WATER AVAILABILITY UNDER CHANGING CLIMATE SCENARIO IN UR RIVER BASIN

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ABSTRACT

The Bundelkhand region in Central India is facing several environmental issues since the last decade including recurrent droughts, dominant land use changes due many influencing factors including over exploitation of the natural resources and its degradation, climatic variability and decreased agricultural productivity. The agriculture of the region is mostly rain-fed which has now become a non-lucrative livelihood option for the local population due to the vagaries of the climate and its variability. The threat of climate change which now seems to be real is likely to aggravate the already precarious scenario, which therefore calls for a detailed investigation into the impacts of climate change on the water resources of the region. The Ur river basin has been selected as a pilot basin in Bundelkhand for the development of a Decision Support System (DSS) integrating climate change, hydrology and livelihood. An attempt has been made to study the impact of climate change by forcing hypothetical climate scenarios on a conceptual water balance model setup for the watershed. The analysis reveals that a 10% reduction in precipitation results in more than 40% reduction in surface runoff whereas a 1°C increase in temperature results in 6% reduction in surface runoff. A 1°C rise in temperature coupled with a 10% reduction in rainfall leads to a further 50% reduction in surface runoff whereas a 2°C rise in temperature coupled with a 10% reduction in rainfall leads to reduction in surface runoff by 59%. This analysis is being used in the development of a DSS for making effective policy

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recommendations to assist the decision makers and stakeholders in selecting appropriate water management practices on a sustainable basis.

Keywords: water balance, supply-demand, Bundelkhand, water resources management, climate change

INTRODUCTION

The freshwater availability in adequate quantity and quality is crucial for the sustenance of life and economic development of any region. Since water is critical to all forms of life in a watershed including domestic, livestock, agricultural, forest and industrial requirements, any shortages in the availability of water supply poses the greatest threat to the watershed health and productivity. Therefore the water resources planning and development needs to be carried in an appropriate manner so that the precious resource can be used beneficially on a sustainable basis. This calls for accurate estimation of the supply-demand scenario prior to introducing planning interventions. In semi-arid watersheds particularly located in the rural areas, lack of basic data on the water resources generally leads to erratic planning and unsustainable practices thereby causing depletion of the available water resources. Therefore it is imperative to understand the water balance of an area. However the inter-relationships between the various components of the water balance viz., rainfall, evapotranspiration, groundwater recharge, groundwater draft, surface and groundwater storages are very complex and any intervention in any of the component of the water balance, is ought to have an impact on the other components of the water balance.

The Intergovernmental Panel on Climate Change (IPCC) reported that the ecosystems and natural resources shall be affected if the if the projected doubling of atmospheric carbon-di-oxide occurs within the next century (Houghton et al. 1990). It is believed that the climate change will enhance the hydrologic cycle thereby causing changes in the rainfall pattern and its distribution leading to variation in the water storages and fluxes at the land surface, soil moisture storage, groundwater, reservoirs, snowpack, runoff and evapotranspiration. Dickinson 1986, stated that as a consequence of climate change, the terrestrial biosphere will be affected due to the changes in the regional energy balance. This will alter the regional water balance due to seasonal shifts in water balance due to changes in precipitation and other climatic conditions (Eagleson 1986). It is also predicted that the changes in soil moisture and evapotranspiration are likely to have large impacts on water and forest resources (Neilson et al. 1992). Changes in the regional water cycle will influence feedbacks between vegetation and climate Rind (1984).

The monthly water balance models have been found useful for water resources assessment and management on a regional scale by identifying hydrologic consequences of changes in temperature, precipitation, and other climate variables (Gleick, 1986; Schaake and Liu, 1989; Mimikou et al., 1991; Arnell, 1992; Xu and Halldin, 1997; Xu and Singh, 1998). There are many factors to be considered while selecting a model (Gleick, 1986). The purpose of study and data availability are the dominant factors responsible for choice of a particular model (Ng and Marsalek, 1992; Xu, 1999). Marks et al, 1993 evaluated the potential effects of climate change on runoff and soil moisture in the Columbia River Basin using 2xCO_2 scenario data from the Geophysical Fluid Dynamics Laboratory (GFDL) general circulation model (GCM). Calvo, 1986 evaluated the Thornthwaite's water balance technique in predicting stream runoff in Costa Rica. Jiang et al, 2007 studied the hydrological impacts of climate change simulated by six hydrological models in the Dongjiang Basin, South China. Xiong & Guo, 1999 developed a two-parameter monthly water balance model to simulate the runoff of seventy sub-catchments in the Dongjiang, Ganjiang and Hanjiang Basins in the south of China. They suggested that this model can be efficiently incorporated in the water resources planning program and the climate impact studies to simulate monthly runoff conditions in the humid and semi-humid regions.

STUDY AREA

The Ur river basin, a tributary of the River Dhasan located in Tikamgarh district of Madhya Pradesh has been selected for carrying out the assessment of water availability under various alternate climate scenarios. The study area represents the typical topography and geology of the Bundelkhand region and is one of the most vulnerable areas in respect of climate change and drought related indicators. Ur river basin lies on the Bundelkhand plateau and extends between latitudes 24°35′00″ N and 25°05′00″ N and between 78°50′00″ E and 79°10′00″ E longitudes with a total geographical area of 990.37 sq. km. The basin is bounded by Chhattarpur district in the east, Lalitpur district in the west, Jhansi district in the north and Sagar district in the south. The basin is elongated with length of 119 km and an average width of 80 km. The location map of the study area is given in Figure 1.

