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Future climate change impact on hydrological regime of river basin using SWAT model

V. Anand*, B. Oinam

Department of Civil Engineering, National Institute of Technology Manipur, India

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ABSTRACT

Hydrological components in a river basin can get adversely affected by climate change in coming future. Manipur River basin lies in the extreme northeast region of India nestled in the lesser Himalayan ranges and it is under severe pressure from anthropogenic and natural factors. Basin is un-gauged as it lies in remote location and suffering from large data scarcity. This paper explores the impact of climate change towards understanding the inter-relationships between various complex hydrological factors in the river basin. An integrated approach is applied by coupling Soil and Water Assessment Hydrological Model and Hadley Center Coupled Model based on temperature, rainfall and geospatial data. Future representative concentration pathways 2.6, 4.5 and 8.5 scenarios for 2050s and 2090s decades were used to evaluate the effects of climatic changes on hydrological parameters. Both annual mean temperature and annual precipitation is predicted to be increased by 2.07°C and 62% under RCP 8.5 by the end of 21st century. This study highlights that change in meteorological parameters will lead to significant change in the hydrological regime of the basin. Runoff, actual evapotranspiration and water yield are expected to be increased by 40.96 m^3/s, 52.2% and 86.8% respectively under RCP 8.5. This study shows that water yield and evapotranspiration will be most affected by increase in precipitation and temperature in the upper and middle sub-basins. Different region within the basin is likely to be affected by frequent landslides and flood in coming decades.

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*Corresponding Author:
Email: *vicky@nitmanipur.ac.in*
Phone: +903 6106997
Fax: +903 85-2413031

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INTRODUCTION

One of the challenging issues in the field of hydrology is the effect of changing climate on water circulation, temporal and spatial distribution of water resources, whose scientific methods mainly include scenario hypothesis, downscaling, model simulation (Lamba *et al.,* 2016). Water cycle processes are influenced by climatic changes in multiple ways, which have the characteristics of complex, no-linear and dynamic (Liu *et al.,* 2014). Regional crop production have partially or completely damaged by several extreme natural disasters. Such extreme weather has led to restricting the sustainable growth of societies and economy (Lesk *et al.,* 2016). In some parts of the world the economic growth rate could be knock down by a figure of 6% of gross domestic product rate because of scarcity of water, sending them into sustained negative growth (World Bank Group, 2016). Rise in temperature can cause higher amount of precipitation from the landscape whereas change in precipitation can lead to extreme weather events like floods and drought (Dai, 2013). India being an agro based country which depends mostly on monsoon rainfall, spatial variability and uncertainty in the rainfall has significantly hampered the amount of production in past decade. Spatial variability in rainfall has led to increase in the frequency of floods, landslides and droughts over the various parts of the country. For the two consecutive years in 2005 and 2006 several districts in Assam were severely affected due to flood which had a signature of climate change on them as vindicated by the IPCC report of 2007 (IPCC, 2007). In 2005, prolonged scarcity of rainfall in Mizoram lead to drying up of springs and streams accompanied by large scale landslides (ICIMOD, 2008). Every year in the northeastern part of India floods inundate at least 2000 villages. The problem is further exacerbated by riverbank erosion, which destroys about 8,000 hectares of riparian land along the Brahmaputra annually. Vast area in the region have been affected by erosion e.g. 815,000 hectares in Meghalaya, 14,000 hectares in Manipur and 508,000 hectares in Nagaland (Venkatachary *et al.,* 2001). Hydrological models make the hydrological systems simpler; forecast hydrological changes; and hydrological phenomena to compute the hydrological effects and formulate various policies on water resource management (Mirza *et al.,* 2003; Zhang *et al.,* 2017). Abroad and more effective depiction of hydrological phenomena in the basin is given by physically distributed based hydrological models as compared to other model types (Refgaard *et al.,* 1996). In hydrologic modeling a mathematical relationship is compiled by analyzing the mutual relationship between surface and climatic variables in order to represent different hydrological phenomena (Gosain *et al.,* 2009).In the recent time period various hydrological models such as soil and water assessment tool (SWAT), MIKE-SHE and VIC have been developed to obtain precise assessments in the field of hydrological modeling (Devi *et al.,* 2015). For hydrological modeling in order to analyze the long term effects of different hydrological parameters in watersheds SWAT has been widely used (Bouraoui *et al.,* 2005). For the various analysis such as hydrologic simulations, nutrient cycles, sediment transportation and other water conservation assessments SWAT model has be extensively used (Liu *et al.,* 2014). The Manipur River basin plays a vital role in the state of Manipur, India. Due to rapid urbanization, deforestation and various other anthropogenic factors has led to significant change in climatic condition over the region in past few decades. Basin is frequently affected by floods, landslides and other natural hazards in the recent years. Future climate change will bring new challenges to water resources management and sustainable utilization of resources with the development of economy any connectivity to this remote area. A hydrological model like SWAT will help us to quantify the challenges because of future climate changes in the future. By doing the climate scenario based analysis for the coming future, this paper aims to explore the impact of climate change towards understanding the inter-relationships between various complex hydrological factors in the river basin and provides some scientific support for the water resources development. This study has been carried out in Manipur River watershed in Manipur, India during 2018 to 2019.

MATERIALS AND METHODS

Study area

Manipur river basin is located between 24^{o} to 25^{o}25’ North (latitude) and 93^{o}36’ to 94^{o}27’ East (longitude) in the extreme northeast region of India in the lesser Himalayan ranges (Fig. 1).Major portion of the region in this basin lies in the land locked Manipur valley. The general elevation ascends at 744 m (above MSL) at the valley region to as high as 3000m in the mountain tracts, which is the birth place or origin of many streams/rivers that traverses through the valley. The valley measures around 75 km along North-South direction and 35 km along East-West direction. One of the major sub-catchment in Manipur River basin is the Loktak Lake, an important wetland in the state of Manipur (Ramsar Bureau, 2016; LDA, 2003). Presence of “Phumdis”, floating herbaceous islands is the distinctive feature of Loktak Lake (LDA, 2003). Total area under Manipur river watershed is around 5062 km^2.Soils found in the catchment area are mostly silty and clayey by texture (NBSS and LUP, 2001). Thickness of the soil layer is more in the hilly terrain region but less in the valley region as it subjected to erosion. The Manipur River basin receives an average rainfall of 1,350 mm. The temperature ranges between 12°C and 31°C and relative humidity ranges from 51 to 81% on average annually.

