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Evaluating the Effect of Land-Use Change Coupled with Climate Change: A Study based on Sal River Flow in Goa, India

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ABSTRACT

There is a constant conflict for water amongst various sectors. This is further aggravated by climate change. It is crucial to establish interaction between land-use combined with climate change and local hydrology to devise sustainable management strategies. This study used the Norwegian Earth System Model (NorESM) climate model, Land Change Modeler (LCM) and Soil and Water Assessment Tool (SWAT) hydrological model. This ensemble of models was used to predict Sal River flow in Goa, India under two Representative Concentration Pathway (RCP 4.5 and 8.5) climate scenarios. The statistically tested results indicate that the future rainfall and temperature is likely to increase and more pronounced under RCP 4.5 scenario. However, climate combined with land-use change reveals that the streamflow is likely to increase with increase in the urban/concrete areas and decline with reduction in the forest areas. For Sal River watershed, the forest cover is likely to decrease by 5.93% up to 2040s, with a corresponding increase in the urban/settlement areas. With the increase in the built-up areas, the surface runoff may increase and lead to an urban flooding-like situation. Dependable flows for this watershed were computed to comprehend future water availability. Site-specific recommendations have been formulated to aid the decision-makers to implement the timely adaptation measures.

Keywords: Climate change, NorESM model, Land Change Modeler, SWAT model, Sal River, Goa

INTRODUCTION

Water shortages and tussles are the signs of an increasing gap between water demand (by various sectors) and supply in most places around the world (Straatsma *et al.,* 2020). These symptoms are already visible in a few regions around India (Rathinasamy, 2011). This is further aggravated by the uncertainty in the available water owing to the changing climate. Surface temperature is projected to rise over the 21st century under all assessed emission scenarios. Extreme precipitation events will likely become more intense and frequent in many regions [Intergovernmental Panel on Climate Change (IPCC) *Fifth Assessment Report* (AR5), 2014].

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Climate change is likely to affect global water availability through compounding changes in seasonal precipitation and evaporation (Konapala *et al.,* 2020). Climate change studies in India predict intense impacts such as higher annual average rainfall and increased drought on water resources. This can have negative impacts on water supply (Krishnan *et al.,* 2020).

In general, assessing the impacts of climate change on watershed hydrology requires the use of watershed models and General Circulation Models (GCMs) or Regional Climate Models (RCMs) (Xu *et al.,* 2005). Several studies have recently been carried out on the impacts of climate change on water quantity in Indian rivers (Sharma *et al*., 2019). Assessment of future climate change impacts on Upper Sind River basin's water resources, India using PRECIS and SWAT models was done by Narsimlu *et al.* (2013). An ensemble of RCMs was used by Moors *et al.* (2011) to study adaptation to changing water resources in the Ganges basin, Northern India. Asokan and Dutta (2008) analyzed the impact of changing climate in the Mahanadi river basin using the Canadian Global Coupled Model (CGCM2). All these studies used the IPCC's older A1B emission scenario. The fourth Assessment Report of IPCC considered different emission scenarios of future human activity that portrays probable future greenhouse emissions pathways. These were used as a basis for exploring a realistic set of future projections of climate change. The A1B scenario was the most balanced one and hence was used by most of the impact assessment studies. It was observed that these emission scenarios did not explicitly incorporate carbon emissions control. To address this issue, the fifth assessment report of IPCC came out with new set of scenarios called Representative Concentration Pathways (RCPs) which took into account climate change mitigation policies to limit emissions. Hence, local hydrological impact assessment studies using these recent representative concentration pathway (RCPs) scenarios are needed.

Further, land use is one of the foremost drivers of hydrologic processes, influencing the available water resources and flow regimes in a river basin worldwide (Gashaw *et al*., 2018). Assessing land-use/land cover (LULC) impacts on hydrology is essential for watershed management and ecological restoration (Panandiker *et al*., 2019). Investigations on land-use change impacts on water resources in India have been done by Wagner *et al*. (2019), Anand *et al*. (2018), Babar and Ramesh (2015), and Wagner *et al*. (2013). To devise sustainable water resource strategies, it is also crucial to establish interaction between climate coupled with land-use changes and local hydrology through proper assessment. To be precise, seeing how much change in climate and LULC affects hydrologic regimes or which land use shall be appropriate for the local hydrological regime can help decision-makers to incorporate necessary measures in the policy instruments (Anand *et al*., 2018). A few old studies, such as Wilk and Hughes (2002), examined the impacts of land-use and climate change on India's water resource availability using empirical models. More studies at a regional or local level are required to closely examine the impact of land-use coupled with climate change on the river flow using distributed numerical models. With this objective, the present study aimed to evaluate the impacts of climate and land-use changes on river discharge or streamflow. The study area under investigation is the Sal river watershed in South Goa, India.