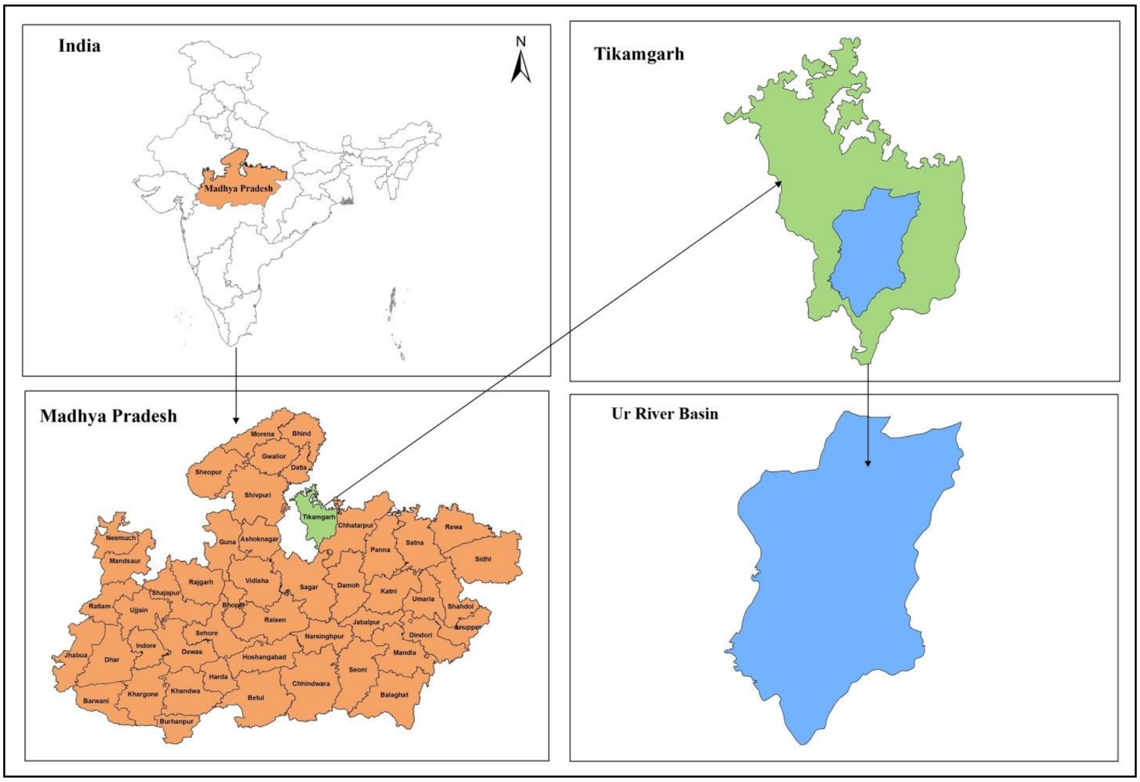

Figure 1. Index map of the Ur basin

The topography of the basin is undulating and comprises of high hills along the ridge line with the elevation varying between 200 m and 400 m above mean sea level. The elevation gradually decreases from the southern part of the basin towards the north. The River Ur also flows in a north-easterly direction till its confluence with River Dhasan. Agriculture is the dominant land use (58.6%) followed by scrub land (13.3%). Other land use classes include settlements (2.0%), dense forests (4.5%), water bodies (3.5%), fallow lands (7.0%) and barren (11.1%). The forests are located towards the western portion of the basin whereas the scrubs are located mostly towards the south-western, western and north-western parts. The agricultural area is well distributed possibly because of the large number of tanks spread all over the basin. The soil in the Ur basin comprises of three dominant soil types. The major portion of the basin is covered by sandy loam soil (68.1%) followed by sandy clay loam (28.5%) and silty clay loam (3.4%) of the total basin area. The land use map and the soil map of the study area is given in Figure 2(a) and 2(b). The daily rainfall data of Tikamgarh district comprising of the various blocks located in and around the basin viz., Tikamgarh, Jatara, Baldevgarh and Palera have been obtained from Superintendent of Land Records, Tikamgarh and the daily climatic data including maximum and minimum temperature, relative humidity, wind speed, solar radiation have been obtained from India Meteorological Department (IMD), Pune. The climate of study area is semi-arid with four distinct seasons.