Hydrologically this river basin has been divided in nine sub-basins: Nambul, Sekmai, Khuga, Imphal, Kongba, Iril, Western, Heirok and Thoubal (Fig. 2). Each sub-basin comprise of hilly terrain along with plain regions, with varying altitude and topographical slope.

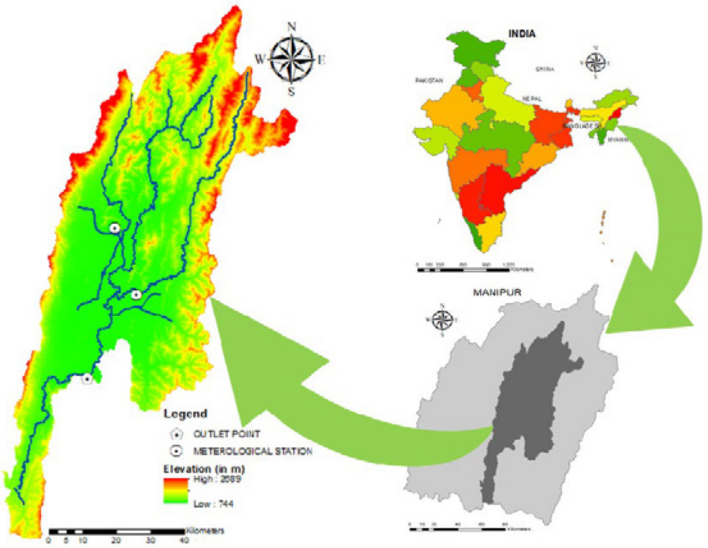
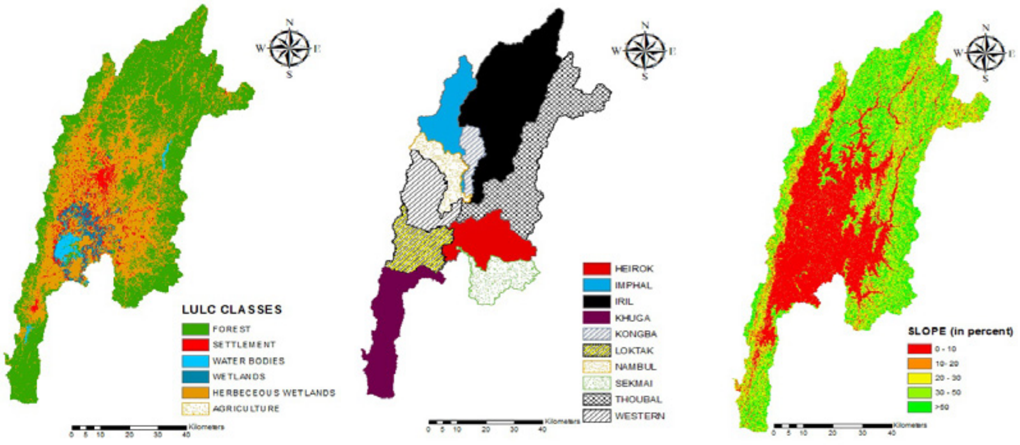


Fig. 1: Geographic location of the study area in Manipur River basin, India



(a) (b) (c)

Fig. 2 (a): Land use/ land cover map, (b): Sub-basin map and (c): Slope map of Manipur river basin

The plain valley part of each sub-basin has a shallow groundwater level, whereas there is a sharp gradient in the water table in the hilly region of the sub-basin.

SWAT model

Development of the SWAT model was started in 1990s (Neitsch *et al.*, 2002). In SWAT a basin is divided into sub-basin and further into HRU based on LULC and soil type. The model is capable of computing sediment, water, nutrient flow using various method. The hydrological cycle in SWAT is governed by land phase equation (Arnold *et al.,* 2005). Manning's equation is used for the computation of watershed concentration time (Neitsch *et al.,* 2011) and for computing the PET Penman–Monteith method is used (Baymani *et al.,* 2013). The detailed depictions of SWAT are given in manual.

Data collection and analysis

The SWAT model requires input data such as DEM, LULC data, weather data, soil data, and the observed flow data for Manipur River basin at the outlet point. Data was acquired from different organizations as mentioned in (Table 1). Land use/ land cover was obtained by performing LULC classification on Landsat 8OLI/TIRS C1 Level-1 image. The model was setup for the period 1999-2017 using the above data set. In order to calibrate the model discharge data was used. As it is an ungauged river basin because of non-availability of direct discharge data, hence the discharge was calculated from the water level data for the period January 2008 to December 2017 obtained from NHPC Power Station Loktak Project, using stage-discharge curve.

General circulation model (GCM) and RCP scenarios

Previously different GCMs like UKMO HadCM3, NCAR CCSM30, UKMO HadGEM1, MPI ECHAM5 and IPSL CM4 have been studied for Irrawaddy river basin and Loktak basin (Singh *et al.,* 2010). HadCM3 model was found to be one of the reliable models for Irrawaddy and Loktak basin. RCP 2.6, 4.5 and 8.5 (2046-2064 and 2081-2100) have been used in this study. In this study bias corrected Hadley Centre Coupled Model, version 3 (HadCM3) is used.

