Identification of water scarce regions of kunthipuzha river basin using water allocation tool

P Neethu Sidharth\textsuperscript{1,2} and Reeba Thomas\textsuperscript{1}
\textsuperscript{1}Department of Civil Engineering, Govt. Engineering College, Thrissur, Kerala, India.
\textsuperscript{2}Email: neethusidharthp@gmail.com

Abstract. Water scarcity and consequent droughts are of serious concern for almost all countries around the world. Since climate change is expected to exacerbate the already existing water stresses, the improvement of water efficiency against water scarcity and drought is very much important. The study aims at pin pointing the water stressed areas in Kunthipuzha River basin so that management practices can be suggested for the identified areas to minimize the water scarcity problems. To contribute towards this goal, Water Evaluation and Planning (WEAP) model is used, which is a Decision Support System (DSS) to assess water availability and investigate the impacts of different water allocation scenarios (water demand management strategies) aimed at meeting various sectorial water demands. The results from the study revealed that out of 13 sub basins of Kunthipuzha, 2 comes under severely stressed, 2 under moderately stressed and 3 under lowly stressed regions. The results derived can be used in future to work out feasible management practices for mitigating the water scarcity problems.

1. Introduction

Inappropriate management of water resources and a general reduction in rainfall has aggravated water scarcity problems in many parts of the country. Over usage of water resources continues to be the greatest constraint on sustainable agricultural development, which is an important factor for poverty alleviation. The quantitative estimates of water supply, water demand and water use, both temporally and spatially, can be assisted by modeling methods that are capable of simulating hydrological processes and water management activities at catchment level for the current situation, as well as alternatives for various scenarios, which are of great importance for socio-economic development [1]. There is also a need to consider the spatial and temporal availability of water on a regional basis so as to devise a tool for planning and decision taking while prioritizing water allocation.

Growth in population, increased irrigation on agricultural land and to top it all, the climate change have significantly increased water demand in the last decade. Consequently, water abstraction for livestock and household use has severely stressed water supplies, particularly during dry seasons. Despite its relatively plentiful freshwater resources, Kerala State experienced problems of water scarcity at an alarming rate in almost all the years in this decade, due to a combination of natural and anthropogenic factors. The State is also extremely vulnerable to the potential effects of climate change, owing to its geographic location and peculiar characteristics. Though Kerala receives abundant rainfall of about 3000mm annually, it faces water scarcity during summer months and water excess in monsoon season. Bharathapuzha River Basin in Kerala is one of the most critical river basins facing acute water stress. Although it is the largest of all of Kerala's rivers, the water flow is relatively low compared to other long rivers in Kerala since a large part of the basin is in the comparatively drier regions.
(Tamil Nadu and Palakkad Gap). Construction of a number of dams since independence also reduced the river flow and worsened the problem. The Bharathappuzha being the lifeline of many villages and cities in the state, often becomes stagnant during the summer month with hardly any flow. The Kunthipuzha River is one of the main tributaries of the Bharathapuzha River. Many areas of kunthipuzha river basin, namely Mannarkkad, Keralasseri, Sreekrishnapuram, Pookottukavu etc. often faces water scarcity problems regularly in summer season. Thus the objective of the study is to identify water scarce region in the Kunthipuzha river basin so that feasible measures can be suggested locally to mitigate water scarcity problems.

2. Description of study area
The Kunthipuzha River flows through Silent Valley National Park and is an important tributary of Bharathapuzha River, Kerala's second largest river basin. It has a total catchment of 1128 km², with mean annual rainfall of 2300 mm and the elevation varying between 20 and 2300m [2]. The major crops cultivated in the river basin include rice, rubber, coconut, pepper, banana etc. As per the 2011 census, the total population within the study area is about 10.65 lakh. Mannarkkad, Thachanpara, Sreekrishnapuram etc. are some of the areas within the basin which often faces the water scarcity problems. The location map of the study area is shown in Figure 1.

![Figure 1. Location of kunthipuzha basin](image)

3. Materials and Methods
A study was conducted by Mutiga et al. (2010) for minimizing the water use conflicts in the Upper Ewaso Ng’iro North Basin, Kenya by using the WEAP model. The goal of their study was to match the water requirements of various competing sectors in the basin with the available water resources. They have simulated the total unmet demand of the study area and also the unmet demand corresponding to various alternative scenarios for choosing the best alternative so as to minimize the water use conflicts [1]. Xue Li et al. (2015) used WEAP modelling system to evaluate the sustainability of limited water resources management strategies in coastal Binhai New Area (BHNA), China. Results from their study revealed that the pressure on the BHNA water supplies will increase in the future, and several recommendations have been suggested by them to assist decision-makers in planning water resources to meet potential needs in the region. [3]. This paper focuses on identifying the water scarce regions of Kunthipuzha basin by estimating the demand coverage rate of each of its sub basin in WEAP model. Thus the sub basins with unmet demand can be identified as water scarce areas, so that feasible Best Management Practices (BMP’s) can be suggested to minimize the water use conflict in future.

