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INTEGRATED SOFT ASSESSMENT OF WATER FOOT PRINTS FOR RIVER BASIN

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Abstract: Water Foot Prints (green and blue) were optimized for Wan river basin based on hydrological response of river basin and management of water resources by incorporating cement nala bunds. The green and blue water foot prints were assessed through rainfall-runoff (SMA) model using HEC-HMS; precipitation deficit with CROPWAT model; optimization of area to be irrigated under particular crop with Lips; and estimated yield of crops of basin using 'FAO crop water productivity model'. It is suggested that two protective irrigations, first of 7.5 cm and second of 6.25 cm during last week of October and second week of November, respectively, should be provided to pigeon pea crop so as to decrease the water foot prints of basin.

Keywords: Water foot print, SMA, CROPWAT, HEC-HMS, crop productivity model

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INTRODUCTION

More than two billion people live in highly water stressed areas (Oki and Kanae, 2006), and the pressure on freshwater will inevitably be intensified by population growth, economic development and climate change in the future (Vorosmarty *et al.*, 2000). There is a need to increase the annual foodgrain production for the growing population by 2050 (GOI, 2006). But, due growing population, urbanization and industrialization, land and water become shrinking resources for agriculture. Therefore, the pathway for achieving this goal has to be the higher productivity per unit of arable land and water.
The water footprint (Hoekstra, 2003) is increasingly recognized as a suitable indicator of human appropriation of freshwater resources and is becoming widely applied to get better understanding of the sustainability of water use. Agriculture contributed approximately 92% to the total water foot print of humanity (Hoekstra and Mekonnen, 2012). As such, the question of decreasing the present level of water foot print in general and for agriculture in particular assumes a great significance in perspective water resource planning.
In water governance realistic information of water foot print to stakeholders would be useful (Hoekstra *et al.*, 2011; Mekonnen and Hoekstra, 2011). Considering this need, a study was carried out which took into account the hydrological response of river basin and thereby possible incorporation of soil and water conservation structures in the river reach aiming to optimize the water foot prints (Green and Blue) for river basin.

2. MATERIAL AND METHODS

2.1 Study Area

Wan river, a tributary of Purna river, forms the part of northwest boundary of Akola district of Maharashtra State of India, after entering from Amravati district. The basin of wan river is spread over 173.65 km^2 in Melghat Tiger Reserve Project in Satpura ranges, Amravati district of Maharashtra State. Rainfed agriculture is dominant in the basin. Major *kharif* crops of basin are cotton, pigeonpea and soybean.

2.2 Data Collection

The required meteorological data such as maximum and minimum temperature, rainfall *etc.* was collected from four observation stations in the basin *viz.* Wari Bhairavgarh, Wan Road Station, Kelpani and Khatkali, for the period 2000-2013. Remote sensed data like digital elevation model, land cover land use map, percent impervious area, soil and hydrography information were also obtained.

2.3 Model Setup

2.3.1 HEC-HMS

HEC-HMS (USACE, 2006) model was used to develop rainfall-runoff model. For real time operation, soil moisture accounting module was chosen and accordingly using HEC-GeoHMS, an ArcGIS extension, basin data was developed. To identify an appropriate R-R model, parameters of selected processes *i.e.* SMA method, transform method, baseflow method and channel routing were optimized within minimum and maximum limit described by Rezaeianzadeh (2013) for the hydrological parameters. R-R model was calibrated and validated from 1st June 2004 to 31st May 2007; and 1st June 2012 to 31st Dec 2013, respectively by manually varying the model parameters *viz.* Groundwater 1, Groundwater 2, GW1 coefficient and GW2 coefficient. The performance of model was judged through statistical parameters viz. Root Mean Square Error (RMSE), Nash Sutcliffe coefficient (R^2_{NS}) and Coefficient of Residual Mass (CRM) [Kale, 2014].

2.3.2 CROPWAT

The CROPWAT (FAO, 2015a) model was used to estimate precipitation deficit for the period June to December 2013. Precipitation deficit or irrigation requirement indicatively represents the fraction of crop water requirements that needs to be satisfied through irrigation contributions in order to guarantee to the crop optimal growing conditions. The model estimated precipitation deficit based on inputs like temperature (minimum and maximum), rainfall, crop parameters (sowing date, period *etc*), soil data etc.

