

## Flooding under changing climate in Vellar river basin using global circulation models

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**सार** – विश्व के अनेक देशों की प्रलयकारी घटनाओं में बाढ़ एक प्रमुख प्राकृतिक आपदा है। बाढ़ हर बार नदी के आकार को प्रभावित करती है जिसके कारण उस नदी के पर्यावरण के वनस्पतियों और जीवों में बदलाव आता है। भविष्य में जलवायु परिवर्तन के कारण बाढ़ और सूखे की आवृत्ति अधिक हो जाएगी जो जल प्रबंधन क्षेत्र के लिए गंभीर खतरा पैदा कर सकता है। इस शोध पत्र में माइके हाइड्रो रिवर 2016 मॉडल का उपयोग करके बाढ़ से जलवायु में परिवर्तन के प्रभाव का विश्लेषण किया गया है। वर्ष 2005, 2008, 2010 और 2011 में आई पिछली बाढ़ की परिघटनाओं का उपयोग करते हुए इस मॉडल को अंशांकित (कैलिब्रेटेड) और वैधीकृत किया गया है। एस डी एस एम (सांख्यिकीय डाउन स्केलिंग मॉडल) द्वारा स्टेशन पैमाने पर किए गए कार्यों से पता चला है कि कनाडाई जी सी एम (ग्लोबल सर्कुलेशन मॉडल) मौसम प्राचलों को कम आंकते हैं। हाइड्रोलॉजिकल मॉडल में दैनिक वर्षा वाष्पोत्सर्जन ( $ET_0$ ) और वायुमंडलीय बदलावों को संख्यात्मक रूप से जलवायु परिवर्तन परिदृश्य आर सी पी (प्रतिनिधि सघनता मार्ग) 4.5 से कम आंका गया है और बाढ़ आने की संभावना के लिए आर सी पी 8.5 को इनपुट और संशोधन के रूप में प्रस्तुत किया गया है। ऐसा पाया गया है कि आने वाले वर्षों 2050 और 2080 में आर सी पी 4.5 एवं आर सी पी 8.5 दोनों परिदृश्यों में अधिकतम वर्षा में वृद्धि होगी और अधिक वर्षा होगी। मौसम विज्ञान संबंधी प्राचलों मंह परिवर्तन से बाढ़ पर बड़ा प्रभाव पड़ेगा क्योंकि मौसम के पैटर्न में एक छोटा सा बदलाव हाइड्रोलॉजिकल चक्र को बहुत प्रभावित करेगा।

**ABSTRACT.** Flooding is one of the major natural disasters from a storm event that is prevalent in many countries and greatly affects river morphology, modifying the flora and fauna of a given river environment. As a consequence of climate change, the probability of frequent floods and drought is acute in the near future, posing serious challenges to the water management sector. This paper analyses the impact of climate change on the likelihood of floods using MIKE HYDRO river 2016 model. The model is calibrated and validated using the past flood events occurred in the years 2005, 2008, 2010 and 2011. The downscaling of weather parameters of Canadian Global Circulation Model (GCM) to the station scale is performed by Statistical Down-Scaling Model (SDSM). In the hydrological model, daily rainfall, evapotranspiration ( $ET_0$ ) and the atmospheric variables statistically downscaled from climate change scenarios - Representative Concentration Pathways (RCP) 4.5 and RCP 8.5 are provided as input and modifications in flood discharge are presented. It is found that there will be an increase in peak rainfall and peak discharge under the RCP 4.5 and RCP 8.5 scenarios for the future years 2050 and 2080. The changes in meteorological parameters would have a significant effect on the flow of floods since minor changes in weather pattern will greatly affect the hydrological cycle.

**Key words** – Climate change, SDSM, MIKE HYDRO river, Flood, RCP.

### 1. Introduction

The purpose of the present study is to assess the climate change impact on floods for a river basin hydrology which helps to deal with the effects of climate change. The present study can substantially aid farmers in understanding and creating environmental adaptation strategies. It can also serve as a reference to hydraulic engineers and water resource managers in designing structures to manage the increase in discharge due to climate change and constructing storage structures in order to reduce flood volume. In turn, the flood water can

be used for irrigation when monsoons fail. Environmentalists could draw inferences from the study to preserve downstream river water quality by maintaining the minimum river flow. The study can also serve policy makers in framing adaptation measures for climatic problems.

The Vellar river basin experiences seasonal flooding between November and December every year. The people who live along the downstream banks of the Vellar river basin are highly vulnerable to flood damages during monsoon. The steep course of the river causes flash

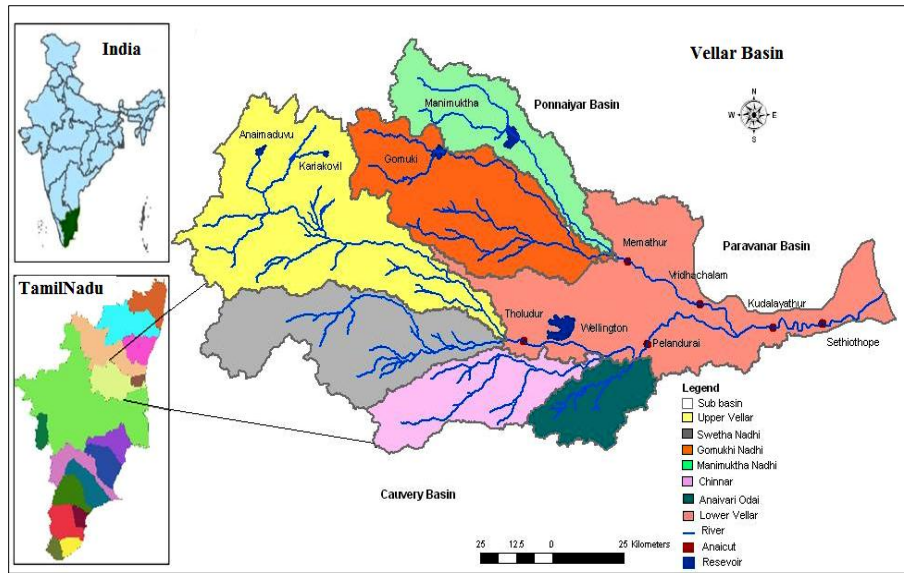


Fig. 1. Vellar river basin of Tamil Nadu

floods, inundating vast areas of the Cuddalore and Chidambaram districts of Tamil Nadu. Climate change has significantly accelerated flooding in the areas that have been studied. In 2009, massive flooding was observed in the Manimuktha river with a high discharge of 207000 cusecs near the Kudalaiyathur village due to which most of the agricultural lands submerged (Needhidasan *et al.*, 2013).