STUDY AREA

Sal River originates from Udear springs/waterfall in Verna, Salcete *taluka* in South Goa district. It runs southwards to join the Arabian sea at Betul. The total river length is 35 km. It has two tributaries, namely Navelim Nallah and Cincolim Nallah. The Sal River watershed was delineated using the Water Resources Department's (WRD) discharge monitoring station at Verna as an outlet. The location of the watershed is shown in Fig. 1. The total watershed area is 37 sq. km. The river is heavily silted, and the flows are disturbed at many locations in the non-saline portion due to on-going road works. The main villages that fall in this watershed include Nuvem, Verna, Nagoa, Arossim, Velsao, Cuelim, Consua, Kesarvale, Dongorim, and Gounlloy. Some parts of Cansaulim and Utorda lie in the watershed boundaries. Agriculture is one of the occupations in the region. Paddy, along with chilies and other vegetables are grown in this region. A perennial lake known as Ambulor is located in this watershed. There are three major streams, namely Uddear, Senaulim, and Handkant. The climate of the area is warm and humid. The area receives an annual rainfall mainly from the Southwest (SW) monsoon from June to September. There is one rain gauging station (operated by the Water Resources Department) at Cuncolim. The average annual rainfall for the period 2010–2018 was recorded to be 2890 mm.

