DEMONSTRATION OF ESTIMATING FLOOD SUBMERGENCE AREA FOR A SELECTED STRETCH ON BENNIHALLA RIVER BY INTEGRATING HEC-RAS WITH SWAT

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Abstract - *Flood is a flow that overtops either hydraulic structure or river bank along a stream resulting in damage to the adjoining property or life. Most of economic and social activities are concentrated close to river banks, i.e., flood plains due to the proximity of water. It becomes essential to protect them from flooding. Certain stretch of Bennihalla falling under Krishna Basin often experiences floods damaging large tract of land property and cause damage to property and life. Hence in the present study an effort is made to estimate the annual discharge values at the selected points on a river stretch using SWAT (Soil and Water Assessment Tool) model and to estimate flood magnitude for various return periods. In order to determine the extent of the area being submerged in flood plain area for a certain return period, a one dimensional hydraulic model HEC-RAS (Hydrologic Engineering Centre – River Analysis System) is being integrated with SWAT model.*

Key Words: Flood Plans, SWAT, Return period and HEC-RAS.

1. INTRODUCTION

Flood is the most common natural disaster which happens very often. India is a country where its flood plains are often exposed to floods due to the encroachment, proximity of water for cultivation along the river side, establishment of mankind, etc., on the flood plains. Due to topography or inefficiency in managing the surface water, the heavy rainfall in certain areas of India tends to cause serious damage in the form of Floods which are considered to be one of the Natural Disaster event even though its occurrence is contradictory between man & the natural phenomena is concerned. Out of the total geographical area of 329 million hectares (mha), more than 40 mha is flood prone every year. Frequency of major floods in India is estimated to be once in every 5 years [9].

It is evident that in Karnataka almost all the districts are facing the brunt of moderate to severe floods. Years 2005 and 2006 have seen devastating floods in the Districts of Gulbarga, Belgaum, Bijapur, Bidar, Bagalkot, Raichur etc.[14]

Bennihalla watershed experiences severe floods during monsoon seasons due to the flat terrain, heavy rainfall, encroachment, sedimentation, insufficient carrying capacity of the channel, lack of impounding structures, etc., The southwest monsoon sets in by June and ends by the middle of October. During this period the basin receives more than 50% of the annual rainfall and the climate will generally be humid [10]. Bennihalla River basin is comprised of black cotton soil (high clay content soil) which are rich in Montmorillonite which is having the property imparting high degree of expansiveness. Possibly these factors are responsible for flooding in the region.

In order to estimate the daily discharge values in a particular reach of Bennihalla, SWAT model was used and this model was calibrated and validated with the observed data. Flood frequency analysis is carried out for the simulated daily flows which are obtained from SWAT model using two statistical techniques – Log Pearson Type-III and Gumbel's Extreme Value Type-I Distribution. To decide on which is the best fit distribution for the data Graphical Method is employed. The flood magnitudes of various return periods (3year, 5year, 10year, 15year and 20year) are estimated with the best fit distribution and for these discharge values water surface profiles are computed using HEC-RAS model and are exported to HEC-GeoRAS tool to know the submergence area.

2. STUDY AREA AND DATA USED

The Bennihalla basin is one of the vital tributary of Malaprabha River which is the principle tributary of Krishna River. The basin lies between latitudes north 15°04'27" and 15°50'23" and longitudes between east 74°58'43" to 75°38'44". The study range covers Rona, Gadag and Shirhatti taluks in the east, Dharwad and Hubli taluks in the west. Shiggaon taluka in the south west and Nargund and Parasgad taluk in the north. Navalgund taluk in the Center. The study territory falls in the semi-dry locale. The physiography of the study area is described by delicately undulating landscape and slope. Geographically, the study region is underlain by Dharwad schistose rocks and granitic gneiss. The northeastern part of the study range is possessed by granitic gneiss [10].

