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A Combined Approach for 1-D Hydrodynamic Flood Modeling by using Arc-Gis, Hec-Georas, Hec-Ras Interface - A Case Study on Purna River of Navsari City, Gujarat

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Abstract: ***This research work represents the application of ArcGIS, HEC-RAS and HEC-GeoRAS interface for 1-D flood modeling of Purna River. The research expectation is to disaster authorities and organizers in the advancement of flood control actions for the Purna River, which experience unexpected floods in 1976, 1977 and 2004, resulting in loss of life and property in the surrounding region. Due to free availability and good accuracy, Digital Elevation Model (DEM) was preferred from open sources, for the extraction of geometrical data for the river. Research represent methodology of combined application of Arc-GIS and HEC-RAS. The first phase for modeling was done in Arc-GIS environment and functions like Geo-referencing, creating Shapefile, Mosaic, extract by mask, etc., were done. From the first phase, geometric parameters like river centerline, bank line, flow path lines, cross section cut lines were extracted into a data file with HEC-GeoRAS extension provided in Arc-GIS. This geometric data file is exported from Arc-GIS to HEC-RAS environment for model execution. The Second phase for model execution is done in HEC-RAS environment to which the geometry data were imported to generate a HEC-RAS model. Results obtained from the HEC-RAS model show the water surface elevation for peak discharge, the cross-section details at various points along the length of the river and certain cross-sections at specific points along the length of the river which experience flooding due to high discharge during monsoon season are shown. Through this approach, research application can be used at Purna River near Navsari district, so that we can identified the cross-sections where flooding phenomenon is prominent and contain the flood within the river by providing embankments, flood wall, etc.***

Index Terms**:** ***DEM, Arc-GIS, HEC-RAS, HEC-GeoRAS, Hydrodynamic modeling, flood***

I. INTRODUCTION

A. Flood impact and techniques for flood control

The incidence of extreme rainfall is a key noteworthy effect of the environmental variation, this prompt increment in the extent and recurrence of outrageous occasions, for example, flood and dry season [1].

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Generally, it can be taken as a certainty that upcoming climatic variations would cause an incredible dissimilitude in water convenience in distinctive areas. Because of which almost each aspect of human lifecycle including agriculture, environment, fishery management and productivity, municipal water supply, industrial water supply and a major impact on flood etc., are affected [2]. A human settlement, framework advancement, industrialization, business, recreational execution, Loss of land for cultivating, impact to drinkable water, and immersion in low laying zone are some of the significant impacts caused due to flood in coastal zones. As a result of flooding, it is fundamental for the flood management boards to prevent or curtail the effects of flood by implementing flood mitigation measures like infrastructure development and river training [3]. River floods accompanied by storms are one of the major devastations and had caused damages worth billions during a flood in Europe. 'Fluctuating complexity' methods can be carried out for flood hazard estimation which is dependent on time, availability of data and information [4]. Recent advancement of technologies introduces the risk reduction approach in flood management. The objectives of such an approach are to minimize the overall flood hazard by applying structural and non-structural flood mitigation measures. Moreover, such methods used for the solution of global level problems [5]. Khan [6] introduced the estimation of flood risk using past flood data for maximum peak discharge and found the magnitude and frequency of catastrophic flood in Pakistan in past years. Flood risk assessment can be done at different special scales. On a global scale, flood mitigation can be done by collecting consistent information and on a mesoscale a better warning system for catastrophic flooding can be modelled [7]. Gin-Ganga and Kalu-Ganga River in Sri Lanka locate the sea between Gulf of Mannar and Bay of Bengal. Due to high breezes, the river flow rate increases in both the rivers, the encompassing district experience two sequential storm season and bring about flooding in the rivers. These regions are having important land for horticulture and cropland. Effects of flooding causes harm to such harvest lands. For this reason, Disaster Release Managing (DRM) set up work to minimize flood in Sri Lanka [8]. Flooding occurs due to a cyclone in northern Australia. Moreover, demography, geography, urbanization, industrialization, are also a major factor for flood. Researcher develops a hydrodynamic model for flood risk assessment [9].

Surat city, being a low-lying area faces entry of flood water during heavy rainfall within minimum time, and cause flooding. Geographical Information system (GIS) and Remote Sensing (RS) system would be used to mitigate the flood risk [10]. Flood is a natural disaster. In the field of agriculture, clearing of land leads to flooding and causes loss of property, lives, tangible and intangible losses [11]. HEC-RAS is a tool used by hydraulic engineers which are used to analyze water flow through channel and river and floodplain control [12]. It is developed by US Army Crop of Engineers used for one-dimensional steady flow hydraulic modelling; it has extensive approach among many government agencies. It is very easy to simulate water surface profile for steady flow and quantify the effect of any obstructions like over bank region, weir, bridges, and culverts with the use of HEC-RAS. Using HEC-RAS, flood inundation can be found out for a given flood that have been reported [13, 14]. Research study develops the one-dimensional model and stage hydrograph and applied simulation, calibration and validation procedure of lower region of Tapi river using past flood data, contour data and hydrological data [15]. Monte Carlo simulation techniques is very effective to measure uncertainties of climate change impact on a flood to minimize flood risk. Using hydrologic modeling research shows the simulation of flow series for present and future condition [16]. Heavy rainfall during monsoon caused a flood in Agliamento, Italy. Artificial Neural Network (ANN) techniques are used for analysis and forecasting flood using water level and rainfall parameters [17]. Combination of Arc-GIS and HEC-RAS software is used to develop floodplain map using river geometry, past flood data, river discharge data, and roughness [18].