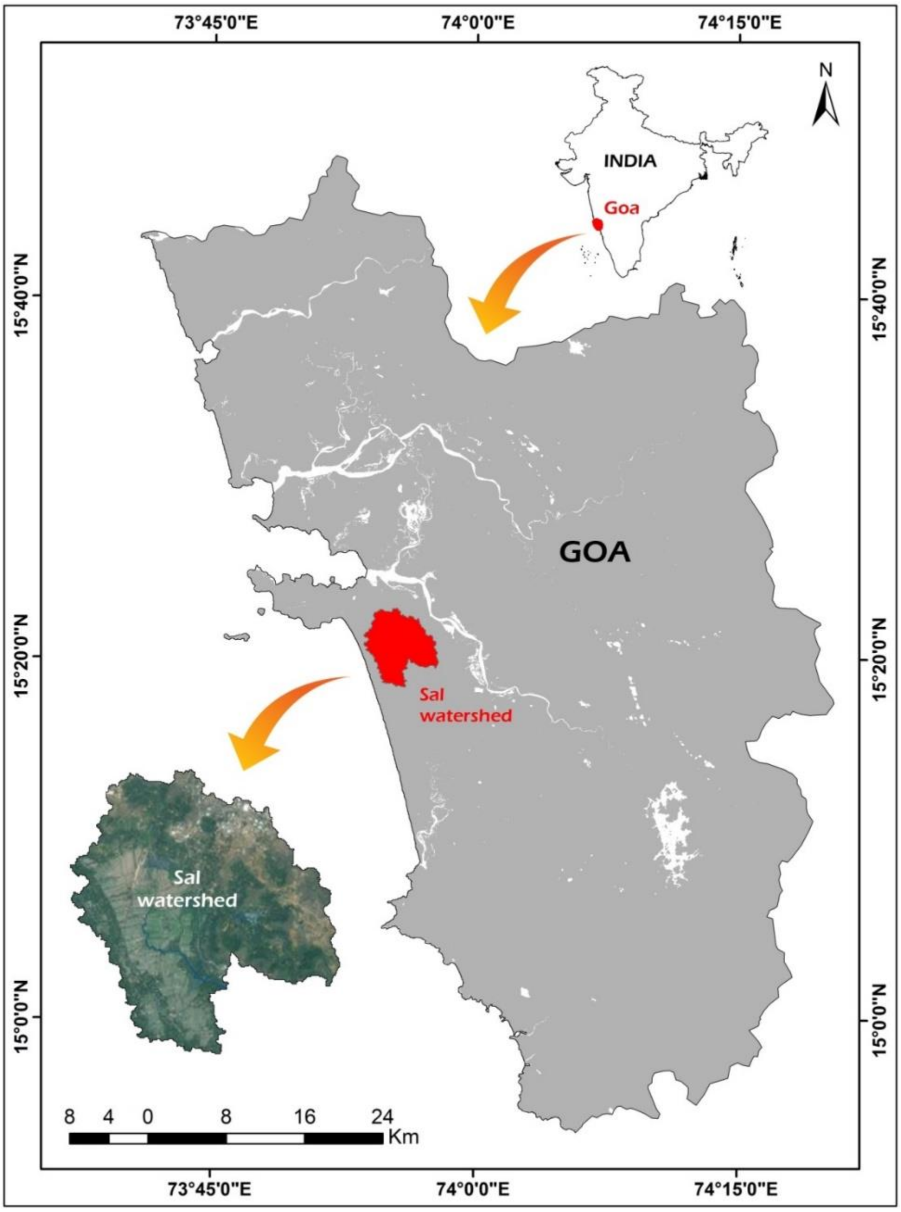


Fig. 1: Location of the Sal river watershed.

METHODOLOGY

This study involved climate modeling using the Norwegian Earth System Model (NorESM), land-use change simulations using Land Change Modeler (LCM), and hydrological modeling using the Soil and Water Assessment Tool (SWAT) model. An ensemble was created, and the results from the climate model and LCM were used as an input into the SWAT model for streamflow predictions. The description of the models and the data used are given below.

Climate Model

Most of the recent hydrological modeling studies considered two RCP scenarios *i.e.* RCP 4.5 and RCP 8.5 to represent the extreme and moderate conditions (Sinha et al., 2020; Nilawar and Waikar, 2019; Sharannya *et al.,* 2018). Since these projected climate scenarios (RCP 4.5 and 8.5) are scientifically acceptable, they were also used in this study. For climate simulation (precipitation and rainfall), a 30-year baseline period was generated using the Norwegian Earth System Model (NorESM). The resolution used was a horizontal grid of 25 km × 25 km. The following steps were followed to get the data from the NorESM model for a historical period (1950–2005) and projected period (2006–2100) from NASA's Climate Data Services (CDS) portal.

(1) Python script was used to download the NorESM data from NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP)
(2) Climate Data Operator (CDO) was used for selecting the study area and converting the files into the required format
(3) R software was used for data analysis and plotting.

The precipitation (mm/day) output from the NorESM was compared with the gridded data from the India Meteorological Department (IMD). The historical data (1950–2005) was used for this verification. Statistical methods of linear scaling and quantile mapping were used for bias correction of the model outputs. The bias-corrected data was used for future rainfall and temperature predictions until 2060.

Land Change Modeler

Land Change Modeler is an innovative land planning and decision support system that is fully integrated into the TerrSet software developed by Clark Labs, USA. The TerrSet Land Change Modeler (LCM) was used to generate and compare land-use maps using the maximum likelihood method. The module for modeling the change is based upon the Markov chain matrices and transition potential maps. CA Markov model is built in the LCM. The methodology used for LCM is shown. The joint NASA/United States Geological Survey (USGS) Landsat series of Earth Observation satellites have continuously acquired images of the Earth's land surface, providing uninterrupted data to help managers and policymakers make informed decisions about natural resources and the environment. Landsat-5 image for 1993 and Landsat-8 image for the years 2014 and 2019 were extracted for the study area and used for analysis. The transition sub-model maps such as Digital Elevation Model (DEM), Slope, and transition sub-models were used for predicting future land use in 2019. This map was validated with the current land-use map of 2019. The validation was statistically tested using Kappa co-efficient and future maps for 2030 and 2040 were generated.

SWAT Model

The Soil and Water Assessment Tool (SWAT2012) version with the QSWAT 1.9 interface was used for this research. SWAT is a physically-based continuous, long-term, distributed model designed to predict the effects of land management practices on hydrology, sediment, and contaminant transport in agricultural watersheds under varying soils, land use, and management conditions. It is a public domain model supported by the USDA Agricultural Research Service (USDA-ARS) at the Grassland, Soil, and Water Research Laboratory in Temple, Texas. SWAT is based on the concept of hydrologic response units (HRUs), which are portions of a sub-basin that possess unique land-use, management, and soil attributes. The runoff, sediment, and nutrient loadings from each HRU are calculated separately based on weather, soil properties, topography, vegetation, and land management and then summed to determine the total loading from the sub-basin (Park *et al*., 2011; Kiniry *et al.,* 2000).