3.1 Hydrologic Modelling
In order to identify the water scarce sub basin within the study region, the total water available in each sub basin must be estimated first. For simulating the discharge at sub basin level, Arc-SWAT Hydrologic model is used, with the assumption that the surface water is the main source of available water [4]. The fundamental equation for SWAT model is water balance equation which is shown in equation 1.
SW_t = SW_o + \sum_{i=1}^{t-1} (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}) \tag{1}

Where, SW_t = Final soil water content, SW_o = Initial soil water content, R_{day} = Amount of precipitation, Q_{surf} = Amount of surface runoff, E_a = Amount of evapotranspiration, W_{seep} = Amount of water entering the vadose zone from the soil profile and Q_{gw} = Amount of return flow.

The Kunthipuzha basin is a basin with variety of crops and diverse land uses. For delineating the basin and dividing it into suitable number of sub-basins based on LULC characteristics, pore points are selected by trial and error. This will be helpful in simplifying and streamlining the process of implementing region-wise BMP’s for water scarcity mitigation. Delineation is done using Arc-SWAT hydrologic model, after tracking down the pore points in selected locations. The basin is divided into 13 sub basins. Figure 2 shows the Kunthipuzha river basin with its 13 sub basins.

![Figure 2. Kunthipuzha basin with 13 sub basins](image)

In order to realistically represent the site-specific hydrologic processes and conditions, calibration and validation of the model is done using SWAT-CUP. For this the model is run with the observed daily discharge values at Pulamanthole stream gauging station, with monthly time step for the period 1997 to 2009, with 3 years warm-up period. Model calibration is done for the period from 2000-2006 by using the observed discharge on a monthly basis [2]. Calibrated model is then validated and the validation is performed with an independent data set starting from 1st January 2007 to 31st December 2009. To test the accuracy of the model coefficient of determination (R^2) and Nash Sutcliffe efficiency (NSE) are used. Equation 2 and 3 are used to calculate coefficient of determination and Nash Sutcliffe efficiency respectively.

\[ R^2 = \frac{\sum (Q_{m,i} - Q_{m})^2 (Q_{s,i} - Q_{s})^2}{\sum (Q_{m,i} - Q_{m})^2 \sum (Q_{s,i} - Q_{s})^2} \tag{2} \]

\[ NSE = 1 - \frac{\sum (Q_{m,i} - Q_{s})^2}{\sum (Q_{m,i} - Q_{m})^2} \tag{3} \]

Where Q is a variable, m and s stands for measured and simulated respectively, i is the i^{th} measured or simulated data.

The coefficient of determination R^2 and NSE are obtained as 0.90 and 0.89 respectively during calibration and the same during validation are 0.98 and 0.97 respectively. Figure 3a and 3b shows the comparison of observed and simulated discharge during calibration and validation respectively. The obtained values of statistical indices R^2 and NSE indicate “very good” performance of the model in simulating the hydrology of the study area.
Figure 3. Figure a shows the Comparison of observed and simulated discharge after calibration. Fig b shows the comparison of observed and simulated discharge after validation.

For simulating the rainfall-runoff process to obtain the sub-basin-wise water availability in Arc-SWAT, the meteorological data corresponding to the year with acute water shortage in the last decade is selected and modelled. For that, the discharge data from Pulamanthole river gauging station from 1987 to 2014 is collected, analysed and identified the most critical year with minimum water availability. A chronological chart of average annual discharge is plotted and identified the year 2003 as the hydrologic drought year with the lowest discharge. The result is confirmed by referring to official publications of Kerala State Disaster Management Authority too. Figure 4 shows the chronological chart of annual average discharge.

Figure 4. Annual average discharge vs Year graph
3.2 Estimation of water demands

The water demands of two major sectors that is, domestic and irrigation are mainly considered and the monthly consumption in these two sectors are estimated. For the calculation of total domestic water demand in any sub basin, the total population within the sub basin must be estimated. To calculate the population in each sub basin, the basic data of village-wise population and growth rate data of all villages within the study area is collected from ‘Indikosh – All about India’ site as per the last Census Year 2011[5]. By overlaying the village administrative boundary map on the sub-basin map, the portions of villages lying in each sub-basin is identified. The population of each sub basin is then found out on a proportionate area basis from the village-wise population data. The summation of the population contributed by each village/part within each sub basin will give the total population corresponding to that sub basin. Table 1 shows the sub basin –wise population for all the 13 sub basins of Kunthipuzha river basin.

For the estimation of irrigation demand, the irrigation requirement is calculated by using the CROPWAT 8.0 software. CROPWAT a decision support scheme developed by FAO Land and Water Development Division for planning and management of irrigation. The water balance method is used for calculation of irrigation schedules in CROPWAT, which means that the incoming and outgoing water flows from the soil profile are monitored. The required input data includes maximum and minimum temperature, wind velocity, sunshine and relative humidity, rainfall, crop data, and soil data. Monthly irrigation requirement of each crop in each sub basin is calculated separately and the irrigation water required for each crop multiplied by its corresponding area gives the total water required for that particular crop. The summation of the irrigation water required for all crops within a sub basin in each month gives the monthly irrigation and gross sum for a year gives the annual irrigation demand for that sub basin [6]. Table 1 shows the sub basin- wise annual irrigation water requirement for each sub basins.