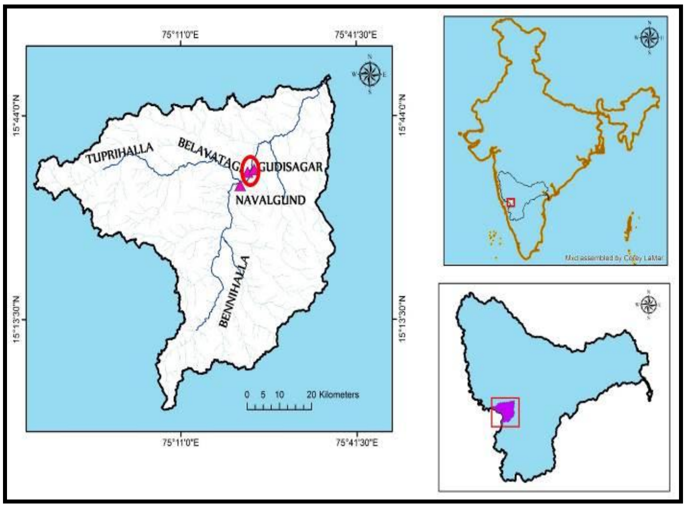

Fig -1: Location map of the study area

In the present case, Gudisagar stretch of about 9km on Bennihalla is selected for flood plain analysis (Ref. Fig.1). The reason behind selecting this particular station is that the stretch experiences frequent floods which results in loss of lives and property in the vicinity of adjoining river.

Following data are used:

- CARTOSAT-1 DEM of 32m resolution
- Land use data based on LANDSAT-7 imagery (2003).
- Soil data from FAO, Scale- 1:50,000 (2000).
- Precipitation data from Irrigation Investigation dept., for the year 1988 to 2014.
- 1^0X1^0 daily temperature data from IMD (Indian Meteorological Department) for the year 1988 to 2014.
- Observed discharge data of Menasagi station for the year 2000 to 2009 from Irrigation Investigation dept., Dharwad.

3. METHODOLOGY

In the present study, SWAT model has been used to get the daily discharge data at the required stations. The SCS-CN is used to estimate runoff generated. Once the calibration and validation of the model is done, annual peak flows at particular river stretch are obtained from SWAT and further frequency analysis is carried out using two statistical techniques (Fig. 2). The best fitting distribution is identified by graphical method. Flood magnitudes for various return periods are estimated by choosing the best fit distribution. i.e., Gumbel's Extreme Value Type-I distribution in the present case. These discharge values are incorporated in the HEC-RAS model to compute the water surface profiles for various return periods. The HEC-RAS output results are transferred to GIS environment wherein flood submergence area are determined for the selected stretch on the watershed.

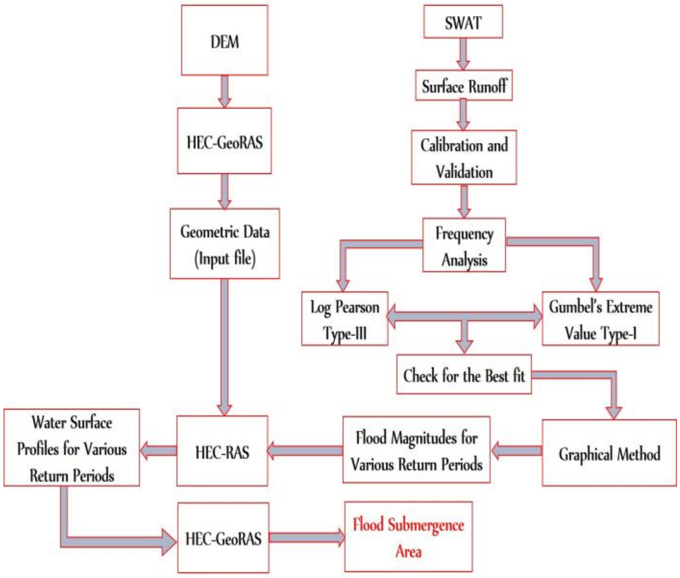

Fig -2: Work Flow

4. SWAT MODEL SETUP

First step in setting up of SWAT model is the watershed delineation using DEM. An interface Arc-SWAT was used in this case to prepare necessary input files to run the SWAT model. Arc-SWAT processes the Digital Elevation Model (Fig. 3) and automatically delineates the watershed and sub-watersheds, generates the stream network, outlet for a given threshold value.