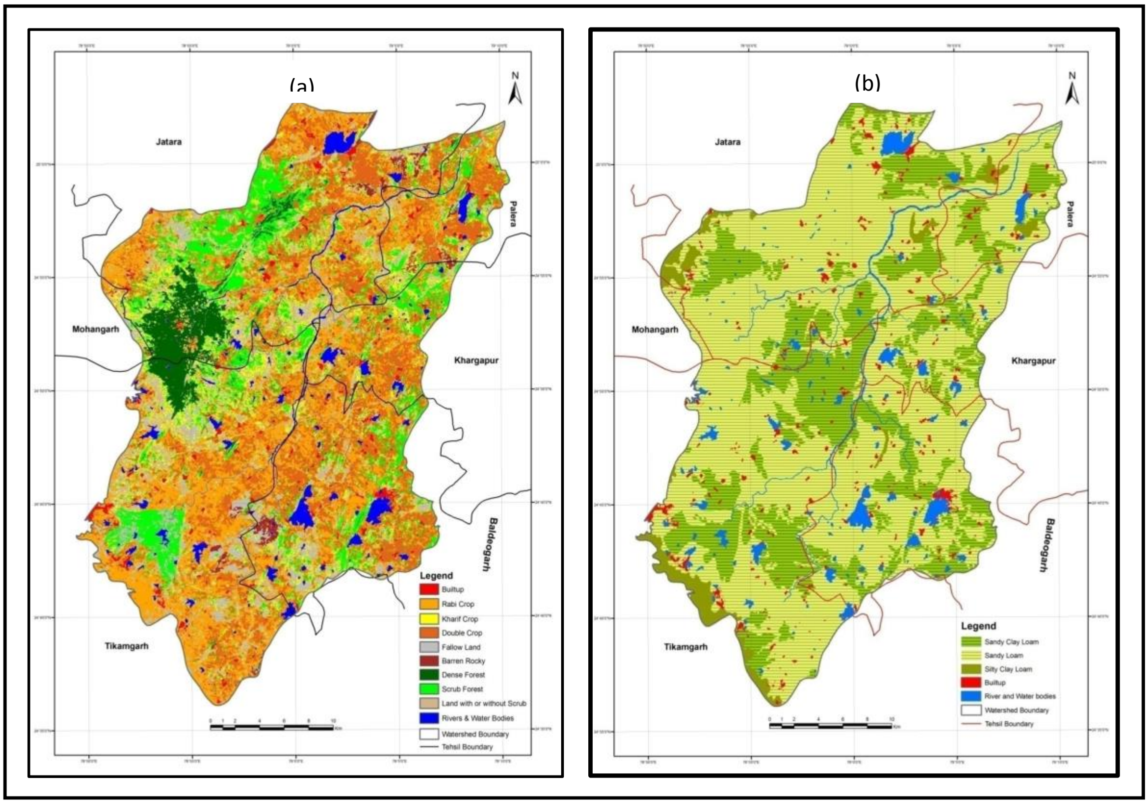

Figure 2. (a) Land use map (b) Soil map

The winter season extends from December to February followed by the summer season from March to mid-June; rainy season from mid-June to September and the post-monsoon season from October to November. The relative humidity is high during the monsoon season being generally above 70 percent whereas in summer season the relative humidity is less than 20 percent.

METHODOLOGY

Computation of Aerial Average Rainfall

The average areal rainfall has been estimated using the Thiessen polygon method, wherein the representative weights of each of the four influencing rain gauge stations has been derived from the Thiessen Polygon prepared for the basin and the aerial average rainfall for the basin has been computed using Equation 1,

$$P_{seas} = \frac{A_1P_1 + A_2P_2 + A_3P_3 + A_4P_4}{A_1 + A_2 + A_3 + A_4} \tag{1}$$

Potential Evapotranspiration

The potential evapotranspiration has been computed by the Penman-Monteith method, which is the sole standard method of determining evapotranspiration as suggested by FAO and has a strong likelihood of correctly predicting ET_o in a wide range of locations and climates and has provision for application in data-short situations also. The FAO Penman-Monteith method is given in Equation 2,

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (2)$$

where, ET_o= reference evapotranspiration [mm day^{-1}]; R_n= net radiation at the crop surface [MJ m^{-2} day^{-1}]; G = soil heat flux density [MJ m^{-2} day^{-1}]; T= mean daily air temperature at 2 m height [°C]; u_2= wind speed at 2 m height [m s^{-1}]; e_s = saturation vapor pressure [kPa]; e_a= actual vapor pressure [kPa]; e_s - e_a = saturation vapor pressure deficit [kPa]; Δ = slope vapor pressure curve [kPa °C^{-1}]; γ = psychrometric constant [kPa °C^{-1}]

Soil Conservation Service Curve Number (SCS-CN) Model

The direct surface water runoff has been estimated by the Soil Conservation Service Curve Number (SCS-CN) model at the outlet of the watershed. The SCS-CN model is based on the single parameter Curve Number (CN), which depends on the land use, land cover, soil type and the antecedent moisture conditions prevailing in the watershed. The composite curve number (CCN) for the watershed is estimated as 78 using hydrologic soil group and land use for the AMC-II condition (average). The AMC changes to dry or wet conditions depending on the 5-day antecedent rainfall. The direct surface runoff has been estimated using the SCS-CN model given in Equation 3 to 5.

$$Q = \frac{(P - I_a)^2}{(P - I_a + S)} \, for P > I_a \quad (3)$$

$$Q = 0, \, for P \le I_a \quad (4)$$

$$S = \frac{25400}{CN} - 254 \quad (5)$$

where, Q = direct surface runoff (mm); S = potential retention (mm); CN = curve number; I_a= initial abstraction = 0.2S for general soils; 0.3S for AMC-I and black soils ; and = 0.1S for AMC-III.

