seems secure (i.e., no scarcity), a rising trend can be observed as the time passes. The blue water scarcity value increased from 0.29 in 1990s to 0.54 (about 2 folds) in 2000s and 0.72 in 2010s (about 2.5 folds). Green water scarcity value increased from 0.91 in 1990s to 0.975 in 2000s and decreased to 0.89 in 2010s. This increasing trend in the scarcity value indicates water insecurity in the coming decades.

A further analysis is done to find out the seasonal variation in water security. Figure 5 shows the comparison of water security in pre-monsoon (cumulative value for the months February, March, April and May) and post-monsoon season (cumulative value for the months October, November, December and January).

Figure 5. Comparison of water security in terms of water scarcity values in the pre-monsoon season and post-monsoon season over different decades

Table 2 shows the blue and green water security in terms of their scarcity values for the pre-monsoon and post-monsoon season over the decades and Figure 6 shows the graphical comparison of seasonal variation of blue and green water scarcity.
Table 2. Pre-monsoon and post-monsoon blue and green water security in terms of their scarcity values for different decades

| Decade | Pre-monsoon | Post-monsoon | Total Water Scarcity |
|--------|-------------|--------------|----------------------|
|        | Blue Water  | Green Water  |                      |
|        | Annual Average Availability (mm) | Annual Average Demand (mm) | Scarcity | Annual Average Availability (mm) | Annual Average Demand (mm) | Scarcity |                      |
| 1990s  | 127.69      | 105.10       | 0.82                 | 62.86      | 99.74       | 1.60                 | 1.07     |
| 2000s  | 120.05      | 106.62       | 0.89                 | 57.79      | 109.63      | 1.89                 | 1.2      |
| 2010s  | 148.75      | 109.53       | 0.74                 | 44.85      | 77.99       | 1.74                 | 0.97     |

In nutshell, Table 3 gives the seasonal variation of scarcity values over the decades.

Table 3. Seasonal variation of blue and green water scarcity values for different decades

| Decade | Pre-monsoon | Post-monsoon |
|--------|-------------|--------------|
|        | Blue water scarcity | Green water scarcity | Blue water scarcity | Green water scarcity |
| 1990s  | 0.82        | 1.60         | 0.21                   | 1.08                   |
| 2000s  | 0.89        | 1.89         | 0.41                   | 1.72                   |
| 2010s  | 0.74        | 1.74         | 0.70                   | 1.82                   |

SEASONAL VARIATION OF WATER SECURITY
From the table, it is clear that, both blue and green water is less secure during the pre-monsoon season compared to post-monsoon season. Considering the case of blue water, it is secure during all the decades in both post-monsoon season and pre-monsoon season, whereas in the case of green water, it is not secure in both pre-monsoon and post-monsoon season in all the decades. Therefore more attention is to be given to conserve and minimize usage of green water. Since both blue and green water shows a decreasing trend in water security, proper measures are to be taken to ensure water security in the future. From the seasonal/annual comparison, it can be inferred that although annual water scarcity values lie on the safer side, temporal analysis shows seasonal variation.

6. Conclusions

Water security analysis is conducted by developing a hydrologic model of the study area in ArcSWAT software. The water demand is found out using the population data of the study area and irrigation water requirement is obtained from CROPWAT model. It is observed that even though the total water security shows a safer value, blue and green water security separately gives a different picture. It is also seen that in most of the study period, both blue and green water are less secure than the total. Therefore, separate assessment of blue and green water gives a better understanding of the water security of the study area. Moreover, though both blue and green water seems secure in the current scenario, trend analysis shows that both have an increasing trend. From temporal analysis, it is found that in both pre-monsoon and post-monsoon season, blue water is secure in all the decades whereas green water shows scarcity. The green water scarcity value shows an increase of 8.67% in 2010s when compared to 1990s in pre-monsoon season whereas it shows an increase of 68.22% in 2010s when compared to 1990s in the post-monsoon season. Thus temporal analysis on water security after labeling it in to blue and green categories has exposed the real issues of scarcity which was otherwise camouflaged. However, this inference cannot be generalized as this observation is obtained from an area which has agricultural land in more than half of the area.

References

[1] Giri S, Arbab N N, and Lathrop R G 2018 Water security assessment of current and future scenarios through an integrated modeling frame work in the Neshanic river watershed Journal of Hydrology 1025-1041.

[2] Bakker K 2012 Water security: Research challenges and opportunitues Science 337 914-915.

[3] Fadil A, Rhinane H, Kaoukaya A, Kharchaf Y, and Bachir O A 2011 Hydrologic modelling of Bouregreg watershed (Morocco) using GIS and SWAT model Journal of Geographic Information System 279-289.

[4] Falkenmark M 1995 Coping with water scarcity under rapid population growth Paper Presented at Conference of SADC Ministers, Pretoria, South Africa 23-24.

[5] Falkenmark M 2008 Peak water: Entering an era of sharpening water shortage Stockholm Water Front 3-4.

[6] Gangwar A, Nayak T R, Singh R M and Singh A 2017 Estimation of cropwater requirement using CROPWAT 8.0 model for Bina Command, Madhya Pradesh Indian Journal of Ecology 71-76.