Identify Areas to Improve Agricultural Water Productivity in Upper Bhima Catchment of South India

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Abstract

The Bhima river is one of the major tributaries of Krishna River which originates from the Bhima Shankar at an altitude of 1014 m. The Upper Bhima subbasin comprises of the catchment area of the river Bhima from its source to its confluence with the River Sina. The subbasin has a catchment area of 46066 km^2 with the majority of it falling in the state of Maharashtra. The basin serves a population of 14.525 million (2001 census) with 6 million urban population. The spatial distribution of rainfall in the Upper Bhima is highly heterogeneous. Rainfall has a very high variation ranging from 2000-6000 mm at Western Ghats to 500-800 mm rainfall in the middle and lower catchment area. Increasing domestic, industrial, and agricultural demand led to construction of many small reservoirs in the western part and one important reservoir (Ujjani) in the middle part of Upper Bhima catchment during subsequent decades. Agriculture in Upper Bhima is characterized by different cropping patterns having crops like sugarcane, sorghum, millets, cotton, wheat, rice, oilseed, and pulses. During recent droughts, agriculture suffered most particularly the irrigation projects in downstream. The only way to sustain agriculture with limited water is to improve water productivity. We present the spatial variability of water productivity in the catchment and identify the potential areas to improve the water productivity in different irrigation projects. The water productivity was measured as a ratio of crop yield per unit of water used divided by the actual evapo-transpiration (ET). The crop yield data were collected from census statistics at municipality level (Taluk). The actual ET was estimated by using a hydrological simulation model called soil and water assessment (SWAT) tool. In addition, the model was used to identify the potential area in terms of water productivity. In SWAT, basin topography, existing land use class and soil type information were used to delineate the subbasin into small watersheds. Weather data at different stations, reservoir inflow and outflow information, and crop management scenarios were also provided for each watershed to parameterize the model. SWAT estimated surface runoff, groundwater recharge, soil moisture change, evapotranspiration in different watersheds. Simulated ET and taluk level census crop yield data were then used to map water productivity in the catchment. After calibration and validation of hydrological model, simulations using different crop scenarios produced the yield potential for specific areas. The gap between potential and acutual yield will help to identify areas with scope for improvement and to take sound decisions for crop selection at sub watershed level in the subbasin. The study of water productivity potential is useful in allocation of water resources judiciously and to plan more efficient cropping pattern during wet, normal, and dry years.

Key words: Water productivity, Evapotranspiration, SWAT, Water allocation

1. Introduction

Achieving self-sufficiency in food production was one of the prime objectives of the nation after the independence, which saw an expansion in water resources development throughout the country. However, country achieved its desirable goal in agriculture production in three to four decades but it exhausted a substantial amount of water in many of the river basins. Limited water resources and increasing water demand led by high population growth resulted in competition among different demand sectors. Krishna river basin is an example of the basins those is water scarce and nearly closed (Gaur, et al., in press). The Krishna Basin is India's fourth largest river basin and covers 258,948 km^2 of southern India, traversing the states of Karnataka (113,271 km^2), Andhra Pradesh (76,252 km^2) and Maharashtra (69,425 km^2).

Due to upstream development, total storage capacity of major and medium reservoirs in basin is almost reached to total water yield therefore basin is nearly completely closed. Basin is not only getting closed at mouth of sea but also at sub-basin level, discharge has been substantially reduced. Domestic and industrial water need has also been increasing with increasing population in the basin has resulted competition among different demand sectors. The proper solution is needed to alleviate water scarcity, which could find out by increasing efficiency in water use. Water productivity is scale dependent term that can be defined from farm level to the basin scale. In simple words, water productivity in agriculture is defined as amount of crop production by unit quantity of water use. Remote sensing and distributed hydrological model is indispensable tool; there application at a time provides a broad understanding in hydrology and land use patterns of concerned area. In this paper, we present the spatial variability of water productivity in Upper Bhima subbasin of Krishna basin and identify the potential areas to improve the water productivity in different irrigation projects using hydrological modeling.

2. Study area

Upper Bhima is one of the subbasin among 12 subbasins of river Krishna and located on Bhima Tributaries. The river Bhima is a tributary of east flowing Krishna river originating from Bhima Shankar at an altitude of 1014.94 M in the N-S Sahyadri mountain range. The river flows in the south-west direction for a distance of about 861 km before joining the river Krishna at an altitude of 343 m. The river receives water from Mula, Mutha, and Pavana rivers that confluence at Pune. In the downstream, the Bhima river is joined by Ghod, Nira, Man and Sina tributaries (Fig.1). The sub-basin has a catchment area of 46066 km^2 and forms 17.9% of Krishna basin. The majority of area is in Maharashtra (98.4) and 1.6% in Karnataka. The basin serves a population of 14.525 million (296 /km^2) (2001 census) with 6 million urban population. There are total 8 districts, which fall in Upper Bhima sub-basin. Pune, Solapur and Ahmednagar are three major districts, which cover 76% percent of the basin.