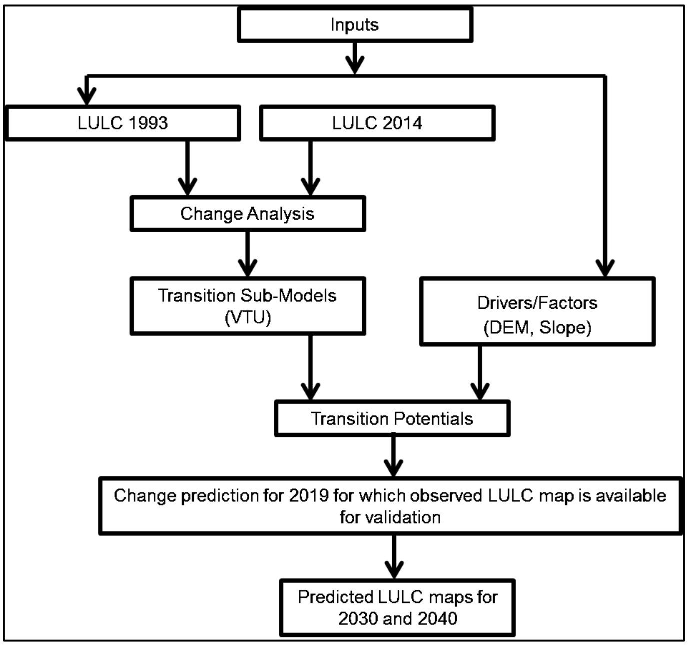


Fig. 2: Schematic diagram of the methodology used in LCM.

RESULTS AND DISCUSSION

Simulations from climate model

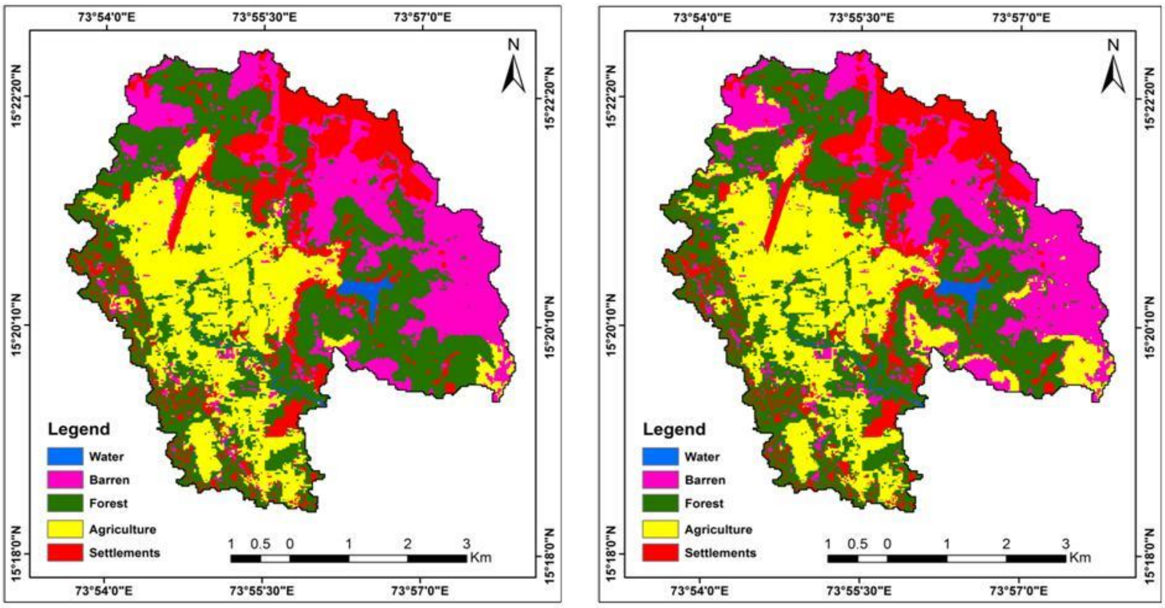
Bias correction of the NorESM output concerning IMD observations was done using the statistical linear scaling method. The reduction in the root mean square error (RSME) value after bias correction of historical precipitation data is shown. Using the bias-corrected historical data, future rainfall, and temperature (minimum and maximum) were projected under RCP 4.5 and RCP 8.5 for the period from 2006 to 2100. These outputs were used in the hydrological model to predict future streamflow.