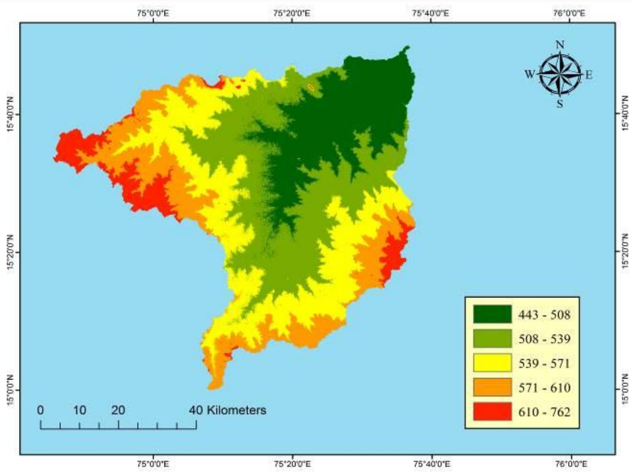

Fig -3: Digital Elevation Map of Bennihalla

The meteorological data required for the SWAT model are precipitation, temperature, relative humidity, solar radiation and wind speed. Precipitation data were collected from Irrigation Investigation Department, Dharwad for the period 1988 to 2014. Temperature data was collected from IMD (Indian Meteorological Department) for the period 1988 to 2014.

The land use and land cover data are collected from LANDSAT – 7 Satellite for the year 2003. Then this data was subjected to supervised classification process. Fig. 4 illustrate the map of different land use and land cover for the study area.

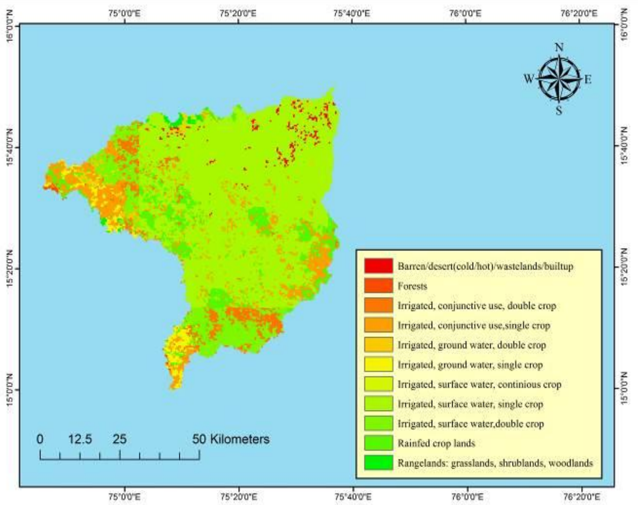

Fig -4: Land Use and Land Cover Map

Soil map was obtained from the FAO (Food and Agricultural Organization) digital soil maps at 1:50000 scale. Fig. 5 illustrates the soil classes within the study area.