2.1 Rainfall, Water Yield and KWDT allocation

The catchment has a highly diverse climate mainly caused by the interaction between the monsoon and the Western Ghat mountain range (Gunnel, 1997). The western Ghats zone is covered with thick forests and receives heavy rainfall to a maximum of

6000 mm. Rainfall decreases rapidly towards eastern slopes and plateau areas where it is minimum (less than 500 mm). It again increases towards east, attains a second maximum of 700 mm in the Sholapur. Thus, the central part of Upper Bhima basin is region of the lowest rainfall in the State. A total of 61% of the area receives less than 750 mm and 25% more than 1000 mm.

As per Krishna Water Tribunal (KWDT 1976), the estimated runoff yield at 75% dependable flow is 10,300 Million Cubic Meter (MCM), out of which 9,290 MCM is allocated and 1,020 MCM is available for inter-basin transfer to lower Bhima. The subbasin accounts for 55% water allocation of the Maharashtra state in Krishna basin. Apparently, the sub-basin is comparatively independent in the context of Krishna basin water transfer. As per Master plan of state, the projects have been allocated a total amount of 7,100 MCM with remainder use of 1064 totaling to 8,164 MCM.

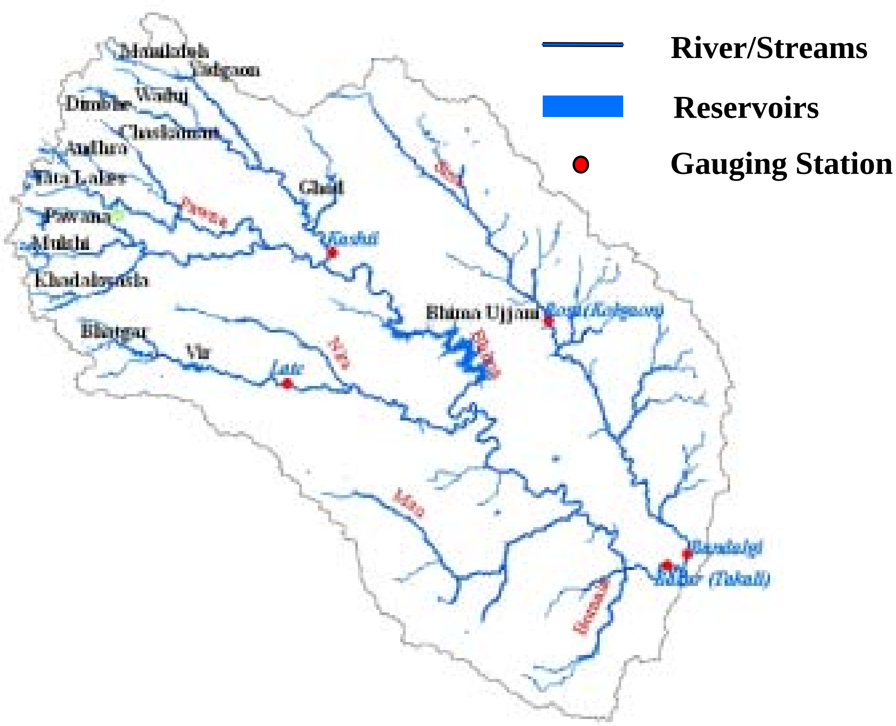

Fig. 1. Major reservoirs, river tributaries and gauging stations in Upper Bhima basin

2.2 Reservoirs in subbasin

The salient features of important projects are listed in Table 1. The major important projects are Pawana, Khadakwasla (Panshet, Warasgaon and Temghar and), Nira canal system (Bhatnagar and Vir), Ghod, Kukadi projects (Chaskman, Dimbhe, Manikdoh, Yadgaon, and Waduj) and Ujjani with a total live storage capacity of 4,669 MCM and irrigating a designed annual irrigation of 341962 ha. Khadakwasla and Ujjani also supply water for major cities, Pune, and Sholapur, respectively. The major projects are designed to use a total of 3,889 MCM. In addition to these, water from Mulshi, Andhra, and Tata Lakes is diverted outside the basin for hydropower generation.