Table-1: Statistical analysis of bias correction of precipitation data

Latitude	Longitude	Before Bias Correction			After Bias Correction		
		Mean Model	Mean Observed	RSME	Mean Model	Mean Observed	RSME
15.375	73.875	6.26	9.46	3.20	9.44	9.46	0.02

Simulations from Land Change Modeler

An evaluation of resemblance between the simulated LULC map for 2019 and the actual 2019 map was carried to examine LCM's applicability to predict the change. Kappa statistics (K) for similarity was estimated to understand the similarity between the projected and the observed land-use maps for 2019. The Kappa coefficient range is between 0 and 1, with 0 representing poor and 1 indicating excellent accuracy (Panandiker *et al.,* 2019; Anand *et al.,* 2018; Gumindoga *et al.,* 2014). A kappa coefficient of 0.8 was obtained, indicating high accuracy. Using this calibrated model, future land-use maps for the years 2030 and 2040 were prepared. The future land-use projections for the Sal river watershed are depicted in Fig. 3. The area under different land-use categories for the years 1993, 2014, 2030, and 2040 is shown. From the graphs, it was observed that the area under forests shows the most temporal variations. In 1993, around 45% of the watershed area had the presence of forests, while 24% was agriculture. Over the years, barren and settlement areas have seen an increase. The reason that can be attributed to this land-use change is the clearance of farms/plantations/orchards for the construction of settlement zones. The concentration of the population is high along the National Highway 66 (previously numbered as NH-17). Rapid urbanization has been observed in this watershed. As seen from figure, in comparison to 2019, the area under forest cover is likely to decrease by 2.59% by 2030 and 5.93% by 2040. A subsequent increase in agriculture (3% by 2030 and 5.7% by 2040) and settlement areas (1.24% by 2030 and 4.34%by 2040) is projected.



2030

2040

Fig. 3: Land-use projections for Sal river watershed for 2030 and 2040.

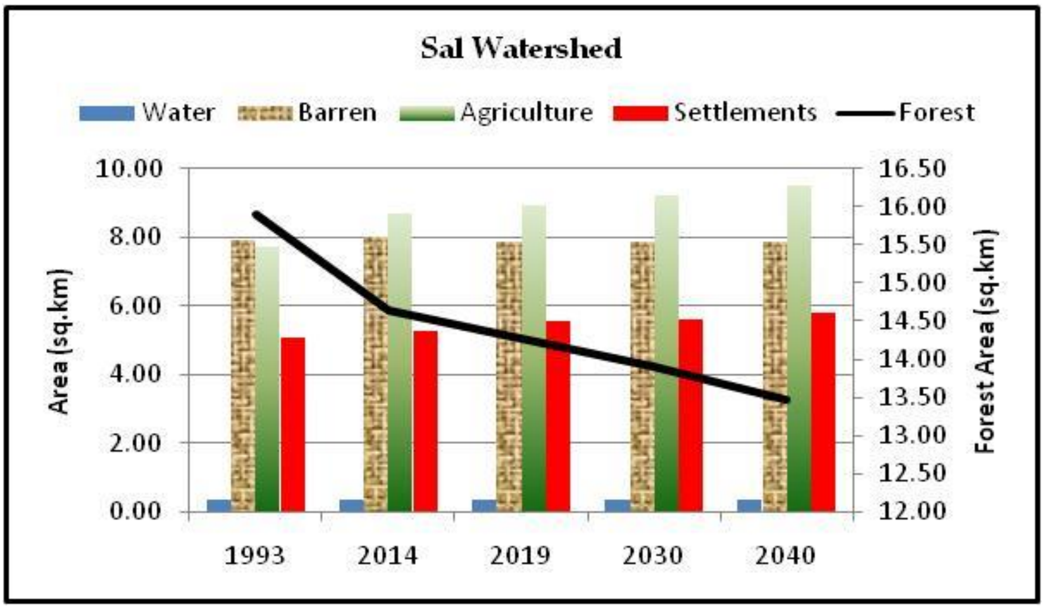


Fig. 4: Temporal variation in the area under various land-use categories.