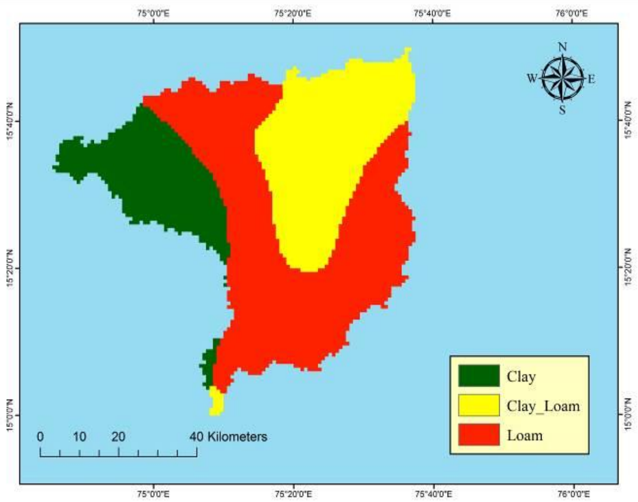

Fig -5: Soil Map of Bennihalla

Monthly observed discharge data (1988-2014) for the Menasagi Station, located within the study area, was obtained from Irrigation Investigation department, Dharwad. These observed discharge data was used for the calibration and validation of the model. Fig. 6 represents the observed monthly discharge data of the Menasagi gauging station.

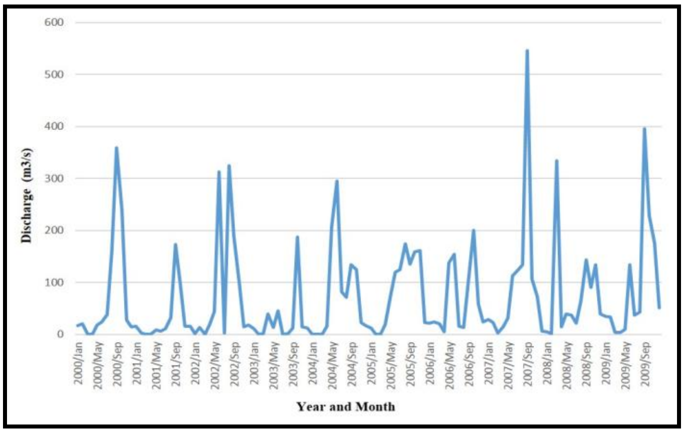

Fig -6: Observed Monthly Discharge (2000-2009)

Land use/ land cover map and soil map were overlaid after the watershed delineation process is done. Based on the overlaying, basic units of modelling (Hydrologic Response Unit, HRUs) were extracted. In the present study, HRUs were defined by taking all land uses, soil type and slope occupying 10% or more of sub-basin area. HRU report was then generated. Precipitation and temperature data obtained from Irrigation dept. and IMD, Pune was fed into model as a user defined data for the weather parameters. Weather generator was used to generate and write meteorological parameters files. Then the SWAT was run for the period of 26 years from the year 1988 to 2014 with the warm up period of 02 years.

5. HEC-RAS MODEL SETUP

Various data are required in setting up of the HEC-RAS model. One of the vital information is the geometrical information of a specific river stretch. The geometrical data of a river is prepared using a tool called HEC-GeoRAS which assists in preparing input file as well as post processing of the HEC-RAS results in GIS environment.

Using Cartosat-1 DEM on the study area, HEC-GeoRAS help to prepare the geometric data which is required for HEC-RAS. The important layers that are created are the stream centerline, Flow path centerlines, main channel banks and cross section cut lines as RAS layers. These parameters are used to establish series of cross-sections along the stream. After preparing the geometric file, the data is imported to HEC-RAS model in .sdf format.

HEC-RAS is a one dimensional flow model, intended for computation of water surface profiles for both steady and unsteady cases. In the present case, steady state is performed using standard step method. The water surface profiles are computed by solving energy equation using an iterative procedure.

The initial boundary condition was assumed for normal depth condition as it was the only available data for the study area. Before simulating the model, certain initial conditions have to be defined viz- Normal depth, discharge at the inlet, manning's "n" value, expansion and contraction values, etc., The model was simulated for various return periods to estimate the water surface profiles for subcritical condition as the Froude's number was found to be less than 1 for the stretch selected. The results have been illustrated in the next section.

The input data for the steady state will be peak discharge data for the particular return period. The model yields the water surface profiles for each of the flood magnitudes and the results are then again exported to HEC GeoRAS wherein the submergence area due to flood is estimated. Based on the inundation area suitable preventive measures against the flooding may be suggested.