Predictor variables have been downloaded from HadCM3 portal which was then used for the purpose of downscaling. Precipitation, minimum and maximum temperature data for above three future scenarios for the basin was then downscaled using predictor variables based statistical downscaling techniques by multiple regressions (Table 2).

Table 1: Input data and source

Data	Resolution	Sources
DEM	12.5 m	ALOS PALSAR, Alaska Satellite Facility
Land use/ land cover*	30 m	Landsat 8, Earth resource observation and science
Meteorological data	Daily	Directorate of Environment Manipur
Soil data*	1 km	NBSS and LUP
River water level	Monthly	NHPC Power Station Loktak Project (Jan 2008 –Dec 2017)
River water level and discharge^	Daily	Loktak Development Authority (April 2000-March 2002)

* Resampled to 12.5 m) , (^ Data was used to develop the stage-discharge rating curve

Table 2: List of predictor variable used for statistical downscaling of minimum, maximum temperature and precipitation

S. No.	Climate parameters	Definition	Parameter name
1		Mean sea level pressure	Ncepmsl pgl
2		500 hPa airflow strength	Ncepp5_fgl
3		500 hPa zonal velocity	Ncepp5_ugl
4		500 hPameridional velocity	Ncepp5_vgl
5		500 hPageopotential height	Ncepp500gl
6	Maximum and minimum temperature	Specific humidity at 500 hPa	Nceps500gl
7		Specific humidity at 850 hPa	Nceps850gl
8		Mean temperature at 2 m	Nceptem pgl
9		Surface specific humidity	Ncepshu mgl
10		500 hPageopotential height	Ncepp500gl
11	Precipitation	500 hPavorticity	Ncepp5_zgl
12		850 hPavorticity	ncepp_zgl

Discharge data

Manipur River basin is an ungauged basin there is unavailability of direct discharge data at the outlet. Discharge was derived from water level data by using stage-discharge curve (Fig. 3). The monthly water level data measured from 2008 to 2017 at the outlet point (Ithai) was collected from the NHPC Power Station Loktak Project. Discharge data was used to calibrate the model. The annual average discharge for Manipur River was found to be 148.30m^3/s for the time period from 1999-2017.

Sensitivity analysis, calibration and validation of the model.

Sensitivity analysis

Sensitivity analysis is the techniques by which the sensitiveness of the parameters in the SWAT model is analyzed (Zheng *et al.,* 2007). After analyzing the sensitive parameter, it is used in rigorous calibration process followed by validation process. Sampling methods used for sensitivity analysis are Latin Hypercube (LH) and One-factor-At-a-Time (OAT) (Veith *et al.,* 2009).

Calibration

There are several algorithms to calibrate a model like SUFI-2, GLUE, PSO, MCMC and Parasol. SUFI2 is the only algorithm in SWATCUP which is not global and it runs parallel calibration. But other algorithms like PSO, GLUE, Parasol and MCMC run on previous simulation result (Abbaspour, 2015). In order to calibrate the SWAT model SUFI-2 is used in this study. Regionalization method can be used to predict hydrological model parameters for ungauged catchment (Tsolmon *et al.,* 2017). The process of transferring hydrological parameters from watersheds which has similar hydrological treatments because of similar characteristics, such transformation is known as Regionalization approach. There are various methods for such transformation which includes regression method (Bastola *et al.,* 2008), physical similarity (McIntyre *et al.,* 2005) and spatial proximity (Merz *et al.,* 2008).

Model performance indices

i) Nash Sutcliffe efficiency (NS), calculated as Eq. 1.

$$NS = 1 - \frac{\sum_i (P_n - P_t)_i^2}{\sum_i (P_{n,i} - \overline{P}_n)^2} \qquad (1)$$

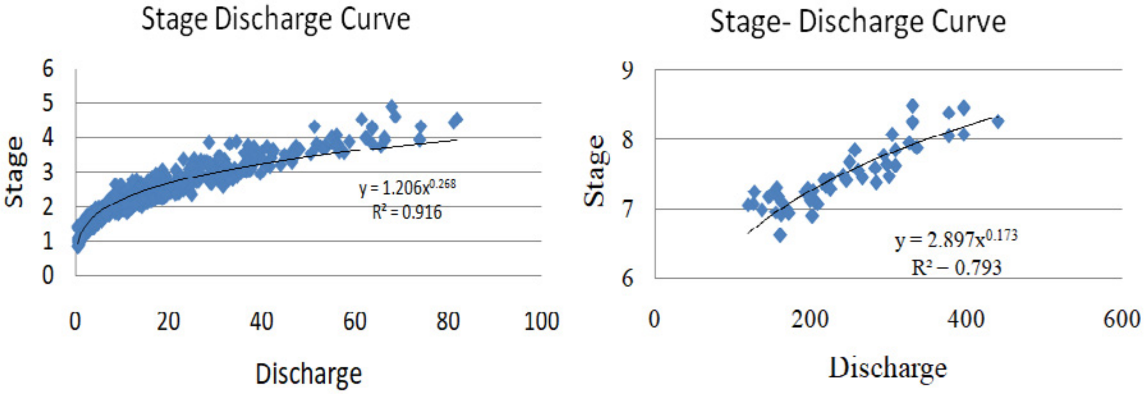
Where, P: a variable, n: measured, t: simulated and bar denotes average, i: ith simulated or measured data (Nash *et al.,* 1970), for more than one variable, the objective function is defined as Eq. 2.

$$g = \sum_j w_j NS_j \qquad (2)$$

Where, w_j is the weight of j^{th} variable

ii) Coefficient of Determination (R^2); calculated as Eq. 3.

$$R^2 = \frac{\left[\sum_i \left(P_{n,i} - \overline{P}_m\right)\left(P_{t,i} - \overline{P}_t\right)\right]^2}{\sum_i \left(P_{n,i} - \overline{P}_n\right)^2 \sum_i \left(P_{t,i} - \overline{P}_t\right)^2} \qquad (3)$$