Table 1. The salient features of Major Project in Upper Bhima

Project	Purpose	Live storage (MCM)*	Power Potential (MWH)**
Bhima (Ujjani)	Irrigation & hydropower	1560	12
Ghod	Irrigation	166	-
Khadakwasla series	Irrigation, drinking & Hydropower	740	8
Pawana	Irrigation & hydropower	281	10
Vir-Bhatghar	Irrigation & Hydropower	923	25
Kukadi Projects			-
Chaskaman	Irrigation & Hydropower	214	3
Yedgaon	Irrigation	79	-
Dimbhe	Irrigation & Hydropower	355	5
Manikdoh	Irrigation & Hydropower	288	6
Wadaj	Irrigation	33	-
Hydropower projects (Westward diversion)			
Mulshi	Hydropower	523	150
Andhra	Hydropower	353	72
Tatalakes	Hydropower	265	72

*** MCM: Million Cubic Meter**
****MWH: Mega Watt-Hour**

2.3 Cropping Pattern

Agriculture in Upper Bhima is characterized by different cropping patterns having crops like sugarcane, sorghum, millets, cotton, wheat, rice, oilseed, and pulses (Neena, 1998). Sorghum and Wheat are being cultivated in Rabi; Millet, Pulses and Rice in Kharif; and Sugarcane is as perennial crop. Vegetable, orchards, and fodder crops also are being cultivated in different parts of Upper Bhima. Crop cultivated area to total gross cropped area for major crops in two districts (Pune and Sholapur) of Upper Bhima is presented in Fig.2. Sorghum occupies 50-70 % of total cropland in both the districts whereas sugarcane is about 4-8 % of total gross cultivated area and need intensive irrigation throughout the year. It is needed to find out that which crop is most water productive; can any other crop with less water use give higher return?

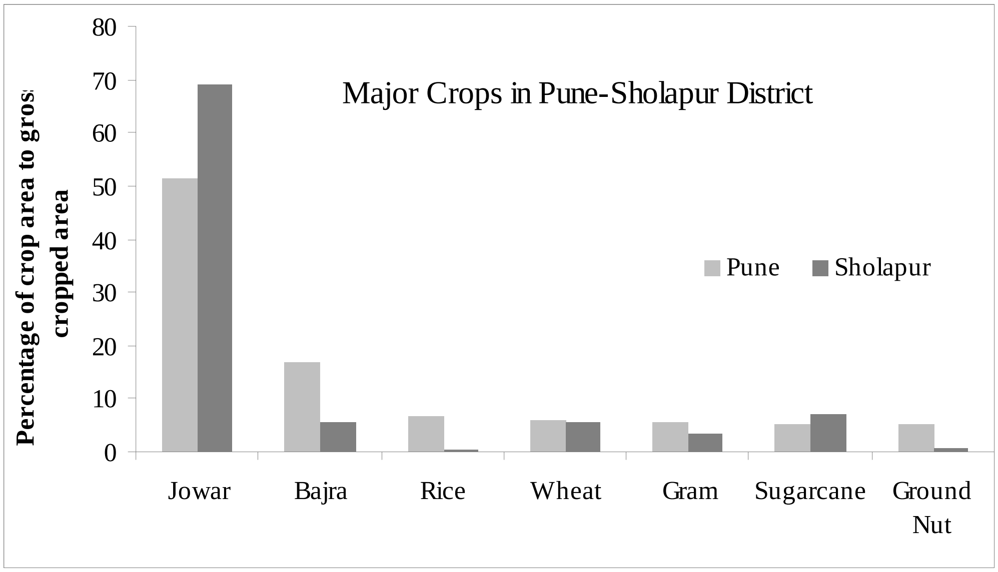

Fig. 2. Major crops in Pune and Sholapur districts

3. Methodology

3.1 Application of SWAT

Soil and water Assessment tool (SWAT) is a process based hydrological model that predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time. The hydrologic cycle as simulated by SWAT is based on the water balance equation:

$$SW_t = SW_0 + \sum_{i=1}^{t}(R_{day} - Q_{Surf} - E_a - W_{Seep} - Q_{gw})$$

where, SW_t is the final soil water content (mm H_2O), SW_0 is the initial soil water content on day *i* (mm H_2O), *t* is the time (days), R_{day} is the amount of precipitation on day *i* (mm H_2O), Q_{surf} is the amount of surface runoff on day *i* (mm H_2O), E_a is the amount of evapotranspiration on day *i* (mm H_2O), w_{seep} is the amount of water entering the vadose zone from the soil profile on day *i* (mm H_2O), and Q_{gw} is the amount of return flow on day *i* (mm H_2O).