Simulations from SWAT and future projections

As described earlier, using the LCM model, future land-use scenarios were developed for the years 2030 and 2040. The 2019 LULC map was used to assess the current or baseline situation. These LULC maps were used as an input and QSWAT model was calibrated and validated. Statistical indicators such as NSE and R^2 were used to examine the calibration efficiency. The calibrated and validated models for Sal watershed is presented. Since the NSE and R^2 values were above 0.6, they were acceptable and, hence, used for future streamflow predictions. Further, using the rainfall and temperature projections from the NorESM model under the RCP 4.5 and 8.5 scenarios, the streamflow was simulated till 2050. The variation in the mean runoff (flow) of JJAS (monsoon) during the Sal river's future time is presented. The observed average monsoonal rainfall between 2010 and 2018 was 18.99 mm. As compared to this baseline data, the future projections under both RCP (4.5 and 8.5) scenarios indicate an increase in rainfall and streamflow. Under the changing climate conditions, this increase in average streamflow is more pronounced in RCP 4.5 as compared to RCP 8.5. The scenarios that combine climate and land-use change indicate a further increase in the streamflow quantity. The forest cover is likely to decrease by 5.93% up to 2040s, with a corresponding increase in the urban/settlement areas. With the increase in the built-up areas, the surface runoff increases and leads to an urban flooding-like situation. There are many agricultural ponds and a lake in this watershed. Increased run-off may lead to siltation of these water bodies.