(a) (b)

Fig. 3(a) Stage-discharge curve for dry season, (b) Stage-discharge curve for wet season

Where, P: a variable, n: measured, t: simulated and bar denotes average, i: i^{th} simulated or measured data, for more than one variable, the objective function is defined as Eq. 4.

$$g = \sum_j w_j R_j^2 \tag{4}$$

Where, w_j is the weight of j^{th} variable.

iii) Kling-Gupta efficiency, calculated as Eq. 5.

$$KGE = 1 - \sqrt{\left((r-1)^2 + (\alpha-1)^2 + (\beta-1)^2\right)} \tag{5}$$

Where, $\beta = \frac{\mu_s}{\mu_m}$ and $\alpha = \frac{\sigma_s}{\sigma_m}$, r: coefficient of linear regression between between measured and simulated variable, μ_s: mean of simulated data, μ_m: mean of measured data, σ_s: standard deviation of simulated data and σ_m: standard deviation of measured data (Gupta *et al.,* 2009). For more than one variable, the objective function is defined as Eq. 6.

$$g = \sum_j w_j KGE_j \tag{6}$$

Where, w_j is the weight of j^{th} variable.

RESULTS AND DISCUSSIONS

Model calibration and validation

Sensitivity analysis was carried out on different sets of parameters. Based on the indices of sensitiveness of parameters, it is categorized as of low, medium and high sensitivity (Lenhart *et al.,* 2002), (Table 3). Due to the lack of direct discharge data availability, model was calibrated using discharge derived from stage-discharge curve. Stage-discharge curve (Fig. 3) was developed based on stage and discharge data for the period (April 2000- March 2002) obtained from LDA. Two separate rating curves was generated for dry period and wet period by polynomial regression. The R^2 value obtained for dry season was 0.916, whereas R^2 value obtained for wet season was 0.793. Monthly observed water level data at the outlet point was

Table 3: Sensitivity of the parameters for the streamflow value of the Manipur River basin

S. No	Parameter name	Definition	File type	Sensitivity	Process
1	CN2	Initial SCS runoff curve number for moisture condition II	.mgt	High	Runoff
2	Alpha_Bf	Baseflow alpha factor	.gw	High	Groundwater
3	Gw_Delay	Groundwater Delay	.gw	Low	Groundwater
4	Sol_Awc	Soil water capacity of the first soil layer	.sol	Medium	Soil
5	HRU_Slope	Average slope steepness	.hru	High	Runoff
6	ESCO	Soil evaporation compensation factor	.hru	Medium	Evaporation
7	SolOrgn	Initial NO_3 concentration in soil layer	.chm	Negligible	Soil
8	Biomix	Biological mixing efficiency	.mgt	Negligible	Soil

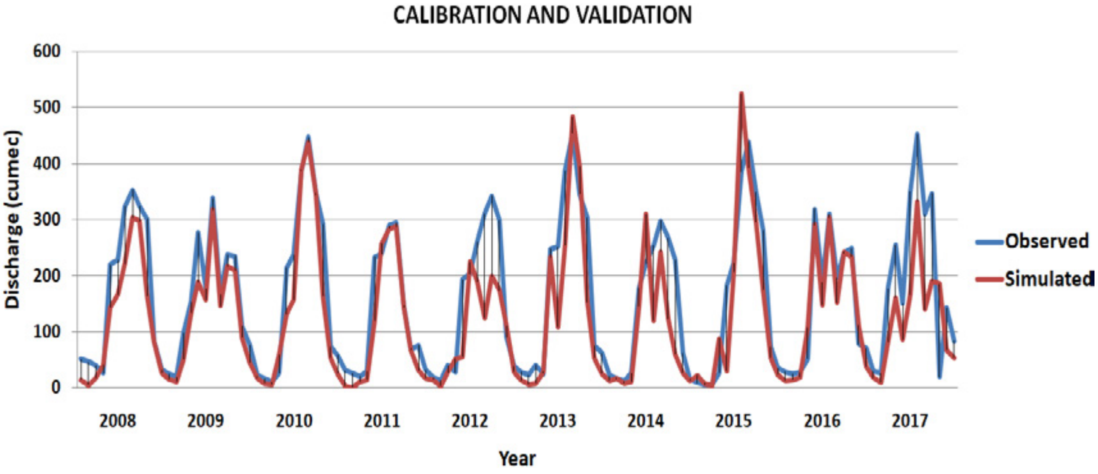


Fig. 4: Calibration and validation result of SWAT model of Manipur River basin at Ithai (2008-2017)

used to obtain discharge value on monthly time step using the rating curves.

The SWAT model was calibrated between the time periods 2010 to 2014 and validated between the time periods 2015 to 2017 at the outlet point of Manipur river basin. In order to develop appropriate water, soil and land use/ land cover condition, a warm-up period of 2 years (2008-2009) is provided for calibration. (Table 4) shows calibrated parameters with their ranges. Calibration and validation result of Manipur River watershed (Table 5) showed good performance of model (Fig. 4).

Climate change analysis for future scenarios and ESM

HadCM3 model with three different future climatic scenarios for 2050s and 2090s decades were used to enumerate the effects of change in climatic condition on the water resource and to identify the uncertainties of future for Manipur river basin.

Projected precipitation

There is a clear indication of increase in annual mean precipitation under different scenarios of GCM. There is a maximum increase of precipitation up to 70% during the period (2081-2100) in contrast to the baseline annual mean precipitation under RCP 8.5 scenario, whereas minimum increment is up to 58.1% during the period (2046-2064) in contrast to the baseline annual mean precipitation under RCP 2.6 scenario.