6. RESULTS AND DISCUSSIONS

6.1 SWAT RESULTS

The model is used to generate discharge values at the selected point- Gudisagar, calibration and validation is done for the downstream gauging located at Menasagi village as data for this is available. Calibration is done for the period 2000 to 2004 and Validation of the model using the data for the period 2005 to 2009.

Fig. 7 represents the comparison between simulated and observed discharge before the calibration. In this case, model seems to be under predictive as simulated peaks are higher than the observed peaks. For the first run, R^2 and NSE were obtained as 0.561 and 0.303 respectively. The objective functions chosen for calibration purpose were R^2 and NSE.

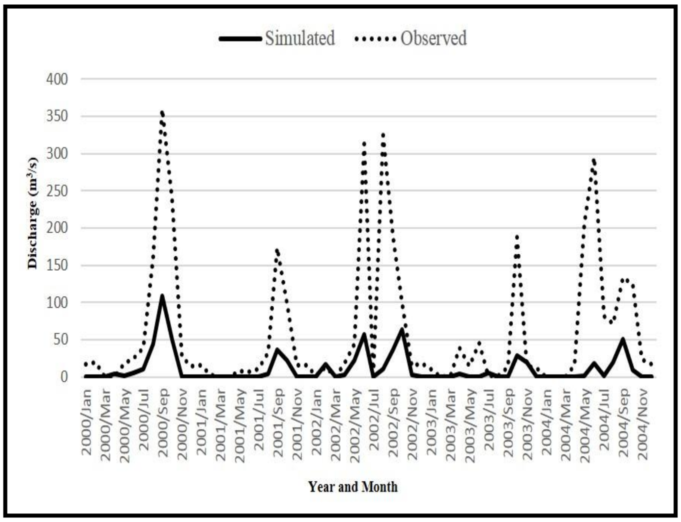

Fig -7: Comparison between observed and simulated discharge values before calibration

The model was simulated for different scenarios by changing the various sensitive parameters (Table I). On doing sufficient number of iteration by assigning different values for sensitive parameters the objective functions were improved as R^2=0.608 and NSE=0.665. Fig.8 shows the relative variations of observed versus simulated flow on model calibration for the period 2000 to 2004.

Table -1: Parameters used in Calibration of the Model

Parameters	Initial Values	Calibrated Values
CN_2	87	89
GW_DELAY	31	120
ALPHA_BF	0.048	0.85
ESCO	0.95	1
SURLAG	2	0.5
SOL_AWC	0.16	0.2

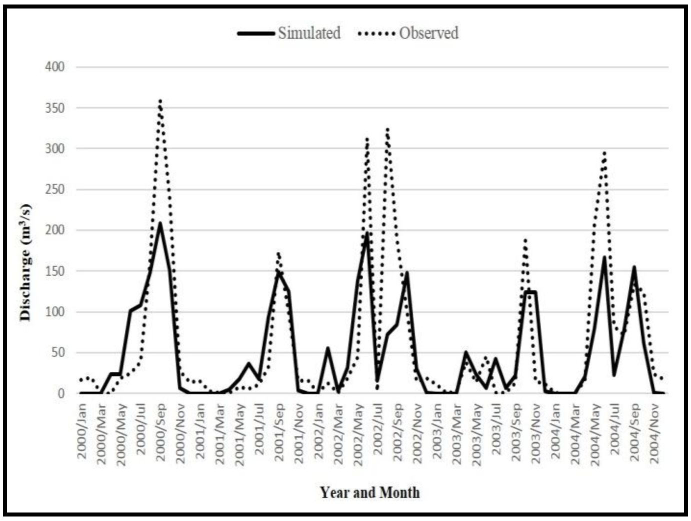

Fig -8: Comparison between observed and simulated discharge values after calibration

Validation of the model was done for the second set of data. i.e., for the period 2005 to 2009. Figure 9 illustrates the variation in observed versus simulated discharge values.