Previous research on the subject suggests that the frequency, depth and extent of flooding in river basins will increase in the future due to changes in climatic conditions (Mujumdar *et al.*, 2012). The timing, frequency and magnitude of environmental flow discharges play a major role in maintaining a healthy river system (Acreman *et al.*, 2004). Notable factors are the flow in the rivers due to climate change.

MIKE11NAM parameters estimated using the auto-calibration and trial and error method for the given flood events provide reliable flood flow simulation (Giang *et al.*, 2010). To evaluate the flood simulations at Sethiothope anaicut using MIKE HYDRO river module, NAM rainfall runoff model is utilized. MIKE11NAM simulates flow of the Vellar basin based on rainfall and  $ET_0$  as input data (Lafdani *et al.*, 2013). The discharge in the river is obtained as an output through the routing process. Rainfall and  $ET_0$  data from meteorological stations in the river basin is used for calibration and verification. The NASH and  $R^2$  were used to check the efficiency of the model (Suman *et al.*, 2014). The flow at stream gauge station of the basin is simulated under two climate change

scenarios - RCP 4.5 and RCP 8.5. The study utilizes second generation Canadian Earth System Model (CanESM2) which is developed by Canadian Centre for Climate Modeling and Analysis (CCCma) of Environment Canada. The Statistical Downscaling Model (SDSM) enables downscaling the daily meteorological data for the required station location and is useful in climate change impact studies.

## 2. Study area description

The Vellar river basin is a semi-arid basin lying at the northern part of Tamil Nadu exposed to frequent floods, droughts and associated water problems. The river itself originates from the Chitheri hills, having a total length of 150 kms up to the draining point of Parangipettai near Bay of Bengal, which has been depicted in Fig. 1. The river basin has seven sub basins. During the northeast monsoon, most downstream areas receive the freshwater and other seasons were in dry condition. Because of this reason the average water salinity is increased to 35-45 ppm during dry seasons (Selvam, 2003). The preferred meteorological station Mangalapuram has 30 years of historical data and other stations have shorter chronological data in comparison. Twenty two rainauge stations and one meteorological station (Mangalapuram) were identified in the study area. Mangalapuram station is used to represent the entire river basin due to the amount of data available. The 32 years of daily rainfall data was collected from Public Works Department, Tamil Nadu and 30 years of daily meteorological data from Institute of Water Studies, Tamil Nadu.

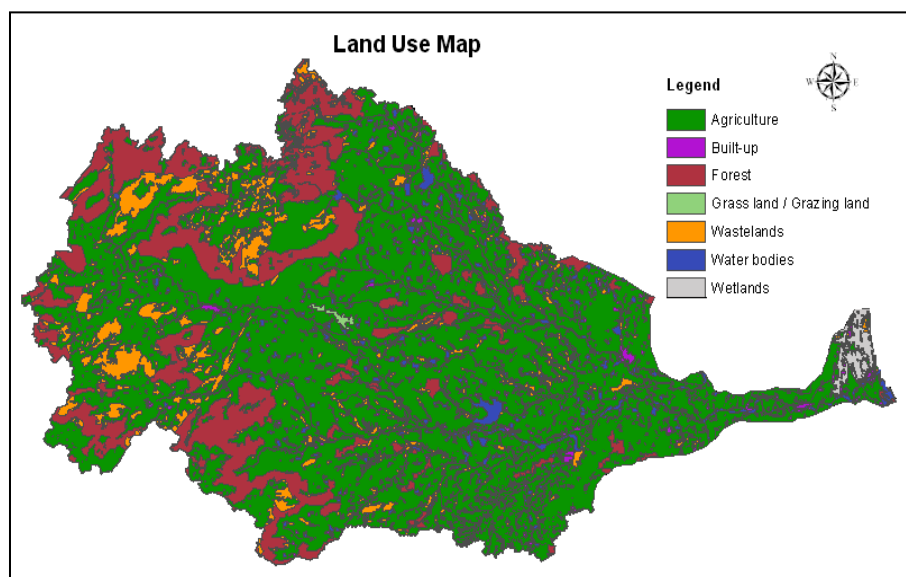


Fig. 2. Land use map

2.1. Land-use details

The LISS III of 2006 satellite land use/land cover data has been classified into seven categories in this present study as Agricultural land of 67.8%, Forest land of 16.44%, Waste lands of 8.48%, Water bodies of 4.52%, Wet lands of 0.25%, grass land of 0.12% and Built-up land of 2.3% is clearly shown in Fig. 2.

3. Data and methodology

3.1. General Circulation Models (GCMs)

General Circulation Models (GCMs) have very high spatial resolution of 200 by 300 km at ground level. The downscaling procedure is necessary to represent the characteristics of the ground terrain up to the basin level.

The GCM adopted in the present study is the second generation Canadian Earth System Model (CanESM2). The CanESM2 output at station location is downloaded and can be used directly as an input to SDSM for downscaling. The AR5 IPCC (Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change) has different climate change scenarios viz., RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5. The CanESM2 output for RCP 4.5 and RCP 8.5 is acquired for this study. Apart from these, National Center for Environmental Protection (NCEP)/National Center for Atmospheric Research (NCAR) reanalysis project I provides large scale atmospheric variables is vital for creating statistical relationship with the predictand data of the station. The

CCCma generates 26 predictors for both CanESM2 and NCEP/NCAR data from 1961 to 2005.

3.2. Statistical DownScaling Model (SDSM)

A statistical downscaling tool works with the multiple linear regression technique for climate change impact studies. Initially, the model computes the relationship between observed predictands and predictors to ascertain the parameters for weather generation. In the second stage, the model generates future series by utilizing the GCM predicted data and the parameter file developed in the earlier stage (Chen *et al.*, 2012).

3.3. Evapo-transpiration (ET<sub>0</sub>)

The FAO ET<sub>0</sub> calculator is utilized to generate ET<sub>0</sub> for the observed data of Mangalapuram station. The original Hargreaves equation is considered to calculate the ET<sub>0</sub> for GCM data which is given by (Subburayan *et al.*, 2011),

$$ET_{0, Har} = 0.0023R_a(T_{max} - T_{min})^{0.5} \left[ \left( \frac{T_{max} - T_{min}}{2} \right) + 17.8 \right] \quad (1)$$

where, ET<sub>0</sub> – Evapo-transpiration in mm/day; R<sub>a</sub> – Extraterrestrial radiation in (MJ m<sup>-2</sup>/day); T<sub>max</sub> – Maximum Temperature (°C); T<sub>min</sub> – Minimum temperature (°C).