In all scenarios, the increase in precipitation for 2090s decade is more as compared to that of 2050s decade. Increment in precipitation will lead to rise in discharge in all the scenarios. In our projection all the scenarios shows the increase in precipitation in monsoon (June to September) and post-monsoon season (October and November) whereas increase in precipitation is less in dry season (December to March) and pre-monsoon season (April and May). This follows the similar trends observed by Indian Meteorological Department (IMD) in past 60 years in the state of Manipur in India (Rathore *et al.,* 2013). Extent of change in seasonal variation in projected precipitation under different scenarios and the projected precipitation under different scenarios is presented in Fig. 5.

Projected temperature

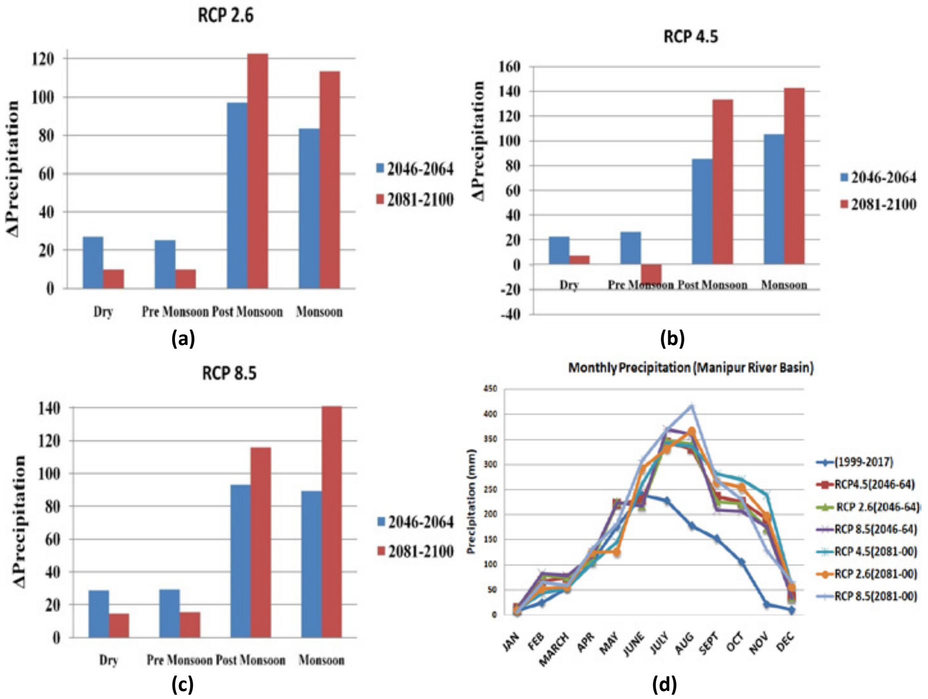
On the temporal basis the increase in temperature appears to be progressive. The annual average temperature increases for all the three scenarios. Temperature will rise more for 2081-2100 time periods than 2046-2064 time periods. The maximum rise in temperature is for the time period 2081-2100 under the RCP 8.5 scenario, whereas minimum increase in temperature is for 2046-2064 time period under RCP 2.6 scenario. There is no indication of reduction in annual mean temperature; this will lead to increase in potential evapotranspiration and actual evapotranspiration (Immerzeel *et al.,* 2012). Increase in precipitation, minimum temperature and maximum temperature for three different RCP scenarios for two different time period 2046-2064 and 2081-2100 is presented in Table 6. The extent of change in temporal variation in projected temperature under various scenarios is presented in Fig. 6.

Table 4: Calibrated parameter values with their ranges

S.No.	Parameter name	Method	File type	Fitted value	Min. value	Max. value
1	CN2	Relative*	.mgt	-21.875	-45.00	-20.00
2	Alpha Bf	Replace	.gw	0.99	0.6	1.00
3	Hru_slp	Relative*	.hru	0.61	0.2	0.7
4	ESCO	Relative*	.bsn	0.22	0.0	0.8
5	Sol_Awc	Relative*	.sol	6.982	0.30	30.00
6	Gw_Delay	Absolute	.gw	-3.25	-10.00	20.00

Table 5: Statistical measures of SWAT model parameters

Basin	Condition	Process	Criteria
Manipur River	Discharge	Calibration	R^2 = 0.78 NSE = 0.71 KGE= 0.73
		Validation	R^2 = 0.75 NSE = 0.67 KGE=0.71



(a) (b) (c) (d)

Fig. 5(a) Seasonal variation under RCP 2.6, (b) Seasonal variation under RCP 4.5, (c) Seasonal variation under RCP 8.5, (d) Monthly precipitation under three different scenarios for 2050s and 2090s decades

Table 6: Annual variation of climatic parameters

Climate variable	Base period (1999-2017)	Annual variation from base period					
		RCP 2.6 (46-64)	RCP 4.5 (46-64)	RCP 8.5 (46-64)	RCP 2.6 (81-100)	RCP 4.5 (81-100)	RCP 8.5 (81-100)
Max. Temperature(°C)	30.89	+0.03	+0.07	+0.19	+0.70	+0.76	+1.4
Min. Temperature(°C)	12.05	+2.32	+2.43	+2.49	+2.25	+2.45	+2.73
Mean Temperature(°C)	21.47	+1.18	+1.25	+1.34	+1.48	+1.61	+2.07
Precipitation(mm)	1303.28	+757.13	+779.62	+782.48	+819.57	+838.06	+925.36

Table 7: Annual variation of hydrological parameters

Hydrological variable	Base period (1999-2017)	Annual variation from base period					
		RCP 2.6 (46-64)	RCP 4.5 (46-64)	RCP 8.5 (46-64)	RCP 2.6 (81-100)	RCP 4.5 (81-100)	RCP 8.5 (81-100)
Runoff (m^3/s)	148.30	+3.90	+6.91	+12.47	+20.74	+22.38	+40.96
Potential evapotranspiration(mm)	1223.97	+59.76	+64.22	+67.96	+75.43	+79.81	+104.18
Evapotranspiration(mm)	583.17	+302.4	+306.61	+308.67	+288.87	+292.21	+304.65
Water yield(mm)	699.06	+444.04	+465.09	+474.03	+518.44	+523.72	+607.01