Monthly Water Balance Model

The understanding of the catchment response in respect to the changing climate and weather pattern is important in the identification and evaluation of the expected changes in the hydrological components including the evapotranspiration, runoff, and recharge to ground water which play a significant role in the water availability and demand scenario within a watershed. The expected changes in the present as well the future scenario can only be quantified based on a simple and complete water balance model, incorporating all the important components of the hydrological cycle which may get affected due to the possible changes in the climate due to the natural and anthropogenic climate forcing. To assess the impacts of the impending climate change on the water resources in the watershed, a water balance model needs to be initially setup and run based on the normal data of rainfall and evapotranspiration based on the average values of the available long-term data. Subsequently the changes in the climate generally represented by the changes in the rainfall or/and the changes in the temperature can be forced on the model to simulate the catchment responses under alternate climate change scenarios.

The Thornthwaite and Mather (1957) water balance model (TMWB) which is a simple but an effective modeling tool has been employed to analyse the impacts of climate change in the Ur river basin. The TMWB which is a simple model and has already been established as a tool for estimating the hydrological effects of climate change, has been chosen as it provides reliable estimation of surface runoff on a monthly time scale using minimal climatic data. As a modification, the potential evapotranspiration (PET) has been estimated by the Penman Monteith method.The procedure followed in the setup of the model includes:

1. Computation of the average monthly precipitation data (P) using daily station rainfall data by Thiessen Polygon method.

2. Computation of PET on monthly basis using climatic data by Penman Monteith method.

3. Estimation of overall water availability scenario with water excess as (+) and water deficit as (-) for each month using Equation 6,

$$Surplus\ or\ Deficit = P - PET \tag{6}$$

4. Computation of accumulated potential water losses (APWL) starting from the month in which the P < PET to account for gross potential deficit during each month using Equation 7,

$$APWL = \sum_0^t Deficit \tag{7}$$

5. Computation of monthly soil moisture storage. The release of soil moisture is assumed to be an exponential function given by Equation 8,

$$SM_t = AWC * exp\frac{Ac(P-PET)}{AWC} \quad \textit{limited to a maximum of AWC} \tag{8}$$

where, SMt = actual storage of soil moisture AWC = available water content i.e., storage capacity of soil moisture zone Ac(P-PET) = accumulated values of (P-PET)

6. Computation of change in storage (ΔSM_t) for each month as given by Equation 9,

$$\Delta SM_t = SM_t - SM_{t-1} \tag{9}$$

when the storage remains at capacity level i.e. AWC, the change in soil moisture, $SM_t = 0$, but when soil moisture reaches values of less than its capacity, then ΔSM_t is calculated as the difference in soil moisture between soil moisture of present month and soil moisture of the previous month. A negative change in soil moisture (ΔSM_t) implies extraction of water from the soil moisture storage for evapotranspiration whereas a positive change implies infiltration of water into the soil leading to addition in the soil moisture storage.

7. Computation of actual evapotranspiration is based on the rainfall, PET and ΔSM_t.

$$\{AET_t = P_t, for\ P_t < PET_t \text{ and } AET_t = PET_t, for\ P_t > PET_t\} \text{for } +ve\ \Delta SM_t$$

$$\{AET_t = P + \Delta SM_t\} \text{ for } -ve\ \Delta SM_t \tag{10}$$

8. The soil moisture deficit starts getting reduced once the precipitation starts getting stored in the soil moisture storage with the onset of the monsoon season. The soil moisture eventually attains field capacity and thereafter the further precipitation excess escapes by gravitational drainage.

9. Thereafter the computation of the net deficit or net surplus which is based on the change in soil moisture being negative and vice versa is computed as given by Equation 11 & Equation 12,

$$Net\ Deficit_t = PET_t - AET_t \ \ or \tag{11}$$

$$Net\ Surplus_t = P_t - \Delta SM_t - AET_t \tag{12}$$

10. The total average runoff (TAVRO) for the first time step during which P > PET is considered equal to the net surplus estimated in the above step. The total average runoff comprises of surface runoff and detention component. It is assumed that 50% of the TAVRO flows down the stream as surface runoff (SRO) and the balance is detained in the watershed as detention storage (DETN).

11. However for the subsequent months of the analysis, the total average runoff is computed as given by Equation 13,

$$TAVRO_t = Net\ Surplus_t + DETN_{t-1} \tag{13}$$

12. Therefore about 50% of surplus water that is available for runoff in any month actually runs off as SRO. The rest of the surplus is detained in the subsoil, ground water, small lakes and canals and is available for runoff during the subsequent month.

Assessment of Climate Change Impacts

The impact of climate change on the water resources systems in the Ur river watershed has to be understood for developing a Decision Support System linking the climate change aspects also. The impact of the climate change can be understood by the scenario analysis based on the climatic data. The climate data pertaining to various scenarios are available for many General Circulation Models (GCM) simulated based on the historical data and is able to give the future climatic data. However owing to the computational constraints, the GCM simulations are available at coarse resolutions and cannot be directly applied for basin scale studies for hydrological application. Under such circumstances, the coarse resolution GCM data needs to be downscaled to a finer resolution so that it can be applied for hydrological applications.