The exponent 0.5 mentioned in the equation (1), over predicts the ET<sub>0</sub> data (Subburayan *et al.*, 2011). Hence, the

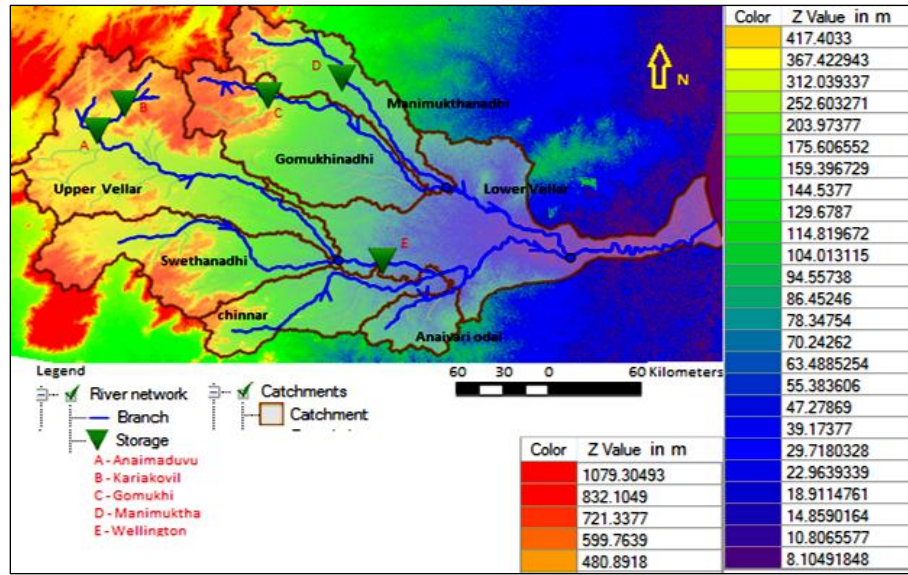


Fig. 3. Digitization of Vellar river basin in MIKE HYDRO river model

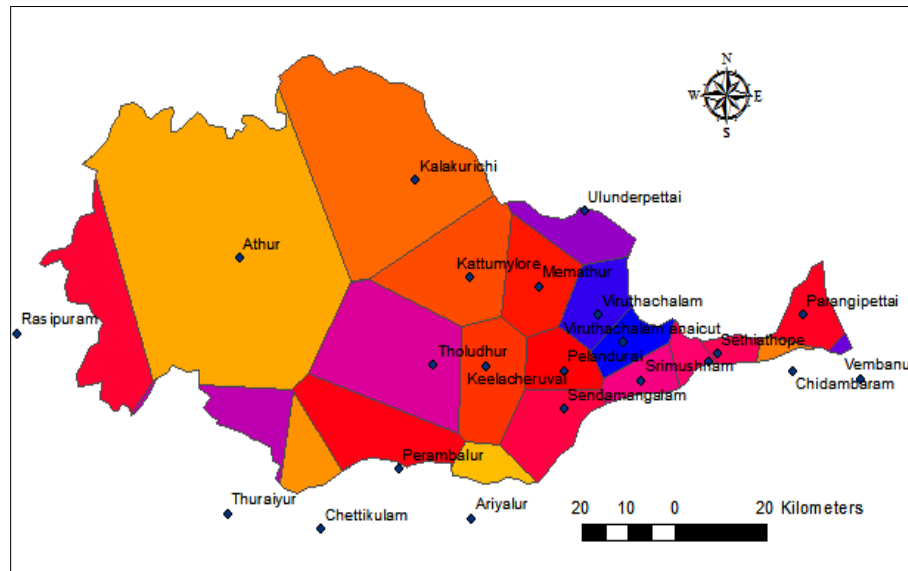


Fig. 4. Thiessen polygon map of rain gauge stations

exponent value is to be calibrated to get the reliable estimates of  $ET_0$ . The modified Hargreaves equation is given by (Subburayan *et al.*, 2011),

$$ET_{0,Har} = ET_{0,PM} = 0.0023R_a(T_{max} - T_{min})^b \left[ \left( \frac{T_{max} - T_{min}}{2} \right) + 17.8 \right] \quad (2)$$

The modified equation is of the form (Subburayan *et al.*, 2011),

$$Y = AX^b \quad (3)$$

where,

$$Y = ET_{0,PM} \quad (4)$$

$$X = T_{max} - T_{min} \quad (5)$$

$$A = 0.0023R_a \left( \left( \frac{T_{max} - T_{min}}{2} \right) + 17.8 \right) \quad (6)$$

Using the meteorological data for the calibration period from 1978 to 1994, the relationship between  $ET_0$  computed by FAO  $ET_0$  calculator (Penman Monteith

**TABLE 1**

**GCM predictor variables and their description**

S. No.	Predictor variables	Predictor description
1.	msslpgl	Mean sea level pressure
2.	p1_fgl	1000 hPa Wind speed
3.	p1_ugl	1000 hPa zonal Wind component
4.	p1_vgl	1000 hPa Meridional Wind component
5.	p1_zgl	1000 hPa relative vorticity of Wind
6.	p1thgl	1000 hPa Wind direction
7.	p1zhgl	1000 hPa Divergence of true wind
8.	p500gl	500 hPa Geopotential
9.	p5_fgl	500 hPa Wind speed
10.	p5_ugl	500 hPa zonal Wind component
11.	p5_vgl	500 hPa Meridional Wind component
12.	p5_zgl	500 hPa relative vorticity of Wind
13.	p5thgl	500 hPa Wind direction
14.	p5zhgl	500 hPa Divergence of true wind
15.	p850gl	850 hPa Geopotential
16.	p8_fgl	850 hPa Wind speed
17.	p8_ugl	850 hPa zonal Wind component
18.	p8_vgl	850 hPa Meridional Wind component
19.	p8_zgl	850 hPa relative vorticity of Wind
20.	p8thgl	850 hPa Wind direction
21.	p8zhgl	850 hPa Divergence of true wind
22.	prcpgl	Total precipitation
23.	s500gl	500 hPa Specific humidity
24.	s850gl	850 hPa Specific humidity
25.	Shumgl	1000 hPa Specific humidity
26.	Tempgl	Air temperature at 2 m

**TABLE 2**

**Thiessen weights of raingauge stations**

Raingauge station	Weightage
Ariyalur	0.012
Attur	0.314
Chettikulam	0.019
Chidambaram	0.003
Kallakurichi	0.171
Kattumylore	0.034
Keelacheruvai	0.033
Memathur	0.038
Parangipettai	0.021
Pelandurai	0.021
Perambalur	0.047
Rasipuram	0.051
Sendamangalam	0.028
Sethiothope	0.008
Sethiothope Anicut	0.011
Srimushnam	0.016
Tholudur	0.084
Thuraiyur	0.023
Ulundurpet	0.019
Vembanur	0.006
Virudhachalam	0.024
Virudhachalam Anicut	0.016

method) as a dependent variable  $Y$  and the independent variable  $X$  is used to find the regression equation. The best fit regression equation is obtained from the Datafit 9 software among the 242 non-linear regression models has the exponent value (b) and A value as 0.574 and 1.100. The regression equation used to compute the  $ET_0$  is of the form,

$$Y = 1.100X^{0.574} \tag{7}$$

The performance of regression equation and the FAO  $ET_0$  calculator (Penman Monteith method) in estimating  $ET_0$  is evaluated using the statistical criteria, namely Mean Absolute Error (MAE), Mean Absolute

Percentage Error (MAPE) and Standard Error of Estimate (SEE). The statistical parameters found to be MAE (0.28 mm/day), MAPE (3.2) and SEE (0.886 mm/day). These statistics indicates that the  $ET_0$  generated using regression equation and the FAO  $ET_0$  calculator matches well during the validation period from 1995 to 2005. The rainfall and  $ET_0$  data obtained from GCM under different climate change scenarios were given as input to MIKE11NAM to simulate the future flow in 2050 and 2080.