Impact on hydrological parameters

Impact on discharge

Different water balance components may affect discharge in the river. There is increase in discharge at the outlet point under all RCPs scenario. Increase of 40.9 m^3/s was observed for the highest scenario RCP 8.5 in the time period 2081-2100, whereas increase of 3.90 m^3/s was observed for the lowest scenario RCP 2.6 in the time period 2046-2064. Lowest discharge was observed in the cold and dry month of January,

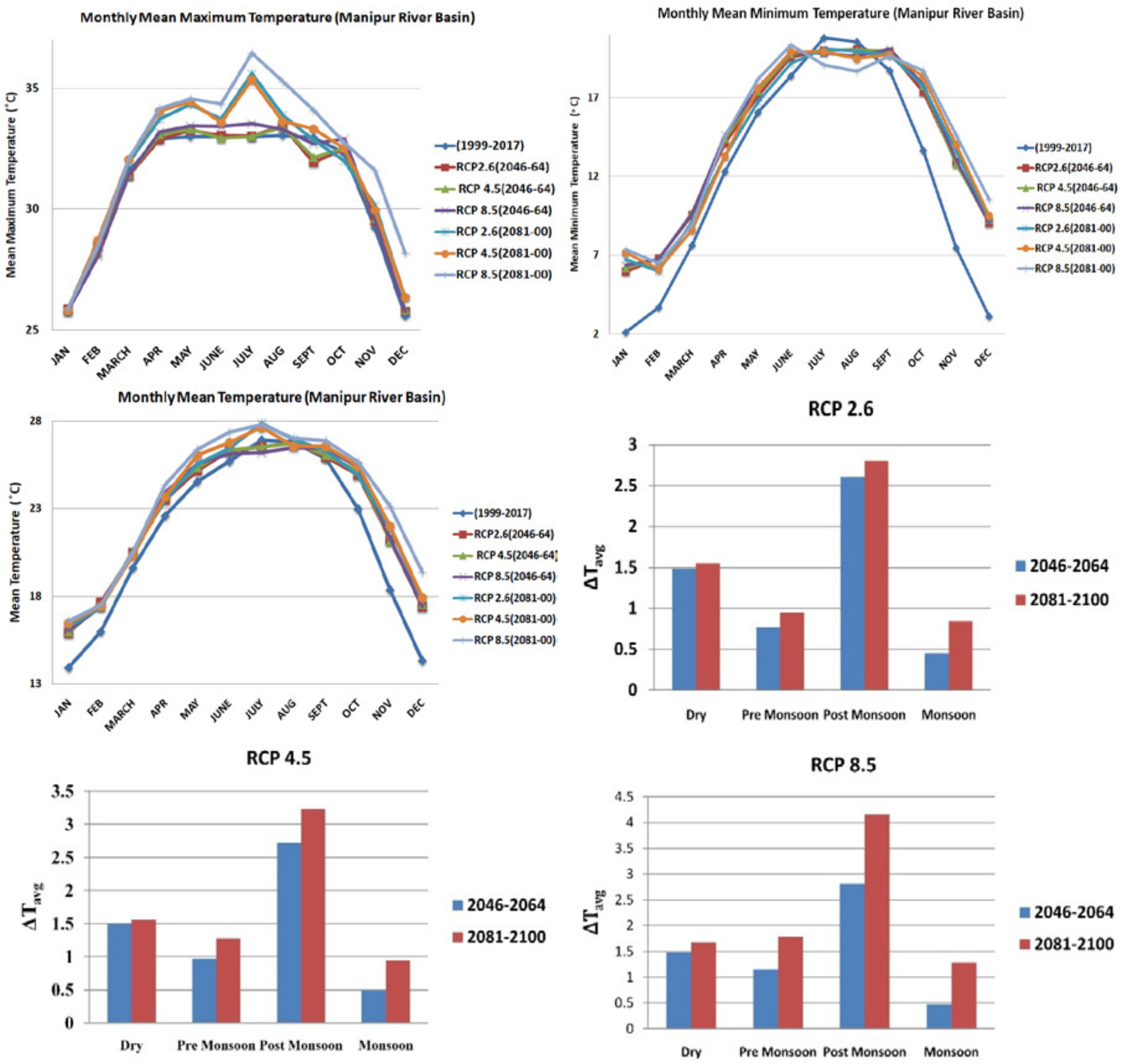


Fig. 6: Monthly average maximum temperature, monthly average minimum temperature and monthly average temperature under three different RCP scenarios for the time period 2046-2064 and 2081-2100. Variation in temporal average temperature under different scenarios

February, March, whereas highest discharge was observed during monsoon and post monsoon season. Increment in discharge under different scenarios for different time period is tabulated in Table 7.

Impact on water balance component

Different parameters of water balance contribute to overall hydrological cycle of the watershed. In this research, effect of climate change on various water balance parameters such as, discharge, precipitation, potential evapotranspiration, water yield and evapotranspiration has been analyzed. Simulated water balance parameters obtained from the calibrated SWAT model has been used as baseline (1999-2017), due to the unavailability of observed data of various water balance parameters. Water yield and PET under all the RCP scenarios increases for both 2050s and 2090s decades. Annual variation in various hydrological components under different RCP scenarios for 2050s and 2090s decades has been tabulated in Table 7. Temporal variation of different water balance parameters has been represented in Fig. 7.