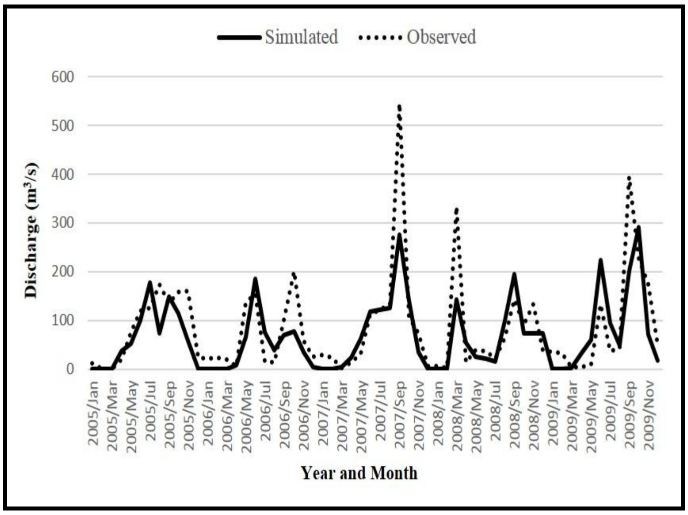

Fig -9: Variation in observed and simulated discharge values on Validation

Coefficient of determination R^2 and NSE was used to assess the model performance. In general, model simulation can be judged as satisfactory if NSE > 0.50 (Moriasi et. al, 2007) [17] and typical value of R^2 greater than 0.5 for stream flows (Santhi et al., 2001; Van Liew et al., 2003) [11] [12]. The low values of R^2 and NSE may be due to the uncertainties associated with the observed data and also may be due to the use of coarser resolution data which directly affects the accuracy and the model performance. Based on the result obtained, model is assumed to be valid and further analysis of model output has been made.

The results of SWAT model for various objective functions during the calibration and validation of the model is shown in the Table 2.

Table -2: Results of Objective Functions for the SWAT model

Objective Function	Calibration	Validation
R^2	0.608	0.617
NSE	0.665	0.658

Daily discharge data for the desired outlet point has been derived from the SWAT model after the Validation of the model for the sub basin 4 for the Tuprihalla river stretch and sub basin 5 for the Bennihalla river stretch near the confluence point. The annual flood peaks are obtained from the daily discharge data generated from the SWAT model and then subsequent annual flood peaks are used for frequency analysis.

Attempt have been made to refine the values of objective function. From the studies it has been found that the most influencing sensitive parameter for surface runoff is the CN (Cure number) varying from 30 to 100 which depends on the area's hydrologic soil group, land use and hydrologic condition [18]. For the model is calibrated, the CN value attained is 89. When the value of CN was assigned more than 89 and less than 89, it is observed that prediction discharge values were either overestimating or underestimating compared to observed ones. This may be due to the fact that the Bennihalla watershed has the flat terrain and the presence of black cotton clayey soil (Ref Fig. 5) in the catchment.

6.2 FREQUENCY ANALYSIS

In order to predict the flood flows corresponding to various return periods a statistical method of frequency analysis is carried out. The flood for various return periods are of great help for engineers to take measures at times. Of the various methods of flood frequency analysis, the more commonly used methods are Gumbel's Extreme Value Type-I distribution and Log Pearson Type-III distribution. To determine the design floods, a minimum of 20 years observed data is essential. In certain situations when the data is not available, the same can be simulated by using suitable approach. In the present case, SWAT model is being used to generate annual flood peaks for the period 1988-2014. The results of simulated annual peak values from the SWAT model is considered as observed peak values for doing frequency analysis using L.P Type-III and G.E.V Type-I distributions.

Frequency analysis is carried out for station Gudisagar, Bennihalla stretch using estimated and the simulated data using both the distributions. Results have been illustrated in the form of graph, refer Fig.10.