### 3.4. MIKE HYDRO river model setup

MIKE HYDRO river is a physical, deterministic, semi-distributed model for the simulation of flood flow (Yu *et al.*, 2015). This model incorporates a modern, map-based and highly intuitive Geographic Information System (GIS) for river modeling. The map layer coordinate system is helpful to project the DEM and other layers.

TABLE 3

Selected set of predictor variables

Predictand	Predictors	Partial r	P value	Predictand	Predictors	Partial r	P value
<b>Mangalapuram</b>				<b>Mangalapuram</b>			
T <sub>max</sub>	ptempgl	0.899	0.00	Rainfall	prcpgl	0.380	0.00
	p1_vgl	0.277	0.00		p850gl	0.152	0.00
	p8_ugl	0.273	0.00		p1_ugl	0.112	0.00
	p8_thgl	0.122	0.00		ps850gl	0.011	0.00
	pshumgl	0.230	0.00		ps500gl	-0.070	0.00
<b>Mangalapuram</b>				<b>Thiessen Weighted rainfall from 22 rain guage stations</b>			
T <sub>min</sub>	ptempgl	0.836	0.00	Rainfall	prcpgl	0.350	0.00
	pshumgl	0.305	0.00		pmslpgl	0.138	0.00
	p1_ugl	0.146	0.00		pshumgl	0.124	0.00
	p8zgl	0.112	0.00		p8zhgl	-0.006	0.00
	p1thgl	0.026	0.00		ps850gl	-0.070	0.00

After pre-processing of DEM, catchments and river branches can be digitized in the model. The basin outlet points, reservoirs, anaicuts and chainage points of river can be represented on maps with ease. The Vellar river basin is digitized with sub-basins and the river network and storages are clearly shown in Fig. 3. The whole basin is considered to simulate runoff at the outlet point of Sethiothope anaicut.

### 3.5. MIKE11NAM

MIKE11NAM is a lumped conceptual model that simulates the rainfall-runoff processes occurring in single or multiple sub-basins in a river (Amir *et al.*, 2013). The general structure of the model has four different but interrelated storages and has corresponding flows simulates flood flows precisely (Hafezparast *et al.*, 2013). MIKE11NAM requires ET<sub>0</sub> data as input to the model. The data from the Mangalapuram meteorological station is utilized for ET<sub>0</sub> determination. The parameters such as maximum temperature, minimum temperature, maximum relative humidity, minimum relative humidity and wind speed were provided as an input to the FAO ET<sub>0</sub> calculator for the computation of ET<sub>0</sub>. The ET<sub>0</sub> and weighted time series of rainfall for the storm events were generated. Nash-Sutcliff index is used to evaluate the simulation results (Tran *et al.*, 2011). The model performance is evaluated during calibration and verification of storm events with Correlation Coefficient R<sup>2</sup> and Efficiency Index (Nash-Sutcliff, 1970) values were given by the equation (8),

$$EI = \frac{(\sum_{i=1}^n (q_0 - q_{avg})^2 - \sum_{i=1}^n (q_0 - q_s)^2)}{\sum_{i=1}^n (q_0 - q_{avg})^2} \quad (8)$$

EI – Efficiency Index,

$q_0$  – Observed flow in m<sup>3</sup>/s,

$q_{avg}$  – Mean value of observed flow in m<sup>3</sup>/s,

$q_s$  – Simulated flow in m<sup>3</sup>/s,

$n$  – Number of data points.

## 4. Results and discussion

### 4.1. Downscaling by SDSM

The statistical relationship between the large scale atmospheric variables and the observed minimum temperature, maximum temperature and rainfall is acquired using SDSM. The GCM data is collected at Mangalapuram station which is located at 11°33'49.7" N (Lat.) and 78°22'34.72" E (Long.). The downloaded file is denoted by the grid box number 29X and 37Y and which contains files like such as NCEP-NCAR\_1961-2005, CanESM2\_historical\_1961\_2005, CanESM2\_rcp26\_2006\_2100, CanESM2\_rcp45\_2006\_2100 and CanESM2\_rcp85\_2006\_2100. The files comprises of mentioned years of 26 daily predictor data, obtained from respective scenarios and the data is normalized with respect to the specified periods. The list of GCM predictor variables and their description is provided in Table 1.