In this study, an effort has been made to study the impacts of climate change using hypothetical scenarios of decrease in precipitation and increase in temperature, both on a standalone basis as well as on a combined basis and thereby analysing the impact on the water availability under each scenario. The scenarios considered include decrease in normal precipitation by 10%, 20% and 30%; increase in temperature by 1^{o}C, 2^{o}C, 3^{o}C and combinations of both precipitation decrease and temperature increase scenarios. The precipitation decrease as well as the temperature increase has been considered, as both will lead to reduced water availability in the basin. The model has initially been setup with the normal rainfall and PET data and subsequently the inputs have been varied based on these scenarios. The increase in temperature is accounted by the increased potential evapotranspiration, which have been estimated separately for each degree rise in temperature. The comparison of the surface runoff availability with the under normal conditions and alternate climate scenarios helps to understand the impacts of possible climate change. The use of the downscaled climate data based on various scenarios from the GCM will definitely give a better idea of the complex mechanisms and their interaction leading to future water availability, even though these analyses still involve considerable uncertainties.

RESULTS & DISCUSSION

The long-term daily average rainfall at each of the four stations have been obtained by taking the average daily rainfall values during 1999-00 to 2009-10 and the monthly average rainfall at these stations have been computed thereafter and the mean areal rainfall computed using the Thiessen Polygon Method. The area of influencing raingauge stations is given in Table 1. It can be observed that the rain gauges at Jatara and Tikamgarh have maximum influence followed by Baldevgarh and the rain gauge at Palera has minimal influence on the rainfall distribution in the basin.

Table 1. Area of influence of various rain gauge stations in Ur river basin

S. No.	Raingauge station	Influencing area (sq. km)	Thiessen weight
1.	Tikamgarh	313.37	0.32
2.	Baldevgarh	275.63	0.28
3.	Jatara	324.66	0.33
4.	Palera	76.70	0.07

The PET has been estimated by the Penman-Monteith method, considering the normal climatic data available at Tikamgarh (Table 2). The average daily evapotranspiration at Tikamgarh is 4.30 mm/day.

Table 2. Climate and evapotranspiration at Tikamgarh

Month	Min Temp °C	Max Temp °C	Humidity %	Wind km/day	Sun hours	Rad $MJ/m^2/day$	ET_o mm/day
January	7.3	24.7	74	94	9	16.4	2.49
February	9.1	27.2	70	95	10	19.8	3.21
March	13.9	33.4	61	99	9.1	21.1	4.30
April	20	38.9	42	96	9.8	24	5.64
May	24.7	42	40	117	10.2	25.3	6.82
June	26.4	39.8	57	183	7.7	21.6	6.69
July	24.3	33.4	79	229	6.1	19.1	4.90
August	23.5	31.5	85	198	5.3	17.4	3.99
September	22.7	32.5	80	115	6.6	18.1	4.07
October	17.7	33.2	66	73	8.6	18.6	3.93
November	11.4	29.8	68	70	9.5	17.4	3.13
December	7.6	25.8	69	78	9.0	15.6	2.47

The Thornthwaite water balance model has been set up for the Ur river basin. The available water capacity (AWC) has been considered to be 150 mm as the soil mostly comprises of sandy clay loam. The water balance computations is given in Table 3. The computations for the accumulated potential water loss (APWL) starts from the month of October when P < PET and continues up to June. No APWL is observed in the computations during July, August and September as the P > PET during this period and situation is of surplus water. The soil moisture (SM) is at its full capacity only during August and September after which it starts reducing up to June. The actual evapotranspiration from the basin is at the potential rate only during July, August and September, when P > PET. Considerable surface runoff is observed during August to December after which minimal flows are sustained in the river. The total runoff observed in the basin is 162.1 mm for the normal rainfall of 844.3 mm. The runoff coefficient based on the normal climatic data is 0.19 which seems to reasonable, but cannot be validated as the catchment is ungauged. The graph showing the temporal variation of the important water balance components based on the normal climatic data is given in Figure 3. The computation of the monthly water balance helps to identify and quantify the important hydrological components during various months of a water year. The analysis reveals that about 20% of the precipitation is converted into surface runoff whereas the remaining water gets stored in ground water aquifers, lakes, detention storages including initial abstraction and evapotranspiration losses.

In order to study the range of variation of individual water balance components, the water balance model has been subsequently run based on the observed rainfall and climatic data during the period between 1999-00 and 2009-10. The comparison of the surface runoff generated by this model as well as that obtained by the SCS-CN method during the monsoon season have been compared and is given in Table 3. It has been observed that the seasonal surface runoff generated by TMWB model is higher than that generated by the SCS-CN model on most occasions as SCS-CN produces the direct runoff only instead of the total surface runoff which includes base flow. Also the SCS-CN model computed the runoff on a daily basis and therefore the rainfall pattern and its distribution also gets reflected in the catchment response whereas the TMWB model computes the surface runoff on a monthly basis based in the water