2.3.3 Soil Water Conservation Measure

As most of the basin is comprised of reserve forest, cement nala bunds (CNBs) along the river reach are taken as soil and water conservation measure to make provision for protective irrigation in the basin. Accordingly, after practical verification of Wan river six sites were selected to construct CNBs. Subsequently CNBs were designed, with total storage capacity of 1486.35 ha-cm. CNBs of designed specifications were inserted in model setup at desired locations.

2.3.4 Optimization of Area under Particular Crop to be Irrigated

If irrigation is provided at important critical stages of Cotton and Pigeon pea, their production increases significantly. The provision of CNBs is aimed to have an assured protective irrigation for better crop planning. But, the water harnessed with proposed CNBs is not sufficient to irrigate the entire basin. Thus, an attempt was made to optimize the area under particular crop to be irrigated (protective) using linear programming technique. The linear programming is implemented with Linear Program Solver software (Lips). The Lips yielded optimal solution for the area to be irrigated under a particular crop with respect to water to be harnessed with proposed CNBs using modified simplex method.

2.3.5 Assessment of Water Foot Prints

The actual yield of different crops in the basin were estimated using output of calibrated HEC-HMS model (*i.e.* actual evapotranspiration) and 'FAO crop water productivity model' (FAO, 2015b) for rainfed and rainfed with protective irrigation scenario. The estimated actual yield of different crops was then converted in to cotton equivalent yield (Vats, 2013) considering the prices of crops for 2013-14.

The water footprints (green and blue) for wan river basin were estimated considering crop water use and yield under rainfed and rainfed with protective irrigation scenario by using following relationships (Hoekstra *et al.*, 2011).

$$CWU_{green} = 10 \times \sum_{d=1}^{lgp} ET_{green}$$

$$CWU_{blue} = 10 \times \sum_{d=1}^{lgp} ET_{blue}$$

$$WF_{proc,green} = \frac{CWU_{green}}{Y}$$

$$WF_{proc,blue} = \frac{CWU_{blue}}{Y}$$

3. RESULTS AND DISCUSSION

3.1 Calibration and Validation of HEC HMS Model

The temporal variation of observed and simulated runoff at the outlet of basin over calibration period is depicted in Fig. 1, whereas Fig. 2 depicts the comparison between simulated and observed runoff on 1:1 line. The runoff varied between 6.7 to 26.4 m^3s^{-1} over calibration period.

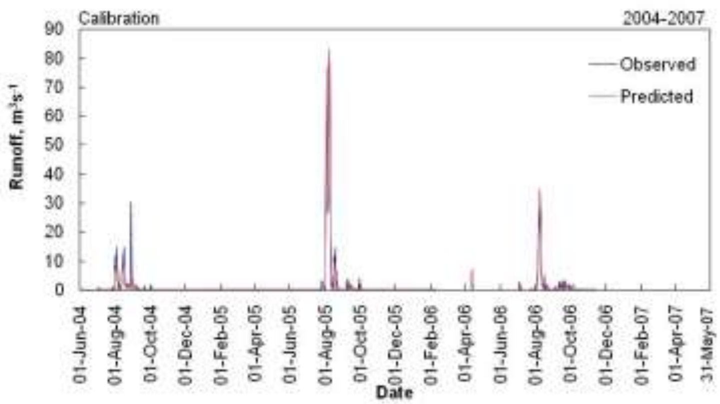

Fig. 1 Temporal variation of observed and simulated runoff for calibration period