SWAT utilizes a single plant growth model to simulate all types of land covers. The model is able to differentiate between annual and perennial plants. Annual plants grow from the planting date to the harvest date or until the accumulated heat units equal the potential heat units for the plant. Perennial plants maintain their root systems throughout the year, becoming dormant in the winter months. They resume growth when the average daily air temperature exceeds the minimum, or base, temperature required. The plant growth model is used to assess removal of water and nutrients from the root zone, transpiration, and biomass/yield production. The model is comprehensively described in literature (Arnold et al., 1998; Srinivasan et al., 1998).

3.2 Model Input

SWAT needs three basic input files: Digital Elevation model (DEM), Soil classes and Land use/ Land classification files. Model divides whole project into different sub-basins and each sub-basin is further sub divided into different hydrological response units (HRUs). HRU is unique combination of soil and land class in sub-basin. In most cases, HRU is not physically connected in subbasin but model conceptually assimilate its output in a single unit. We generated DEM from Shuttle Radar Topographic Mission (SRTM) 90 m digital elevation files whereas soil classes were taken from FAO soil series. Land use/Land classes were classified for year 2004 using time series Moderate Resolution Imaging Spectroradiometer (MODIS) images of 8 days interval (250 m spatial resolution). Initially, unsupervised classification with a large number of classes (150) is performed. Further, these classes were attributed into the seven main land use classifications (Table 2) by verifying ground truth survey and google earth images.

Table 2. Land use classes derived by MODIS imagery with a spatial resolution of 250 m

Land Use/ Land Class	Area (%)
Water Body	1.5
Forest Land	4.3
Range Land	21.2
Rainfed Land	38.6
Irrigated land	16.7
Sugarcane Land	8.9
Urban Land	8.8

Rainfall data of 50 rain gauge stations those are falling in and around the basin were provided as an input to model. Sunshine hours, Relative humidity, Maximum and Minimum temperature, Wind speed, solar radiation data at Pune, Sholapur and Dhapoli observatory were provided to model. Reservoirs were created at proper position during building the project. Command area of each reservoir were delineated separately and overlapped with SWAT project. Command area is irrigated by respective reservoirs in management inputs of the model. Groundwater has assumed as irrigation source for HRUs those are outside the command. Crops were selected based on senses data and land use classes and allocated into different HRUs (Table 3). Water used in power generation by Mulshi, Andhra and Tata lakes was diverted outside from the basin.

Table 3. Crop allocation in different HRUs for SWAT simulation

Season	Crop	Area cultivated (Km^2)
Rabi (post Monsoon)	Sorghum (Jowar)	17077
Rabi	Wheat	2043
Rabi	Gram	1640
Kharif (Monsoon)	Millet (Bajara)	4147
Kharif	Pulses	2282
Kharif	Rice	543
Perennial	Sugarcane	2817

3.3 Model Calibration

Monthly discharge at five gauge locations (Kasti and Takli stations at Bhima river; Rosa and Bandalgai stations at Sina river; Late station at Neera river, shown in Fig.1) and reservoir inflows were used to calibrate the model. Model was calibrated by changing the curve number in management files and soil parameters (Hydraulic conductivity, available water capacity, Soil evaporation compensation factors) in HRUs. Year 2004 was used as calibration year.

3.4 Water Productivity Analysis

Model produces crop yield, biomass yield and ET value for different HRUs. Water productivity is calculated in terms of kg/m^3 from estimated crop yield and ET values. The yield was also compared with senses yields for different subbasins. Different scenarios were built up in SWAT by switching one crop to other crop and water productivity was calculated. Further, spatial distribution of water productivity was also analyzed.

4. Results and Discussion

4.1 Water Balance

Fig. 3 shows variability of rainfall and Evapotranspiration (ET) in Upper Bhima basin during year 2004. Rainfall at Western Ghats is high and comparatively less in middle part of basin. High ET zones were found more in upper part of basin than down stream part. Forest area is located at Western Ghats of Upper Bhima (falling into Pune) and rainfall is also very high. ET is also found high in subbasins inside the command areas. ET value was found in a wide range from 300 to 900 mm at different parts of the basin. Model do water balance and divides rainfall into different segments. Model provides time series information about surface-groundwater flow/discharge, potential ET, and soil moisture content (Data not shown).