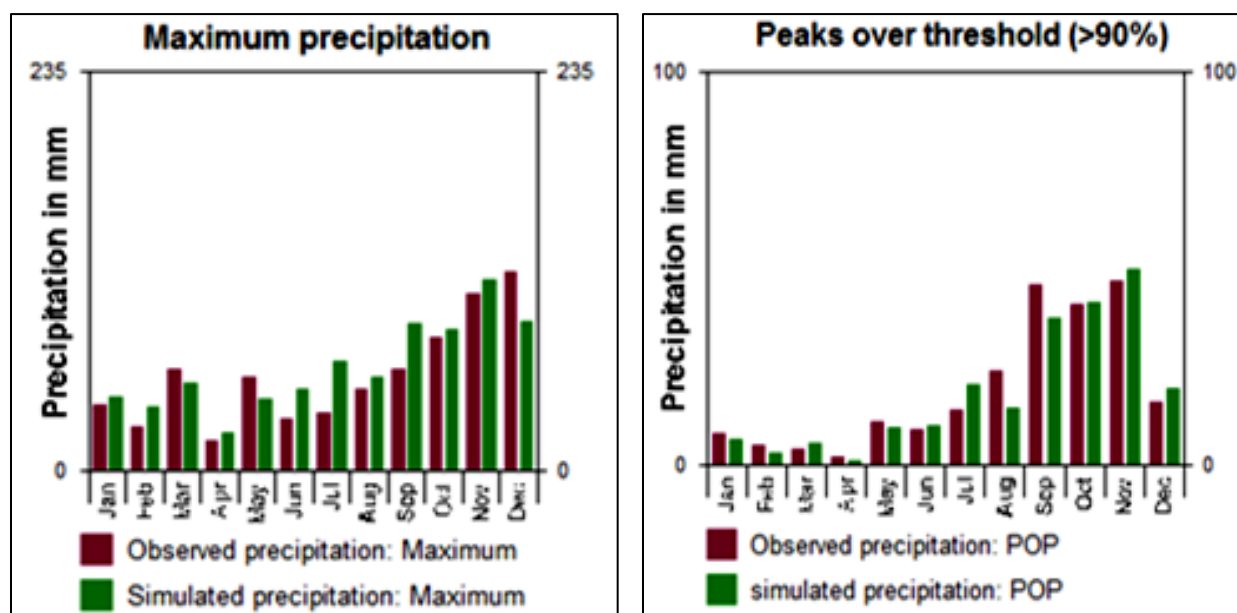


Fig. 5. Observed and simulated mean monthly precipitation by SDSM

The observed NCEP-NCAR data consists of 366 days allowing for 29 days in February due to the leap year. The CanESM2 model has 365 days and hence the value to be changed to 365 days as default value. During the calibration step, the event threshold values to be specified to account trace values. The event threshold value is set zero for temperature and 0.1 mm/day for precipitation. The model modifies the missing data into -999. The quality control step identifies the errors in the data. Fourth root model transformation (conditional model) is applied to predictands of daily precipitation, since the predictands has shown skewed distribution. The predictands of daily temperature variables are normally distributed and hence no model transformation is employed. The default value of variance rise is given as 12 for daily temperature and 20 for daily precipitation. The downscaling model under conditional process can compute higher or lower than the mean value, it is rectified by bias correction. The bias correction value is fixed by trial and error method which continues till the observed and simulated variables matches well. After several trial and error, the bias correction value is found to be 0.98. The temperature data from Mangalapuram meteorological station and rainfall data from 22 rain gauge stations of Vellar basin were utilized. The Thiessen weightages are computed for all the rain gauge stations is provided in Table 2 and the resulting Thiessen polygon map is shown in Fig. 4. The precipitation process can undergo changes based upon local weather conditions. Hence the precipitation downscaling to local scale was performed by Thiessen

**TABLE 4**  
**Performance of SDSM model during calibration**

Predictand	E%	R <sup>2</sup>	S. E
<b>Calibration</b>			
T <sub>Max</sub>	73%	0.80	0.41
T <sub>Min</sub>	71%	0.89	0.35
<b>Rainfall</b>			
Mangalapuram	27.5%	0.30	0.43
Thiessen weighted rainfall of 22 stations	28%	0.31	0.38

weighted average rainfall values of 22 rain gauge stations and one climate station.

The explained variance of various predictors was estimated from NCEP/NCAR reanalysis data in order to select the most suitable predictors. The high explained variance possessing predictors are chosen for correlation analysis to analyze the relationship among predictors and predictands. The correlation coefficient (r) and significance level (P) is used to decide the set of predictor variables selection. The set of predictor variables selected for downscaling based on ‘r’ and ‘P’ is clearly depicted in Table 3. In this study, the significance level was considered as p<0.05 (default value). The NCEP/NCAR predictors were selected based on the highly explained variance and correlation coefficient. The reason for the

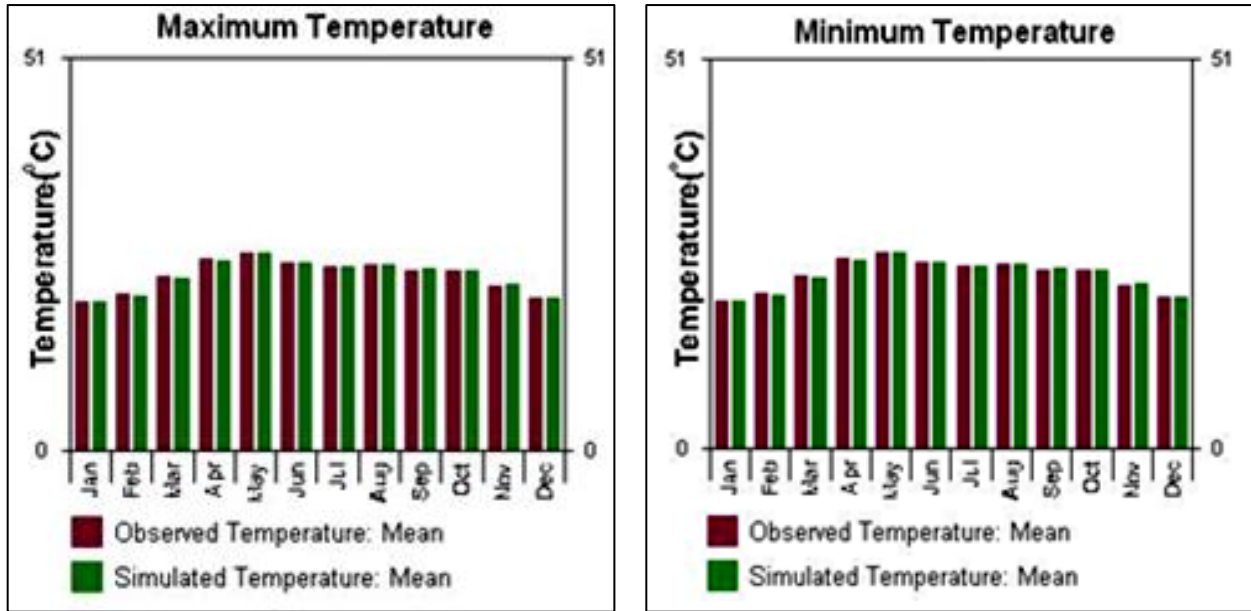


Fig. 6. Observed and simulated mean monthly maximum and minimum temperature by SDSM

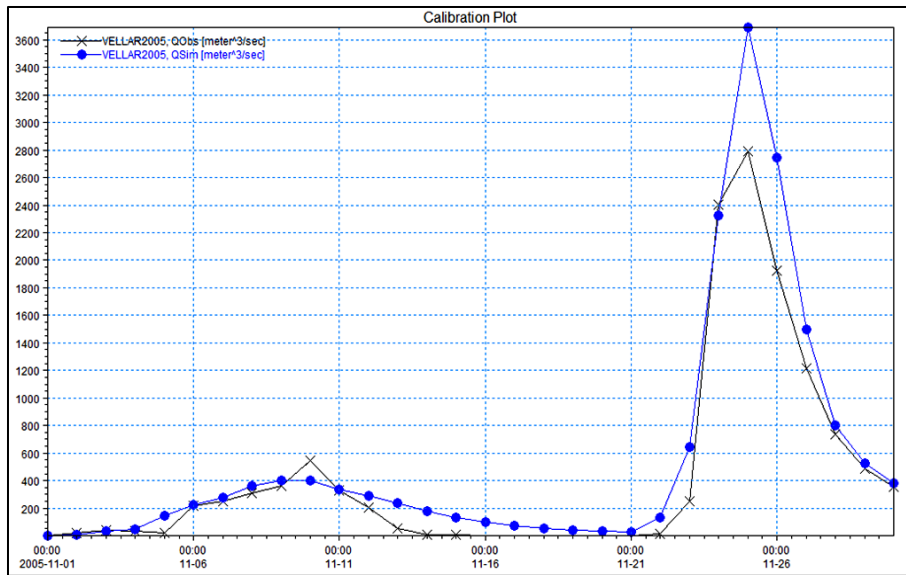


Fig. 7. Observed and simulated flood hydrograph for flood event - 2005

selection of Thiessen weighted average rainfall of all the stations is that it has shown good correlation relationship with predictors compared to other individual rainguage stations. The chosen predictors are utilized to establish transfer function. Then the new synthetic series was developed by this parameter file (.PAR file). In this study, the inter-annual variation is specified by selecting conditional processes for precipitation and unconditional process for temperature data (Shimola *et al.*, 2014). The model calibration was performed by multiple linear