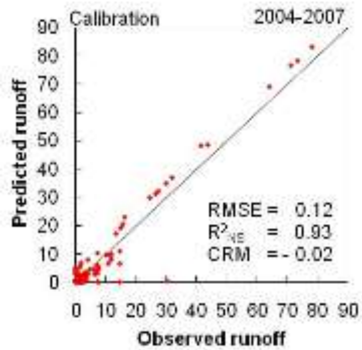

Fig. 2 Comparison between observed and simulated runoff

Fig. 1 clears that the observed and simulated runoff for calibration period were in close match. It is seen from scattered plot (Fig. 2) that the simulated runoff depths lie on both sides of 1:1 line, which clears that there is no consistent over or under estimation. The statistical parameters *i.e.* RMSE, R^2_{NS} and CRM were found as 0.12 mm day^{-1}, 0.93 and -0.02, respectively**.** Model slightly overestimated the runoff, as indicated by negative value of CRM. Value of R^2_{NS} close to 1 indicates that the model simulates the runoff accurately. As such the model setup was considered as calibrated. Table 1 presents the calibrated values of model parameters for Wan River basin.

Table 1 Calibrated model parameters

Sr. No.	Parameters	Value
1.	Groundwater 1, %	72.00
2.	Groundwater 2, %	10.00
3.	GW1 coefficient	387.00
4.	GW2 Coefficient	1010.00

3.2 Validation of HEC-HMS model

Model validation is in fact the extension of calibration process. Therefore, model is validated for the period 1st June 2012 to 31st December 2013. The runoff varied between 13.08 to 24.75 m^{3}s^{-1} over validation period. Fig. 3 depicts temporal variation of observed and simulated runoff at the outlet of the basin, whereas Fig. 4 depicts the comparison between simulated and observed runoff on 1:1 line.

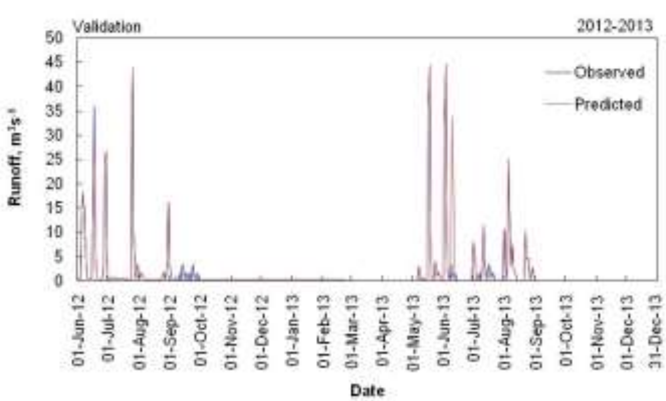

Fig. 3 Temporal variation of observed and simulated runoff for validation period

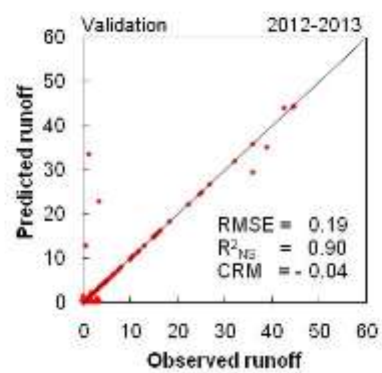

Fig. 4 Comparison between observed and simulated runoff

Fig. 3 clears that the observed and simulated runoff over validation period were in close match. It is seen from Fig. 4 that the runoff lie on both sides of 1:1 line, which shows that there is no consistent over or under estimation by model over validation period.

The statistical parameters *i.e.* RMSE, R^2_{NS} and CRM for observed and simulated runoff over validation period were estimated as 0.19 m^3s^{-1}, 90 and -0.04, respectively**.** Negative value of CRM indicates that the simulated runoff is slightly overestimated by the model. But Fig. 4 clears that most of simulated runoff is along 1:1 line. R^2_{NS} values close to 1 confirmed that the model simulates runoff accurately. As RMSE, R^2_{NS} and CRM statistics were acceptable, the HEC-HMS model was accepted as validated.

3.3 Precipitation deficit for the basin

Precipitation deficit in respect to crops of basin is depicted in Fig. 5.