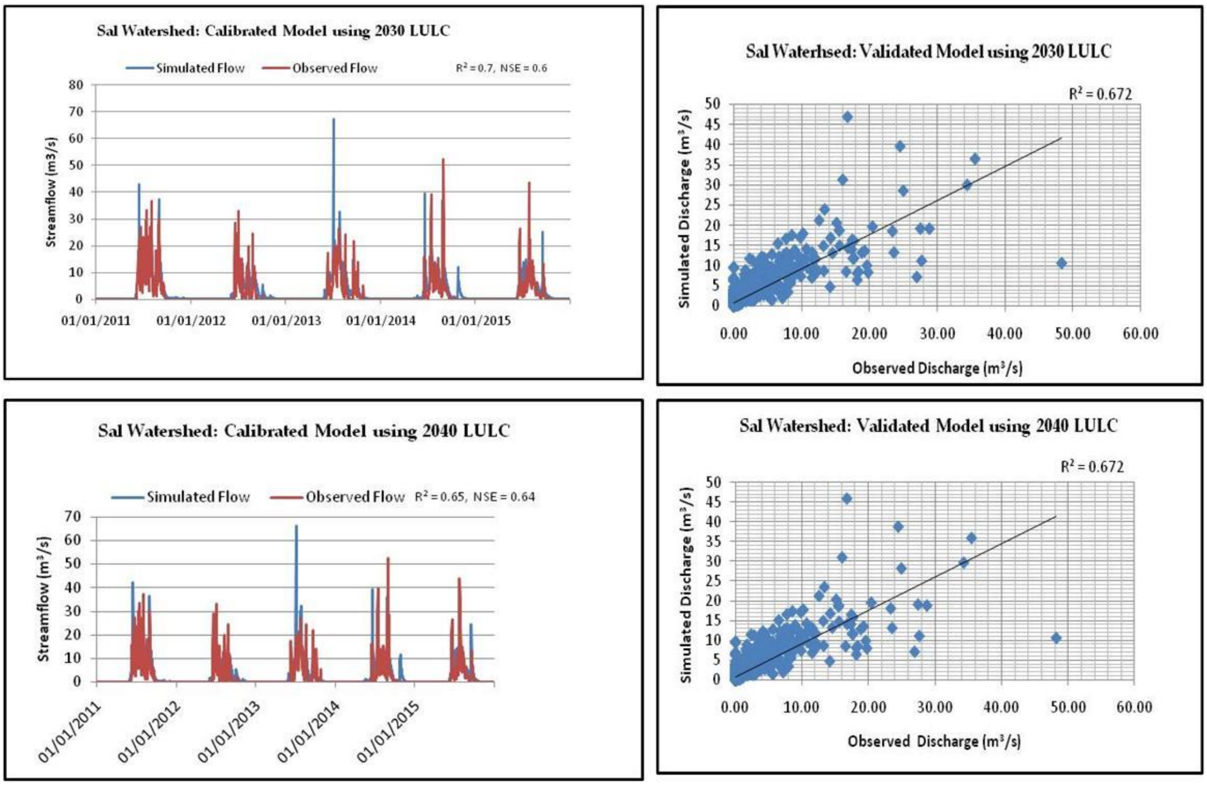


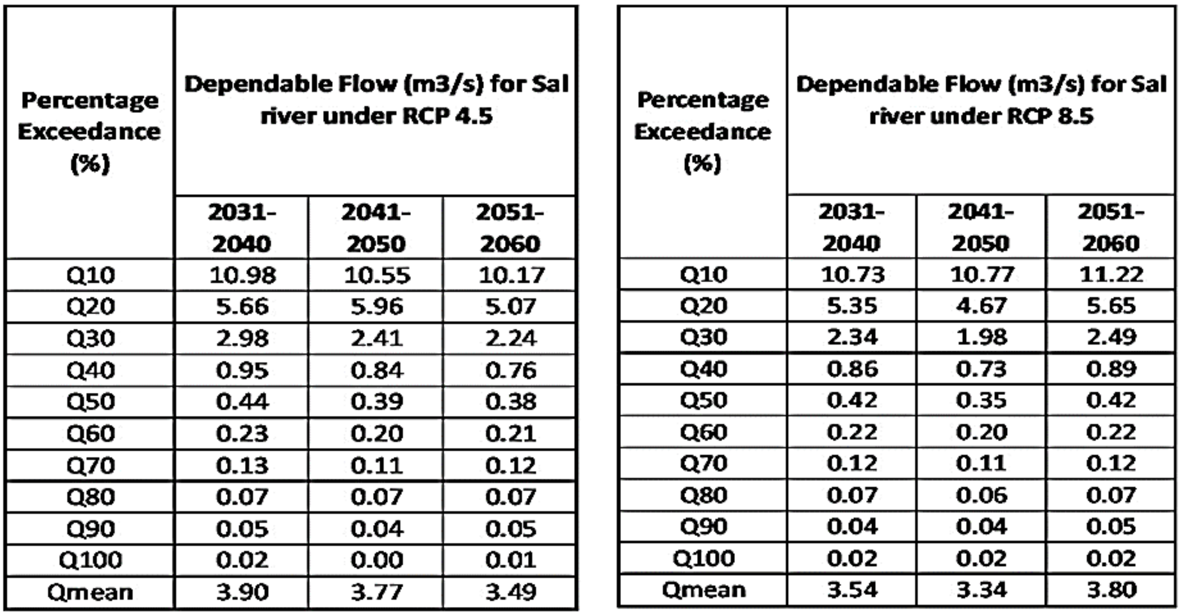
Fig. 5: Calibration and validation of QSWAT model using 2030 and 2040 LULC maps.

To comprehend the temporal variation in water availability in the future, a dependable flow analysis was done. Flow rate is often referred to as ‘Q’ and the exceedance value as a subscript number, so Q_{90} means the flow rate equalled or exceeded 90% of the time. Q_{mean} is the average or mean flow rate and is the arithmetic mean of all the flow points in the data set. It occurs typically between Q_{20} and Q_{40} on the flow duration curves (FDC), depending on the river's steadiness. Based on the FDC, the dependable flow was estimated for the three decades under the two RCP scenarios (4.5 and 8.5) and is presented.

Table-2: Variation in mean runoff in JJAS (monsoon) during future time

YEAR	**CLIMATE CHANGE (CC) ONLY**				**LULC 2030 + CC**		**LULC 2040 +CC**	
	RCP 4.5		**RCP 8.5**		**RCP 4.5**	**RCP 8.5**	**RCP 4.5**	**RCP 8.5**
	Change in average JJAS rain (%)	**Change in average JJAS runoff (%)**	**Change in average JJAS rain (%)**	**Change in average JJAS runoff (%)**	**Change in average JJAS runoff (%)**	**Change in average JJAS runoff (%)**	**Change in average JJAS runoff (%)**	**Change in average JJAS runoff (%)**
2021-2030	33.39	34.68	27.16	27.52	36.90	30.17	32.99	30.25
2031-2040	30.18	30.70	28.69	28.08	33.20	31.01	36.34	31.04
2041-2050	40.45	43.11	28.69	29.41	44.80	32.00	42.81	32.08

Flow rates between Q_0 and Q_{10} are considered high flow rates, with Q_0 and Q_1being extreme flood events. Flows from Q_{10} to Q_{70} would be the medium range of flows, while the flow rates from Q_{70} and Q_{100} are low flows. As seen from Fig. 6 under the RCP 4.5 scenario, the high flow rates (Q_{10}) are likely to gradually decrease over the decades, thereby affecting the water availability. Q_{90} and Q_{50} flows are often used as low-flow indices and could be used by the government and planners to manage water resources better and prioritize its use. The numerous uses of the Q_{90} and Q_{50} values (Pyrce, 2004) are presented in Table-3. This table could come in handy for WRD planners.