Table 3. Water balance computations for Ur river basin

Water balance components	Jun	Jul	Aug	Sep	Oct	Nov
Precipitation (P)	73.8	263.8	282.0	163.9	29.8	2.8
PET (mm)	200.7	151.9	123.7	122.1	121.8	93.9
Surplus/Deficit (P - PET)	-126.9	111.9	158.3	41.8	-92.0	-91.1
Accumulated potential water loss (APWL)	-1039.4	0.0	0.0	0.0	-92.0	-183.2
Soil Moisture (SM)	0.1	112.1	150.0	150.0	81.2	44.2
Change in soil moisture (ΔSM)	-0.2	111.9	37.9	0.0	-68.8	-37.0
Actual ET (AET)	74.0	151.9	123.7	122.1	98.6	39.7
Net deficit	126.7	0.0	0.0	0.0	23.2	54.2
Net surplus	0.0	0.0	120.4	41.8	0.0	0.0
Total average runoff (TAVRO)	0.2	0.0	120.4	102.0	51.0	25.5
Surface runoff (SRO)	0.1	0.0	60.2	51.0	25.5	12.8
Detention	0.1	0.0	60.2	51.0	25.5	12.8

All units are in mm *contd…*

Water balance components	Dec	Jan	Feb	Mar	Apr	May
Precipitation (P)	4.4	10.7	6.0	3.7	0.9	2.4
PET (mm)	76.6	77.2	89.9	133.3	169.2	211.4
Surplus/Deficit (P - PET)	-72.2	-66.5	-83.8	-129.6	-168.3	-209.0
Accumulated potential water loss (APWL)	-255.3	-321.8	-405.7	-535.2	-703.5	-912.5
Soil Moisture (SM)	27.3	17.6	10.0	4.2	1.4	0.3
Change in soil moisture (ΔSM)	-16.9	-9.8	-7.5	-5.8	-2.9	-1.0
Actual ET (AET)	21.3	20.5	13.5	9.6	3.8	3.4
Net deficit	55.3	56.7	76.3	123.7	165.4	208.0
Net surplus	0.0	0.0	0.0	0.0	0.0	0.0
Total average runoff (TAVRO)	12.8	6.4	3.2	1.6	0.8	0.4
Surface runoff (SRO)	6.4	3.2	1.6	0.8	0.4	0.2
Detention	6.4	3.2	1.6	0.8	0.4	0.2

All units are in mm

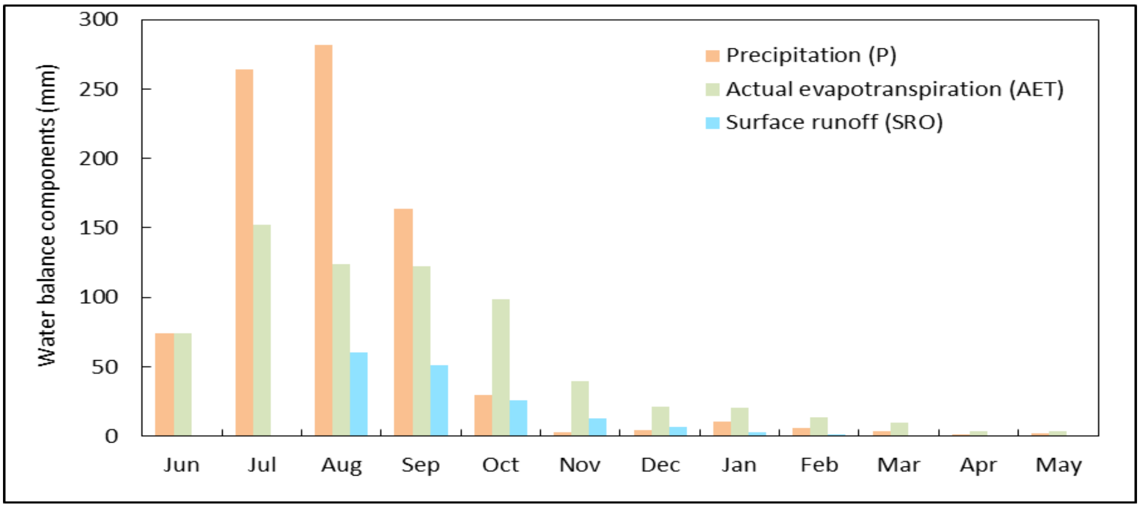

Figure 3. Temporal variation in important hydrological components

Table 4. Comparison of seasonal surface runoff (MCM)

Year	TMWB model	SCS-CN model
1999-00	468.75	300.55
2000-01	60.97	44.65
2001-02	77.87	20.53
2002-03	170.04	108.52
2003-04	297.60	205.90
2004-05	67.64	76.65
2005-06	39.59	63.24
2006-07	20.91	22.01
2007-08	0.00	0.04
2008-09	356.92	333.02
2009-10	71.93	76.55

available in the soil moisture storage. However it can be observed that both models reproduce the surface runoff with reasonable degree of accuracy, even though the individual model responses cannot be validated due to lack of observed stream flow data as the basin is ungauged. The comparison of the seasonal runoff generated by both models is given in Figure 4.