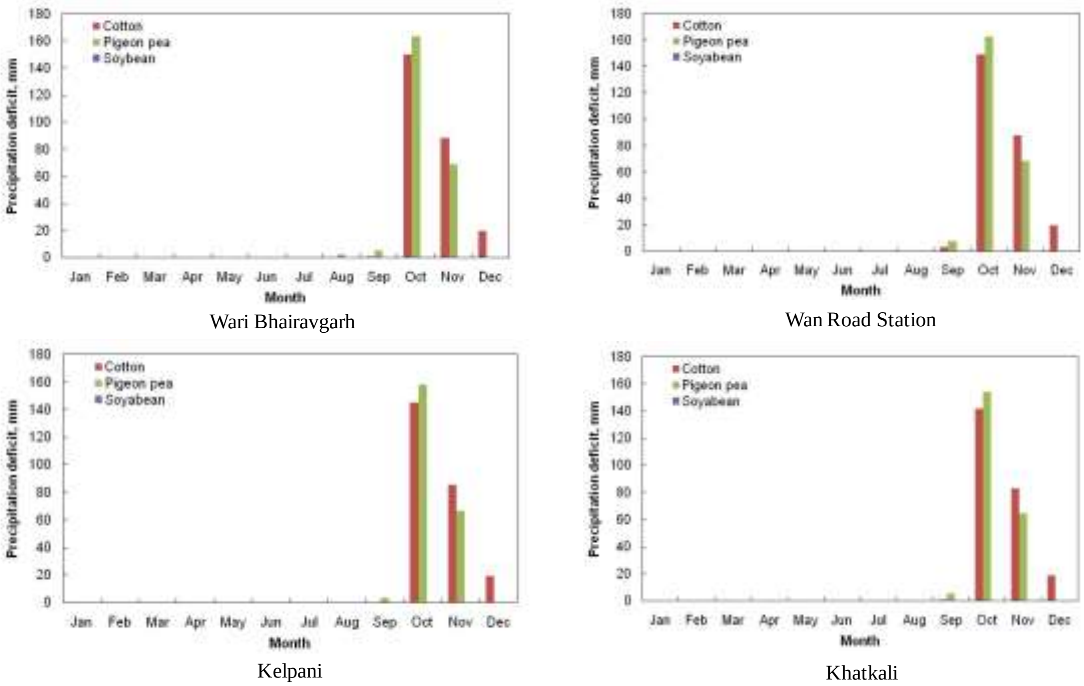

Fig. 5 Crop wise soil moisture deficit in the basin

It is cleared from Fig. 5 that there was no precipitation deficit in case of soybean crop whereas it was observed maximum for pigeon pea followed by cotton. The precipitation deficit in case of cotton crop varied between 141.5 to 150.3 mm, while for pigeon pea crop, it varied from 154.2 to 163.8 mm, during month of October. The precipitation deficit decreases from October to December at all station in case of both crops. It is due to late stage of crop which might decreases actual evapotranspiration (ETa), as crop life ceases. However, the precipitation deficit was, more or less, followed similar pattern over the entire basin as evidenced from Fig. 5.

Maximum precipitation deficit was observed to be 163 mm during October and 88 mm during November. Therefore, two and one irrigation of 7.5 cm is required during October and November, respectively, to bring soil moisture to field capacity.

As water to be harnessed with proposed CNBs is less than total water required for irrigation. It is decided to provide two irrigations (first 7.5 cm and second 6.25cm) to pigeon crop and one irrigation (7.5 cm) to Cotton crop during October - November month.

3.4 Optimization

The Linear Program Solver yielded optimal solution. Optimal area to be irrigated is estimated as 19.12, 49.92, 23.90, 18.45, 5.87, 1.38 ha, with water to be harnessed with proposed CNBs ID 6, 5, 4, 3, 2 and 1, respectively. Total optimal area under cotton and pigeon pea to be irrigated, is estimated as 25 and 93.64 ha, respectively. Proposed total irrigated area is estimated as 118.64 ha, using 1475.05 ha-cm water.

3.5 Estimation of water footprints (WF)

The estimated water footprints (green and blue) for Wan river basin were presented in Table 2 and depicted in Fig. 6.