As per the Global Environmental Flow Information System, the minimum environmental flow (E.F) requirement is 25% of the available discharge in the river throughout the year [7]. Hence to maintain a fair Ecological condition of the river, 25 % of discharge is allocated exclusively for E.F and balance only is considered as available water to meet any other requirements.

Table 1. Sub basin- wise population and Annual Irrigation water demand

| Sub basin No. | Total Population | Total irrigated area (km²) | Annual Irrigation water demand (Mm³) |
|---------------|------------------|-----------------------------|--------------------------------------|
| 1             | 19754            | 6.653                       | 7.672                                |
| 2             | 53302            | 59.525                      | 66.22                                |
| 3             | 81318            | 56.494                      | 56.70                                |
| 4             | 58652            | 77.508                      | 61.38                                |
| 5             | 10923            | 13.141                      | 13.69                                |
| 6             | 6664             | 7.210                       | 7.89                                 |
| 7             | 23178            | 28.178                      | 23.37                                |
| 8             | 68072            | 58.764                      | 69.01                                |
| 9             | 64752            | 60.861                      | 53.35                                |
| 10            | 104357           | 51.733                      | 38.91                                |
| 11            | 55374            | 53.357                      | 48.07                                |
| 12            | 169205           | 119.680                     | 116.21                               |
| 13            | 348248           | 177.446                     | 145.52                               |
3.3 Identification of water scarce sub basins using WEAP model
For identifying the water scarce sub basins, the available water obtained from the Arc-SWAT model, the estimated population, irrigation demands, environmental flow requirements, monthly variations in irrigation water requirements in m$^3$/m$^2$ etc. are given as input data in WEAP and modelled the availability-demand prioritisation [3]. The WEAP model is a user friendly software developed by the Stockholm Environment Institute (SEI), Boston, which takes a holistic approach to water resource planning and operates on the basic water balance accounting principle. As per the national water policy the first priority is given to domestic demand and second priority is given for irrigation demand after allocating for environmental flow requirements.

WEAP modelling of all the 13 sub basins were done to simulate the demand coverage rate for identifying the sub basins with water scarcity. Total available water and total water demand for each sub basin were plotted. Finally demand coverage rate showing the % of requirement met is generated for all the sub basins using the model for identifying sub-basins with unmet demand/water shortage.

4. Results and discussion
WEAP modelling of all 13 sub basin were done to identify the sub basin with water scarcity. Figure 5 (a) to (d) shows the result obtained from WEAP model for selected sub basin 1, 2, 3 and 13 representing different levels of water stress. In the graph plotted with volume of water Vs time, the water available curve below the water demand curve indicates demand greater than the available water which in turn points to water scarcity in that particular sub basin. The demand coverage rate Vs time graph gives the % of requirements met in each month. If demand is fully met throughout the year, it is represented by a horizontal line with 100% demand coverage rate [1].

![Graphs showing demand coverage rate for sub basins 1, 2, 3, and 13](image)

Figure 5. (a) to (d) WEAP simulation results of typical sub basins 1, 2, 3 and 13

Figure 6 shows the graph of average demand coverage rate of summer months (January to May) of 13 sub basins of Kunthipuzha. The results from the graph shows that out of 13 sub basins of Kunthipuzha, 6 sub basins are totally free from water scarcity problem since the average demand coverage rate (DCR) is 100%. Out of the remaining sub basins, 2 comes under severely stressed.
(DCR < 60%), 2 under moderately stressed (DCR between 60% and 75%) and 3 lowly stressed regions (DMR>75 %). Figure 7 shows the water scarcity map of Kunthipuzha river basin showing the sub basins with ‘no scarcity’, lowly, moderately and severely stressed sub basins.

5. Conclusion
In order to identify the water scarce sub basins within the study area, it is necessary to assess the total available water and total water demand over there. The discharges from all 13 sub basins of Kunthipuzha river basin were simulated using the Arc-SWAT model. The CROPWAT 8.0 software is found to be efficient in computing the irrigation water requirements for different crops within the sub basins. The study attempted to use WEAP model to assess the water stressed sub basins within the Kunthipuzha river basin by allocating the available water for various demands and water scarce areas were identified. The results from the study revealed that out of 13 sub basins of Kunthipuzha, two comes under severely stressed, two under moderately stressed and three under lowly stressed regions. Addressing the problem of using the limited water resources available to meet the increased demand is a key issue we need to resolve in these areas. Exploring strategies to cope with the challenges of water scarcity and identifying sustainable interventions and practices to optimise and impede the unscrupulous usage of limited water resource is the need of the hour.
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