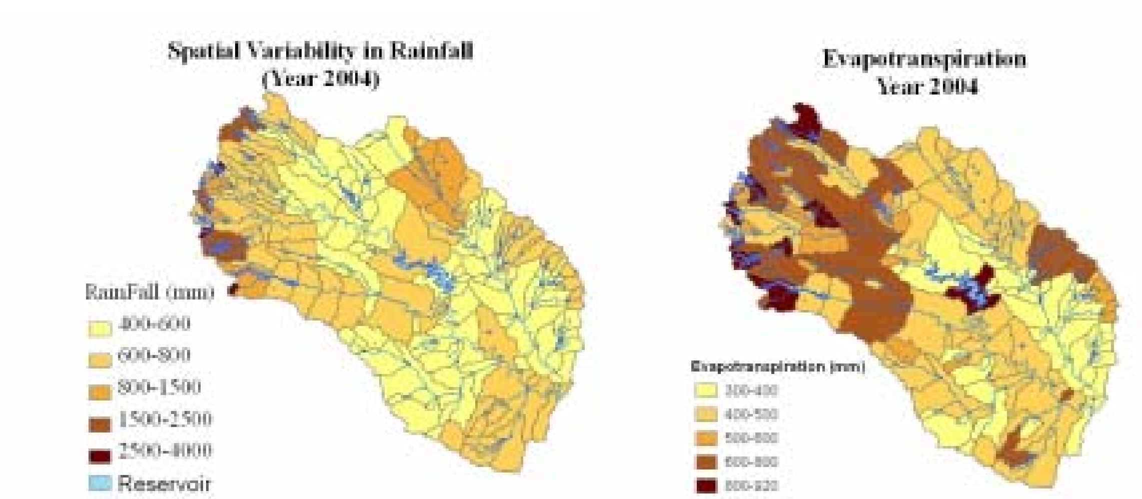

Fig. 3. Variability of Rainfall and Evapotranspiration in Upper Bhima basin during the year 2004.

4.2 Water Productivity

Crop water productivity (CWP) for sorghum was estimated using SWAT-ET and crop yield which is presented in Fig.4. CWP is found in range from 0.30 kg/m^3 to 1.3 Kg/m^3 in different subbasins of Upper Bhima basin. We found that water productivity is highly dependent on water stress condition in HRUs. Water productivity is found poor in many subbasins outside the command as well as within the command. It was seen that crop yield is not only dependent on total irrigation input but also depends on irrigation timing. Irrigation input at critical growth stages is found more valuable compare to other growth

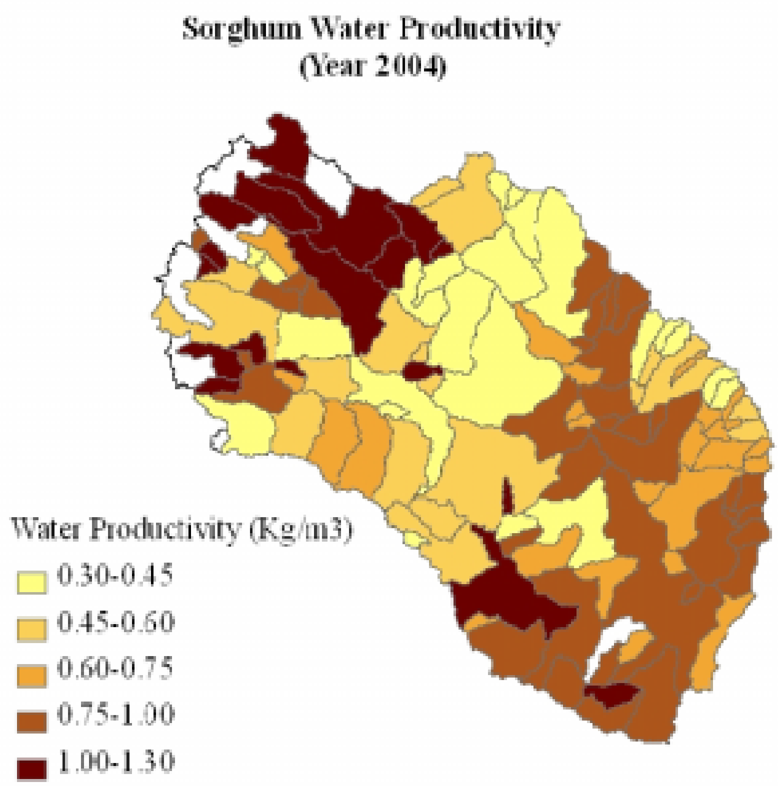

Fig.4. Sorghum Water Productivity in Upper Bhima

stages. We found that if water is conserved by not irrigating (or less irrigating) the crop during less sensitive growth stages and supply that quantity of water during critical growth stages (like milking and grain formation), it adds more value. We are in process to develop different scenarios using this approach and at middle of the study. The study of water productivity potential is useful in allocation of water resources judiciously and to plan more efficient cropping pattern during wet, normal, and dry years.

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