Assessment of Climate Change Impacts

Since the TMWB model is able to produce the surface runoff satisfactorily, it can therefore be readily applied for analyzing the impacts of climate changing by forcing various scenarios and studying the runoff pattern emerging from the catchment under changed climatic conditions. The scenarios considered include decrease in normal precipitation by 10%, 20% and 30%; increase in temperature by 1^{o}C, 2^{o}C, 3^{o}C; and combinations of both precipitation decrease and temperature increase scenarios. The TMWB model has been run separately for each of these scenarios and the change in the surface water availability compared amongst various scenarios. The comparison of the surface water availability under various alternate climate scenarios is given in Figure 5. It has been observed that there is substantial variation in the catchment response in the form of generated surface runoff for each of the climate scenario. The change in

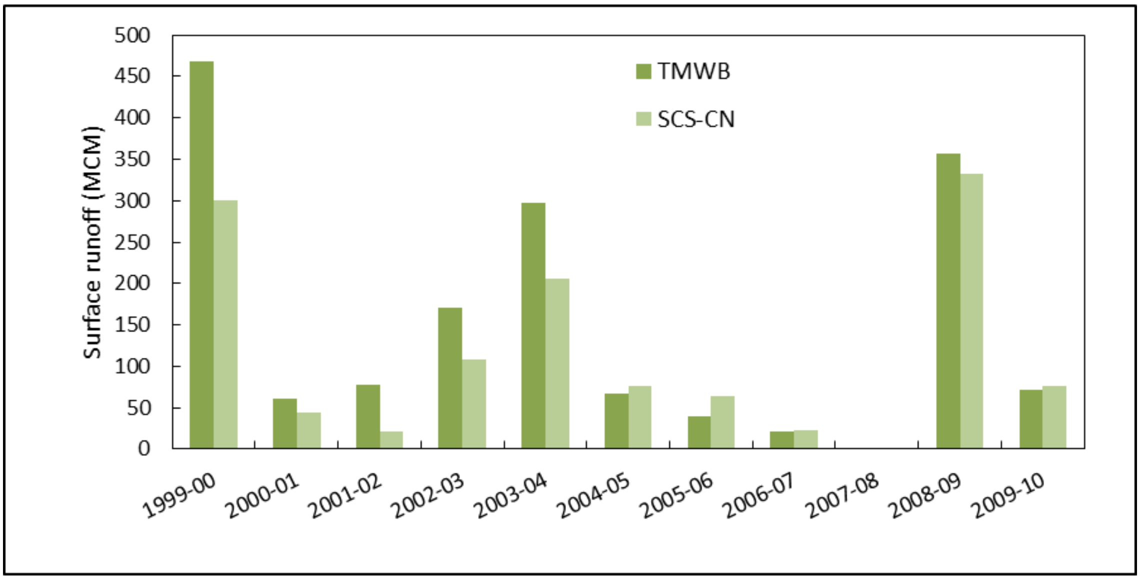

Figure 4. Comparison of seasonal surface runoff by SCS-CN and TMWB models

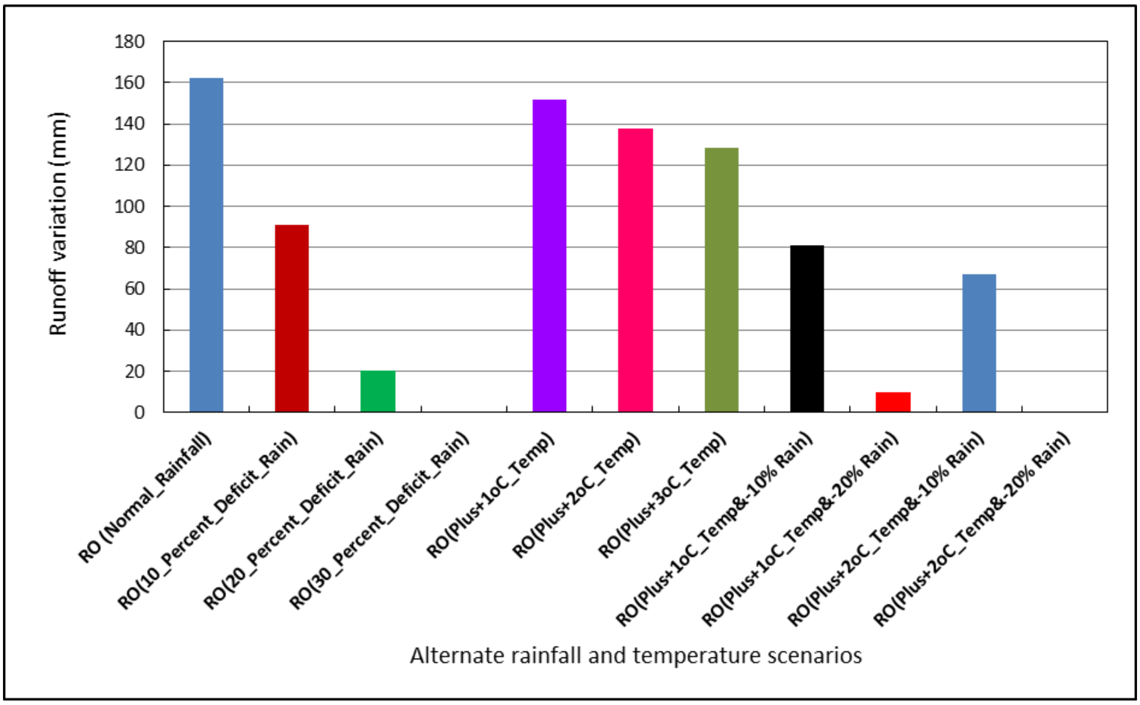

Figure 5. Comparison of surface runoff under various climate scenarios

surface runoff under various alternate climate scenarios can be better understood by critically analyzing Figure 6, which gives the percentage reduction in runoff. It is observed from the analysis that a 10% reduction in precipitation leads to more than 40% reduction in surface runoff whereas a 20% reduction in precipitation leads to more than 80% reduction in surface runoff. Similarly for various temperature scenarios, a 1^{o}C increase in temperature which leads to increase in PET ultimately results in 6% reduction in surface runoff whereas an increase in temperature by 2^{o}C and 3^{o}C leads to reduction in surface runoff by 15% and 20% respectively.