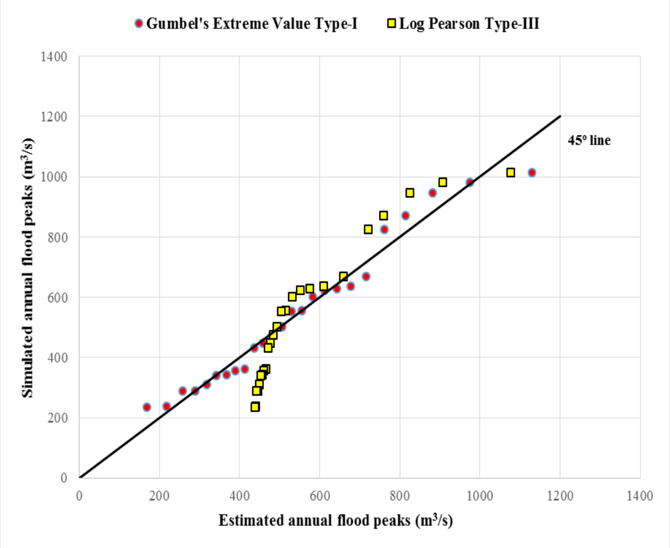

Fig -10: Simulated v/s Estimated annual flood peas for Bennihalla tributary

From the above graph it can be concluded that, the deviation from the 45^0 line by the L.P Type-III distribution is more for both estimated and the simulated values when compared to Gumbel's distribution. Hence for this case, Gumbel's Extreme Value Type-I distribution is preferred over L.P Type-III distribution for estimating flood magnitudes for various return periods for the Station Gudisagar, Bennihalla river stretch. Also, L.P. Type-III distribution overestimates the discharge values for lower magnitudes of annual peaks. Hence Gumbel's Extreme value Type-I Distribution is used as a base to estimate the flood magnitudes for various return periods, refer Table 3.

Table -3: Annual Flood Peak for Various Return Period

Stretch	Distribution	Return period (yrs)				
		3	*5*	*10*	*15*	*20*
Bennihalla	GEV-I	621.99	751.90	915.15	1007.24	1071.73

6.3 SUBMERGENCE AREA

The HEC-RAS model was simulated for steady condition under subcritical criteria, for various return periods and the water surface profiles at each of the defined cross section is found out. The HEC-RAS results are then exported to GIS environment. Using HEC-GeoRAS tool, post processing of the HEC-RAS results is carried out to determine submergence area for various return periods. The increasing submerged area for various return period is summarized in the Table 4 below.

Table -4: Inundation area for Various Return Period

Sl No	Return Period (yrs)	Water Spread area (acres)
1	3	862.82
2	5	967.90
3	10	1119.06
4	15	1224.91
5	20	1271.07

7. CONCLUSIONS

The method demonstrates the use of SWAT model to generate annual flood peaks for any station on the watershed. In the present case, the flood frequency analysis is carried out using the simulated flood values on Bennihalla watershed. The model was calibrated and validated with the observed values at gauge station Menasagi. The R^2 and NSE values was found to be 0.608 and 0.665 during calibration and 0.617 and 0.658 on validation respectively. The analysis reveals that Gumbel's Extreme Value Type-I distribution fits well for the simulated data when compared with L.P Type-III distribution. This has been well supported by graphical method. (Refer Fig. 10).

This study also demonstrates the integration of HEC-RAS and SWAT and appears to give reliable results. The water surface elevations which are estimated from HEC-RAS using SWAT discharge values are used in GIS environment to determine are of submergence corresponding to various return periods with the use of HEC-GeoRAS tool is also demonstrated.

High resolution digital elevation model or detailed channel cross section is not available for this study. In spite of this, the study demonstrates the use of CARTOSAT-1 DEM of 32m resolution which can be used for the flood plain analysis as a primary data for flood mitigation. The accuracy in the results can be achieved with the use of finer resolution data.

It is proposed to adopt the suitable structural and non-structural measures like storage structures, non-settlement of people on the flood plains, levees, etc., to reduce likely damage caused by flooding along the river course.

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