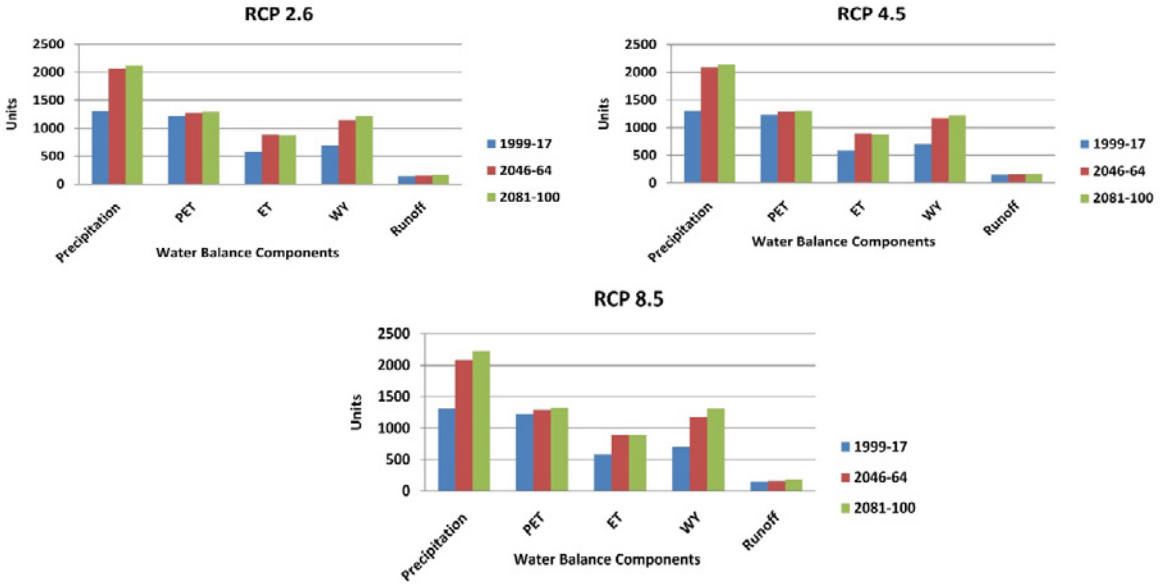
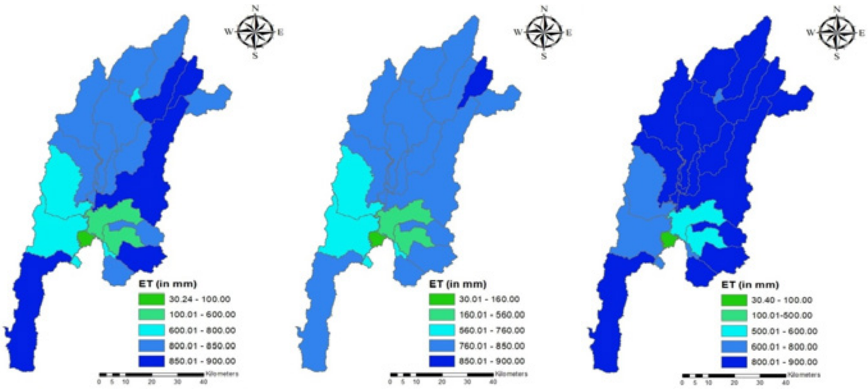


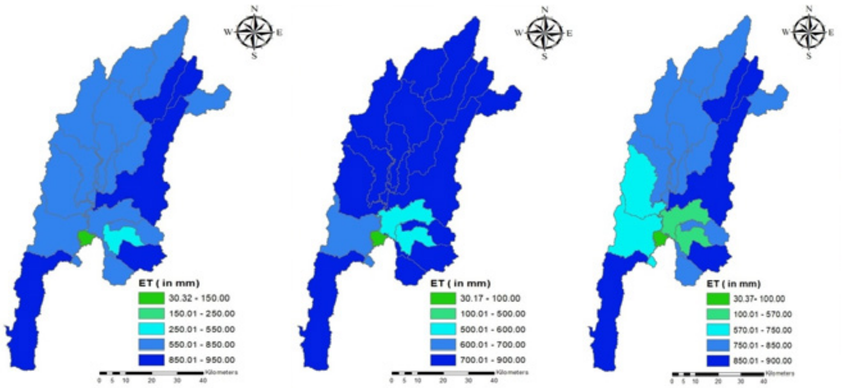
Fig. 7: Annual variation on different water balance components under different RCP scenarios



RCP 2.6 (2046-2064)

RCP 2.6 (2081-2100)

RCP 4.5(2046-2064)

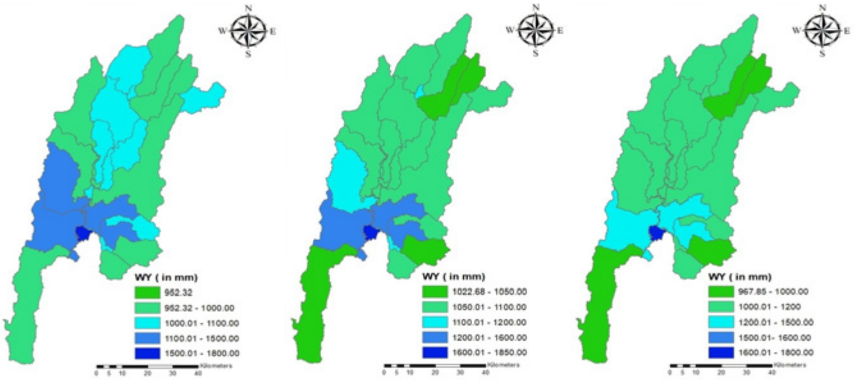


RCP 4.5 (2081-2100)