However the combination of reduced precipitation coupled with the increased temperature leads to more drastic reduction in the surface runoff availability scenario. A 1^{o}C rise in temperature coupled with a 10% reduction in rainfall leads to reduction in surface runoff by 50% whereas a

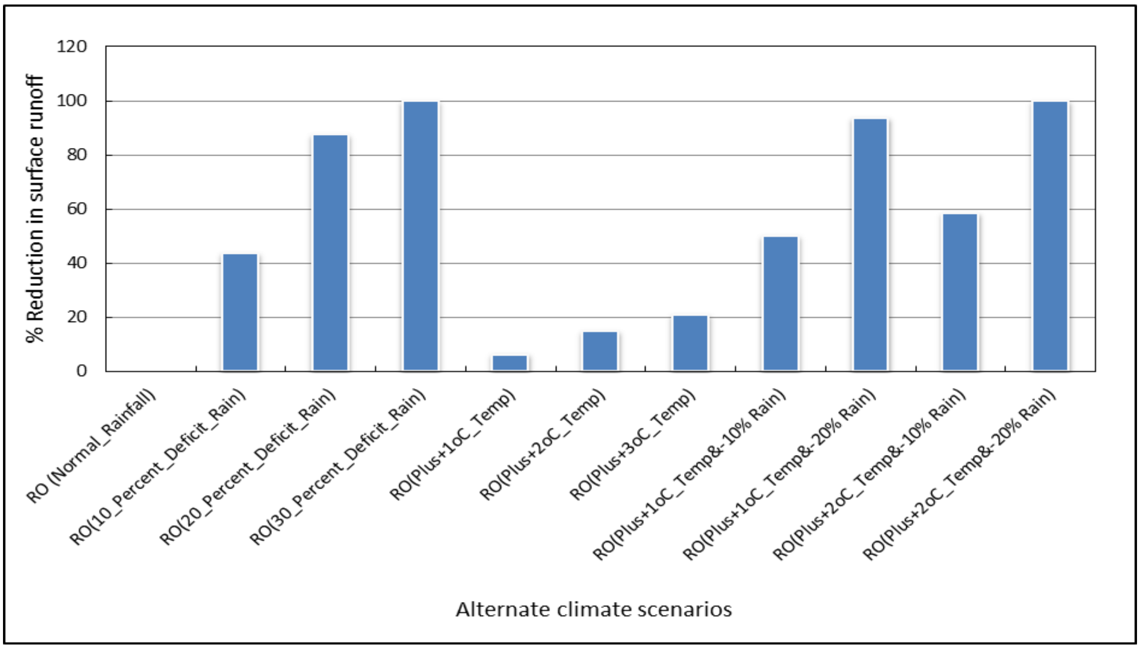

Figure 6. Percentage reduction in surface runoff under various climate scenarios

2^{o}C rise in temperature coupled with a 10% reduction in rainfall leads to reduction in surface runoff by 59%. The analysis under the various climate scenarios helps to understand the change in the hydrologic regime due to the changing climate scenario which has become more pronounced in recent times and is expected to continue so with greater impacts in the future too.

CONCLUSIONS

The range of variation of individual water balance components have been studied using the TMWB model and simulation performed during 1999-00 to 2009-10. The surface runoff generated by the TMWB model has been compared with the runoff generated by SCS-CN model. The comparison of the runoff generated by both models reveals that the SCS-CN model underestimates the runoff as it gives on the direct surface runoff and is computed on a daily basis thereby incorporating the effects of rainfall pattern and distribution and antecedent moisture conditions. Various model runs have been carried out using the hypothetical scenarios of decrease in normal precipitation by 10%, 20% and 30%; increase in temperature by 1^{o}C, 2^{o}C, 3^{o}C, and combinations of both precipitation decrease and temperature increase. It is observed that a 10% reduction in precipitation leads to more than 40% reduction in surface runoff. Similarly a 1^{o}C increase in temperature results in 6% reduction in surface runoff whereas an increase in temperature by 2^{o}C and 3^{o}C leads to reduction in surface runoff by 15% and 20% respectively. However the combination of reduced precipitation coupled with the increased temperature leads to more drastic reduction in the surface runoff availability scenario. A ^{o}C rise in temperature coupled with a 10% reduction in rainfall leads to reduction in surface runoff by 50% whereas a 2^{o}C rise in temperature coupled with a 10% reduction in rainfall leads to reduction in surface runoff by 59%. The analysis under the various climate scenarios helps us to understand the change in the hydrologic regime due to the changing climate scenario which has become more pronounced in recent times and is expected to continue so with greater impacts in the future too. However, the use of downscaled GCM datasets of precipitation and temperature for various future emission scenarios with give better representation of the climate change impacts as the relationship between the temperature rise and precipitation is very complex and therefore the use of hypothetical scenarios can only throw an insight into the approximate changes in the water balance components.

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