regression equations using predict and predictor variables. The ordinary least squares optimization was selected for the entire station variables. The daily time step was adopted in the downscaling process. The initial 15 years of all the stations data was used for calibration which is from 1976 to 1990 for temperature and 1980 to 1994 for rainfall. In this SDSM procedure, the standard error (S.E.),  $R^2$  and explained variance (E) in percentage are generated which is represented in Table 4.



**TABLE 5**  
**Sensitivity analysis of NAM parameters**

NAM parameters	Percentage variation of model parameters								Significance level
	Runoff volume (Water balance error in %)				Peak runoff in %				
	-20%	-10%	+10%	+20%	-20%	-10%	+10%	+20%	
U <sub>max</sub> (mm)	-5.93	-2.91	2.51	5.00	-0.12	-0.11	-0.10	-0.09	Moderate
L <sub>max</sub> (mm)	-12.54	-6.07	5.13	10	-0.48	-0.42	-0.28	-0.22	High
CQOF	15.42	7.3	-7.25	-13.94	0.11	0.09	-0.21	-0.31	High
CKIF (hrs)	-0.49	-0.34	0.00	0.00	0.00	0.00	0.00	0.00	Less
CK1, 2 (hrs)	-3.41	-1.94	1.81	4.12	-0.29	-0.21	0.00	0.09	Less
TOF	-0.24	-0.23	0.00	0.00	-0.11	-0.11	0.00	0.00	Less
TIF	-0.45	-0.34	0.01	0.06	-0.1	-0.1	0.00	0.00	Less
TG	1.72	0.61	-0.73	-0.95	-0.06	-0.08	0.00	0.00	Less
CKBF (hrs)	-0.35	-0.27	0.00	0.00	-0.11	-0.11	0.00	0.00	Less

**TABLE 6**  
**Best and optimal set of parameters for MIKE 11 NAM**

NAM Parameters	Parameter description	Units	Optimal parameter values
U <sub>max</sub>	Maximum water content in surface storage	mm	14.646
L <sub>max</sub>	Maximum water content in root zone storage	mm	179.2
CQOF	Overland flow runoff coefficient	-	0.78434
CKIF	Time constant for routing interflow	hours	575.12
CK1,2	Time constant 1, 2 for routing overland flow	hours	44.886
TOF	Root zone threshold value for overland flow	hours	0.0024
TIF	Root zone threshold value for interflow	-	0.35446
TG	Root zone threshold value for groundwater storage	-	0.67886
CKBF	Time constant for routing base flow	hours	2498

The calibrated model was validated by the weather generator. The weather generator produces synthetic daily weather records for the given period based upon the parameter file or regression weights and large scale atmospheric predictor variables from NCEP/NCAR dataset. Twenty ensembles of synthetic daily weather records were generated for station data and variables. The summary statistics step is used to compare the observed with the simulated data and if any adjustment is needed then the variance inflation and bias correction on data is performed. The validation period is from 1991 to 2005 for temperature and 1995 to 2005 for rainfall. The performance of SDSM simulated rainfall data during validation stage is evaluated with maximum precipitation and peaks over threshold (>90%) as given in Fig. 5. The

performance of SDSM simulated temperature data during validation stage is evaluated with mean monthly temperature as depicted in Fig. 6. These values are used for the development of synthetic weather record.

The scenario generation step is based on the assumption that the predictor-predictand relationship is valid in present as well as in the future climate conditions. The synthetic weather data series is created by scenario generation option in the same way as weather generator. At this time the CanESM2 model output was provided as an alternative to NCEP/NCAR reanalysis data. Two CanESM2 scenarios, RCP 4.5 and RCP 8.5 are considered in this study. Twenty ensembles of synthetic daily weather records were generated for each scenario with the period