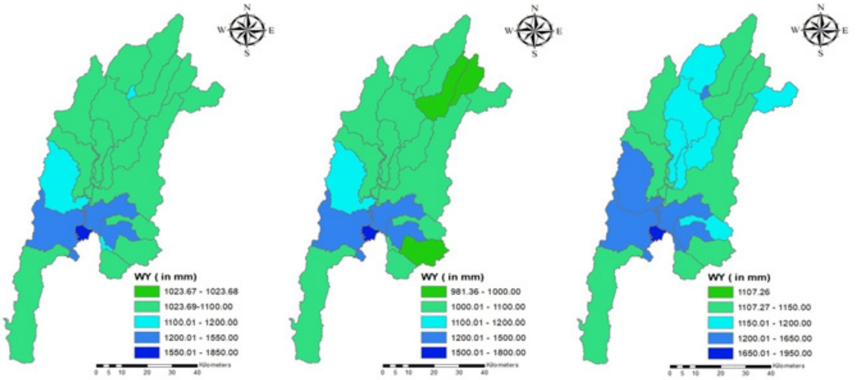
RCP 8.5 (2046-2064)

RCP 8.5(2081-2100)

Fig. 8: Spatial distribution of evapotranspiration under different RCP scenarios for different time period



RCP 2.6 (2046-2064) RCP 2.6 (2081-2100) RCP 4.5(2046-2064)



RCP 4.5 (2081-2100) RCP 8.5 (2046-2064) RCP 8.5(2081-2100)

Fig. 9: Spatial distribution of water yield under different RCP scenarios for different time period

Impact on evapotranspiration

There will be increase in evapotranspiration in all the three RCP scenarios in the coming future as indicated by simulated result from SWAT model. Evapotranspiration in the basin will increase due to increase projected temperature in future both spatially and temporally. Combining the effect of rise in temperature with precipitation will have significant effect on the evapotranspiration. Spatial variation of evapotranspiration in the basin has been represented in Fig. 8. Area under the forest cover in the basin is more susceptible to evapotranspiration.

Impact on water yield

Water yield includes the direct surface flow, groundwater flow, lateral flow and losses. It increases with increment in precipitation. Simulated data from future SWAT model reveals that there will be increment in water yield under all the scenarios for 2050s decade and 2090s decade. For the time period 2046-64 maximum water yield of 1173.1 mm was observed under scenario RCP 8.5, whereas for time period 2081-100 maximum water yield of 1306.7 mm was observed under scenario RCP 8.5. Area around Loktak Lake is highly susceptible to water yield. This indicates that area around Loktak Lake is more susceptible to change in climate than the other regions in the basin. Spatial distribution of water yield in the basin is represented in Fig. 9.

Uncertainty in HadCM3 future climate projection

In-order to minimize the vagueness in the effect of change in climatic condition in Manipur River basin three RCP scenarios, RCP 2.6, 4.5 and 8.5 (2046-2064 and 2081-2100) were used. By using the three RCPs, the variation in the projected precipitation and temperature is expected most likely to be in the mid-range of highest scenario (i.e. RCP 8.5) and lowest scenario (i.e. RCP 2.6), somewhere closer to the range of mid scenario (i.e. RCP 4.5). Using RCP 4.5 as the mid scenario between highest scenario (RCP 8.5) and lowest scenario (RCP 2.6) further minimizes the uncertainty in HadCM3 future climate projection.

CONCLUSION

The impact of climate change on water resources is a serious concern in the northeastern part of India which lies in the lesser Himalayan region. Rise in precipitation and temperature in the basin will have serious consequence on water balance components on both spatial and temporal scale. Future downscaled precipitation and temperature data of HadCM3 GCM model was coupled with SWAT hydrological model in order to assess the impact of climate change on hydrological regime of Manipur river basin. During the monsoon and post-monsoon season, the precipitation within the river basin is expected to increase as per the model result and analysis. It may be effectively harvested by adopting sustainable approaches to meet the requirement for irrigation purpose and hydroelectric power generation. The increase in discharge in the region may lead to frequent flooding in low lying regions and landslides in the hilly regions. Benefits can be harnessed from climate change in the sector of water demand and supply and in generation of hydroelectric power but it is hard to ignore the fatalistic impacts of change in climate such as floods and landslides. As this current study considers single GCM model by minimizing the vagueness of uncertainty by using three different RCP scenarios in predicting the future data, similar studies may be carried out by using multiple GCM models to analyze the associated uncertainties in the modeling approach. Future scenarios studies can incorporate the predicted future LULC along with the predicted future meteorological parameters to understand the combined effect of both LULC and climate on the hydrological parameters of the basin.

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CONFLICT OF INTEREST

The author declares that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

ABBREVIATIONS

%	Percentage
Alpha_Bf	Baseflow alpha factor
Biomix	Biological mixing efficiency
CN2	Curve number moisture condition II
DEM	Digital elevation model
Eq	Equation
ESCO	Soil evaporation compensation factor
ESM	Earth system model
Fig.	Figure
GCM	General circulation model
Gw_Delay	Groundwater delay
HadCM3	Hadley centered coupled model, version 3
HRU	Hydrological response unit
IMD	Indian Meteorological Department
KGE	Kling Gupta efficiency
km	kilometer
LDA	Loktak development authority
LH	Latin hypercube
m^3/s	Cubic meter per second
m	meter
mm	Millimeter
MSL	Mean Sea Level
MW	Megawatt
NBSS and LUP	National bureau of soil survey & land use planning
NHPC	National hydroelectric power corporation
NS	Nash Sutcliffe efficiency

OAT	One factor at a time
OLI/TIRS	Operational Land Imager/ Thermal Infrared Sensor
PET	Potential evapotranspiration
R^2	Coefficient of determination
RCP	Representative concentration pathways
SCS	Soil conservation service
SWAT	Soil and water assessment tool
SWATCUP	Soil and water assessment tool calibration and uncertainty programs
SolAwc	Soil water capacity of the first soil layer
USDA	United States Department of Agriculture

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AUTHOR (S) BIOSKETCHES

Anand, V., Ph.D. Candidate, Department of Civil Engineering, National Institute of Technology Manipur, India.
Email: vicky@nitmanipur.ac.in

Oinam, B., Ph.D., Associate Professor, Department of Civil Engineering, National Institute of Technology Manipur, India. Email: bakim143@gmail.com

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