Percentage Exceedance (%)	**Dependable Flow (m3/s) for Sal river under RCP 4.5**		
	2031-2040	**2041-2050**	**2051-2060**
Q10	**10.98**	**10.55**	**10.17**
Q20	**5.66**	**5.96**	**5.07**
Q30	**2.98**	**2.41**	**2.24**
Q40	**0.95**	**0.84**	**0.76**
Q50	**0.44**	**0.39**	**0.38**
Q60	**0.23**	**0.20**	**0.21**
Q70	**0.13**	**0.11**	**0.12**
Q80	**0.07**	**0.07**	**0.07**
Q90	**0.05**	**0.04**	**0.05**
Q100	**0.02**	**0.00**	**0.01**
Qmean	**3.90**	**3.77**	**3.49**

Percentage Exceedance (%)	**Dependable Flow (m3/s) for Sal river under RCP 8.5**		
	2031-2040	**2041-2050**	**2051-2060**
Q10	**10.73**	**10.77**	**11.22**
Q20	**5.35**	**4.67**	**5.65**
Q30	**2.34**	**1.98**	**2.49**
Q40	**0.86**	**0.73**	**0.89**
Q50	**0.42**	**0.35**	**0.42**
Q60	**0.22**	**0.20**	**0.22**
Q70	**0.12**	**0.11**	**0.12**
Q80	**0.07**	**0.06**	**0.07**
Q90	**0.04**	**0.04**	**0.05**
Q100	**0.02**	**0.02**	**0.02**
Qmean	**3.54**	**3.34**	**3.80**

Fig. 6: Decadal Dependable Flow for 2030–2060 under RCP 4.5 and 8.5.

Table-3: Uses of flow percentile for better water management

Flow Percentile	**Use**
Q_{90}	❖ Commonly used low flow index ❖ Monthly value provides stable and average flow conditions ❖ Monthly value gives minimum flow for aquatic habitat ❖ Used to examine discharge duration patterns of small streams ❖ Threshold warning water managers of critical streamflow levels ❖ Used as a conservative estimator of mean base-flow ❖ Licensing surface water extractions and effluent discharge limits assessment
Q_{50}	❖ Aquatic base-flow policy for water resources planning and management. It can be used to protect aquatic biota ❖ Used to recommend seasonal minimum discharges for waterpower rivers

CONCLUSION AND RECOMMENDATIONS

While analysing the climate change scenarios exclusively, it was observed that the streamflow is likely to increase under both the RCP scenarios (4.5 and 8.5) when compared with the baseline of 2010–18. The flow is likely to be less under RCP 8.5 as compared to RCP 4.5. It must be noted that under RCP 8.5, the high levels of greenhouse concentrations are assumed until the end of the 21st century. Further, climate combined with land-use change reveals that the streamflow is likely to decrease with the decrease in forest cover and increase with an increase in the urban /concrete areas. As a general tendency in land cover change, open forest usually gets converted into agricultural/urban settlement. In such a case, a slight increase in runoff and a corresponding decrease in evapotranspiration is predicted (Aggarwal *et al*., 2012). An increase in streamflow may lead to urban flooding. With increased runoff, the ponds and lake present in the watershed would require frequent de-silting. Further, the groundwater table is high in this watershed and hence with increased precipitation-runoff events and inadequate sewerage network, probability of pollution of water bodies is high and will need immediate attention. Dependable flow values computed for this watershed would come in handy for the planners while giving licenses for water extraction and decide effluent discharge limit. The findings of this study could be improved by using outputs from some more climate models. However, the currents findings are reasonable and overall outcomes of this analysis would provide substantive information to the decision-makers required to develop ameliorative strategies especially for this watershed which is urbanizing very rapidly. It can also be integrated into a master plan and policy for water resources management in the State.

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