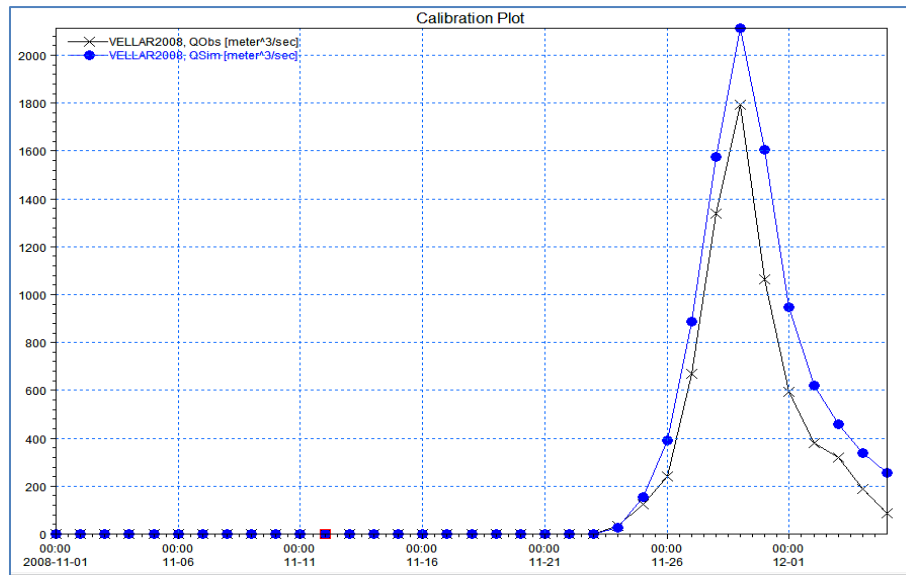


Fig. 8. Observed and simulated flood hydrograph for flood event - 2008

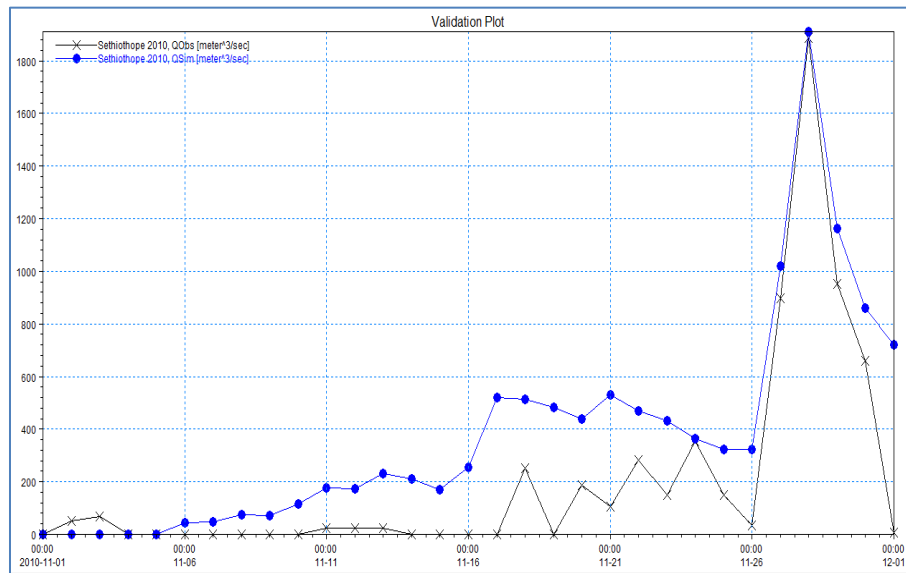


Fig. 9. Observed and simulated flood hydrograph for flood event - 2010

of 2006 to 2100 to all the variables and station data. The average of twenty ensembles was utilized as a daily weather data for the required period. Large number of ensembles does not improve or much more prone to higher deviation compared to the mean of twenty ensembles, which gives satisfactory results. The future years considered for the downscaling of maximum temperature, minimum temperature and rainfall are 2050 and 2080. Under the present study, the future rainfall, maximum temperature and minimum temperature for the two different climate change scenarios were established.

#### 4.2. Calibration and parameter optimization by MIKE11NAM

The initial condition of the catchment is specified for each storm event until the simulated flow matches with the observed flow at the beginning of hydrograph. Among the four flood events, two events (2005 and 2008) were chosen for calibration to find the best parameters of MIKE11NAM model, the 2010 and 2011 events are used for testing the calibrated parameters. The auto-calibration procedure based upon shuffle complex evaluation

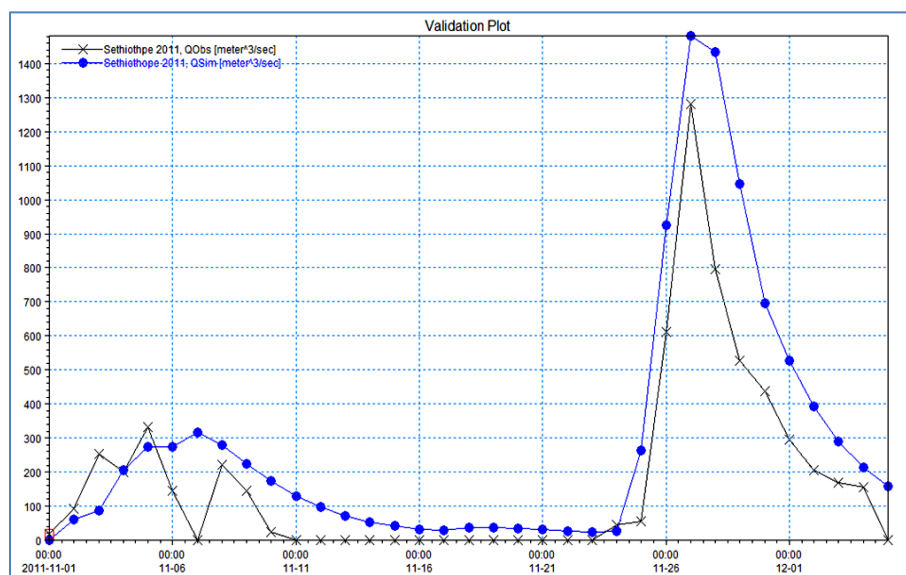


Fig. 10. Observed and simulated flood hydrograph for flood event - 2011

algorithm and trial and error method are employed to find the best set of parameters. Some of the NAM parameters associated to ground water (GW) flow such as  $C_{area}$  (change ratio of GW area to catchment area),  $S_y$  (specific yield),  $GWLBF0$  (GW depth for base flow threshold),  $GWLBF1$  (capillary flux) and  $C_{qlow}$  (lower base flow recharge to reservoirs) were not considered in calibration. The water balance error and peak runoff values were analyzed to assess the effectiveness of the model in simulation of runoff. The  $U_{max}$  value 14.64 mm shows that the amount of water reserved with the interception storage, depression storage and top most part of the ground surface. The  $L_{max}$  value 179.2 mm represents the amount of maximum water available in the root zone for crop transpiration. A slightly higher CQOF value of 0.784 was acquired due to the existence of rocky terrain and low permeable soil in the upper part of the basin. The  $U/U_{max}$  value 0.4 denotes that there is a low surface storage due to the presence of thin forest cover in the upper region. The  $L/L_{max}$  value 0.6 signifies that there is a presence of major crop land having prominent root zone storage. The overland flow is occurring during wet periods is indicated by the higher value of  $L/L_{max}$  in comparison with TOF. The QOF and QIF values are given as zero for the initial condition.

The sensitivity analysis is carried out by changing the NAM parameters with  $\pm 20\%$  and  $\pm 10\%$  of the optimal value and then it is investigated with model output is given in Table 5. The variations of model parameters with respect to model outputs like water balance and peak runoff were compared to assess the sensitivity. The level

of sensitivity has been classified as high for model output variation higher than 10%, moderate for variation between 5-10% and less for variation less than 5%. The  $U_{max}$  value with respect to the calibrated value shows that moderate percentage variations exist between -5.93% to 5% due to the influence of thin forest cover. There is a significant percentage variation between 12.54% to 10% in comparison with calibrated value depicts that the effect has been made by the major crop land and major root zone storage. The CQOF value with respect to the water balance error and peak runoff shows that there is a higher percentage variations exist between -5.42% to 6% and 15.42% to 13.94%. The other NAM parameters such as CKIF, CK12, TOF, TIF, TG and CKBF has less significance on runoff volume except CK12 which has evident effect on peak runoff is clearly given in Table 5. The selection of values for the prominent NAM parameters like  $U_{max}$ ,  $L_{max}$ , CQOF and CK12 which has major effect on peak runoff and water balance is a challenging task in developing a rainfall-runoff model.