Table 2 Water foot prints for basin

Sr. No	Sub-basin	Cotton equivalent yield, t ha^{-1}			Water utilized, m^{3}ha^{-1}			Water foot prints, m^3 t^{-1}		
		Green	Blue	Opti-mized	Green Water	Blue Water	Total	Green	Blue	Optimized
1	Wari Bhairgarh	1.08	0.09	1.08	5575.00	625.00	6200.00	5179.06	7178.94	5750.63
2	Wanroad	1.04	0.08	1.08	5342.50	625.00	5967.50	5136.32	8209.04	5528.47
3	Kelpani	0.91	0.07	0.92	5270.00	625.00	5895.00	5770.23	8494.25	6383.02
4	Khatkali	0.99	0.16	1.04	4277.50	500.00	4777.50	4329.97	3125.00	4615.89

The green water foot prints are found varying between 4277.50 to 5575.00 m^{3}t^{-1}. The water foot prints due to protective irrigation only *i.e.* blue water foot prints were found varying 3125.00 to 8494.25 m^{3}t^{-1}, whereas the optimized water foot prints were found varying between 4615.89 to 6383.02 m^{3}t^{-1}. In each case, water foot prints were found maximum for Kelpani sub-basin while minimum for Khatkali sub-basin. The optimized foot prints were in between green and blue water foot prints. It is evidenced in Fig. 6.

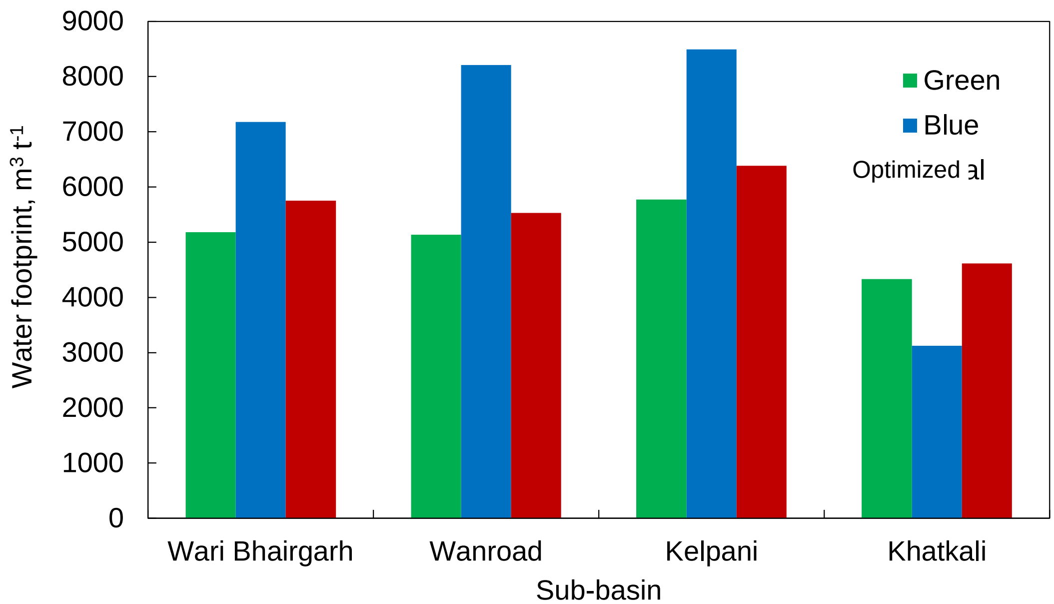

Fig. 6 Water foot prints for wan river basin

Table 2 and Fig. 6 clears that the water prints for cotton increased whereas that for pigeon pea decreased, with provision of protective irrigation. It clearly indicates that in case of pigeon pea, application of protective irrigation is appropriate as water foot prints were decreased, while in case of cotton, application of protective irrigation could not be justified as water foot prints were increased, in all sub-basins. Therefore it is recommended that two protective irrigations should be given to pigeon pea crop in Wan river basin so as to decrease the water foot prints, while no irrigation is recommended for cotton crop.

3.6 Inference

Two protective irrigations, first of 7.5cm and second of 6.25cm during last week of October and second week of November, respectively, should be given to pigeon pea crop in Wan river basin so as to decrease the water foot prints, while no irrigation is recommended for cotton crop.

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