The observed discharge data matches well with the simulated discharge data of the two storm events during the calibration period are clearly shown in Figs. 7&8 and also the scatter plots are represented in Figs. 11&12. The effects of changing the MIKE11NAM parameters will vary the simulated discharge was analyzed (Shamsudin and Hashim, 2002). The optimal parameters are represented in the Table 6. During calibration of two storm events,  $R^2$  and EI values depicts that there is a good correlation between observed and simulated flood flows mentioned in Table 7.

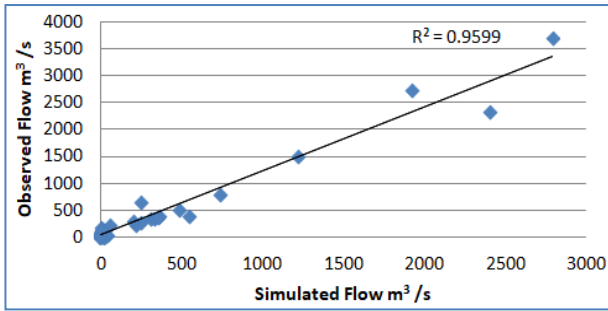


Fig. 11. Scatter plot of observed and simulated flow for flood event 2005

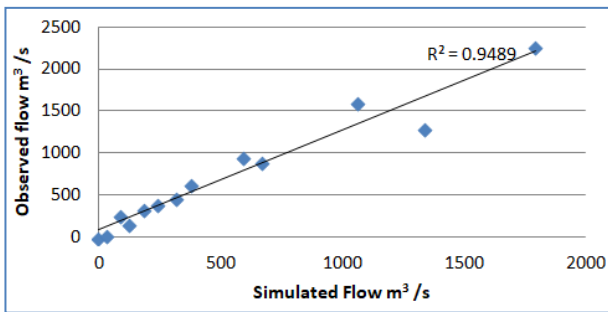


Fig. 12. Scatter plot of observed and simulated flow for flood event 2008

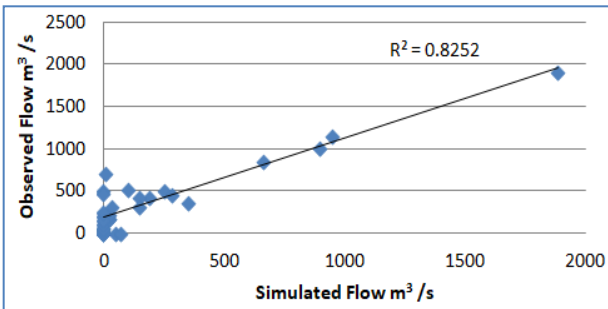


Fig. 13. Scatter plot of observed and simulated flow for flood event 2010

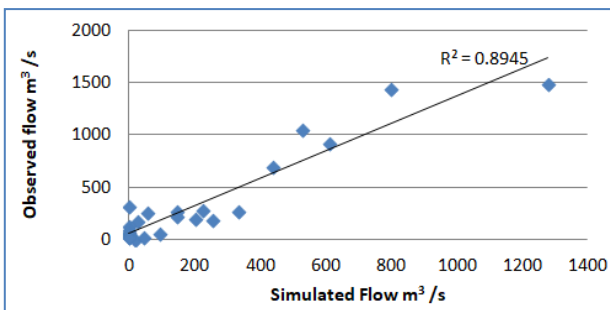


Fig. 14. Scatter plot of observed and simulated flow for flood event 2011

TABLE 7

Results of MIKE11NAM for calibration and verification events

Period	EI	R <sup>2</sup>
<b>Calibration period</b>		
2005	0.88	0.95
2008	0.89	0.94
<b>Verification period</b>		
2010	0.70	0.82
2011	0.80	0.89

TABLE 8

Peak discharge changes in 2050 and 2080 under the RCP 4.5 and RCP 8.5 Scenarios

Items	CanESM2	
	2050	2080
Percentage of peak discharge increase in RCP 4.5 scenario	56.9%	108.06%
Percentage of peak discharge increase in RCP 8.5 scenario	104.12%	519.3%
Percentage of peak rainfall increase in RCP 4.5 scenario	170.94%	285.24%
Percentage of peak rainfall increase in RCP 8.5 scenario	232.79%	424.1%

4.3. Model verification

The observed discharge data matches well with the simulated discharge data of 2010 and 2011 storm events during the validation period are clearly mentioned in Figs. 9&10 and also the scatter plots are represented in Figs. 13&14. The best optimal sets of parameters generated by calibration step were utilized to run the 2010 and 2011 storm events in MIKE11NAM model. During verification of the two storm events, the R<sup>2</sup> and EI values proves that there is a very good correlation between observed and simulated flood flows and it is depicted in the Table 7. The best optimal parameters of MIKE11NAM are utilized to simulate flood flows under the RCP 4.5 and RCP 8.5 climate change scenarios.

4.4. Flood simulation under different climate change scenarios

The rainfall is downscaled by SDSM from the CanESM2 GCM model under the RCP 4.5 and RCP 8.5

scenarios for 2050 and 2080. The GCM results were compared with the major flood event in the year 2005, to analyze variability in peak rainfall and peak discharge. The CanESM2 predicts an increase in rainfall by 170.94% in 2050 and 285.24% in 2080 under RCP 4.5 and increase in rainfall by 232.79% in 2050 and 424.11% in 2080 under RCP 8.5 shown in Table 8. The increase in discharge computed as 56.9% and 108.06% in RCP 4.5 and 104.12% and 519.3% in RCP 8.5 in 2050 and 2080 years is denoted in the Table 8. According to the results obtained from the CanESM2, there will an increase in peak discharge under the RCP 4.5 and RCP 8.5 scenarios for 2050 and 2080.

## 5. Conclusions

The present research paper on climate change and its impact on flood flows in the Vellar river basin were analyzed. The possible variability of flood was assessed using the MIKE11NAM hydrological model. SDSM model gives better results in simulating rainfall under AR5 scenarios with the selected GCM. The  $ET_0$  generated using observed data and GCM data is essentially provided as an input to the hydrological model. The GCM CanESM2 predicts an increase in peak rainfall and discharge compared to the 2005 flood event. According to the results obtained from the GCM CanESM2, there will be an increase in peak rainfall and peak discharge under the RCP 4.5 and RCP 8.5 scenarios for both future years 2050 and 2080. The flood risk will increase and produce flash floods in a quick response river basin. The excess release of water for few days and dry flow will be prevailing for most of the year is revealed through the analysis of all flood events. As major part of the land use is agricultural land of 67.8% of the whole area is under serious threat due to floods and climate change effect. Because of lesser flow the average water salinity is increased to 35-45 ppm at present and in future, this will cause a detrimental effect on river environment. Taking the high flood flow as per RCP 4.5 and 8.5 into account, structural control measures has to be made on the upstream side of the river basin to reduce the flood damage.

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## Disclaimer

The contents and views expressed in this research paper are the views of the authors and do not necessarily reflect the views of their organizations.

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