II. CASE STUDY AREA

Navsari district is situated in the southern part of Gujarat State, India. Navsari area lies between Latitude 20°32' and 21°05' North and Longitude 72°42' and 73°30' East and it falls in Survey of India, Top sheet nos 46C, 46D, 46G& 46H. It is compelled by Dangs region in the east, Surat region in the north, Arabian Sea in the west and Valsad region in the South. Navsari city has a topographical region of about approximate 2210.97 km^2. Study area map and Google map are shown in Figure 1 and Figure 2. Purna River starts from the Saputara close to the town of Chinchi in Maharashtra. The Total length of the Purna River from its beginning stage to release in the Arabian Sea is approximately 181 km. PURNA river basin lies between 200º 41' to 210º 05' North zone latitude and 720º 45' to 740 º 00' East zone longitudes. The total catchment region of the Purna Basin is 2432 km^2.

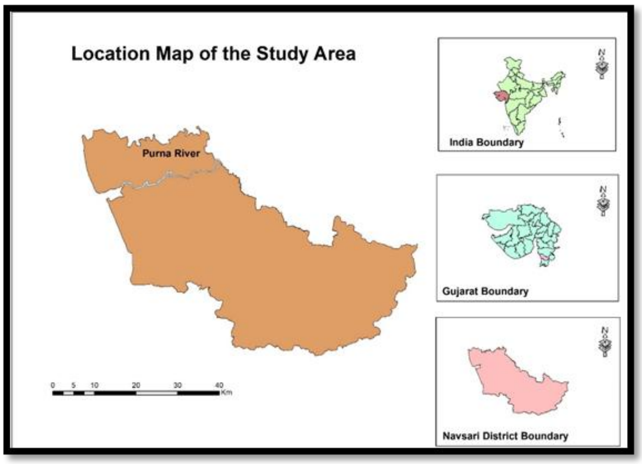

Fig. 1. Location map of Study Area

Fig. 2. Google Map of Study Area (Sources: Google)

A. Flood frequency in Navsari City

From the last 34 years of data, it was observed that in the years 1976, 1977, 2002 major flood events have occurred which lead to damage of properties and lives in huge amount. Following Figure 3. shows the year-wise discharge phenomenon in Navsari District.

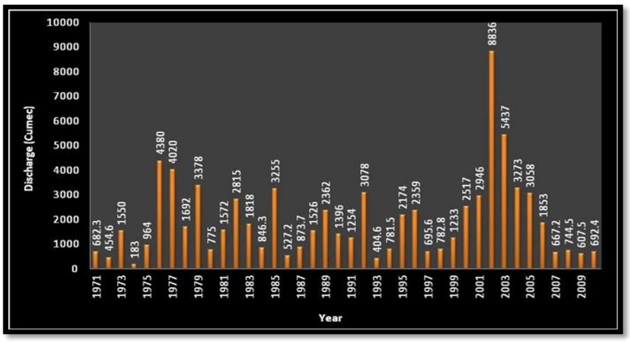

Fig.3. Annual rains in Navsari city from 1971 to 2012

III. MATERIALS AND METHODS

GIS data set like GRD mages and triangular irregular network also survey population dataset. Land use data and Remote sensing technology can be used in GIS. It is very advancement in flood mitigation measures for municipal department [3]. Satellite images are very useful to notice the degree of flood and to minimize the flood events [10]. Dynamic and inactive remote sensing information utilized to decide the stage, release and water surface region of river [21].

Four Advanced Very High-Resolution Radiometer (AVFIRR), National Oceanographic Atmospheric Administration (NOAA) imagery data sets can be used for flood hazard map. Out of four data sets, they took one image for the dry season and three images for flooding season [22]. RADARSAT images can be utilized for cost-effective and significant information on past flood extent [21]. Geometry of river bathymetry and its surrounding area, topography, Light Detection and Ranging (LIDAR) images, hydraulic parameter, Digital Elevation Model (DEM) can be used for flood inundation mapping [24]. Satellite radar images (e.g. Synthetic aperture radar SAR) can be utilized. Out of two imaged, the first image was one month before the flood event took place and another image was taken after three days of the flood, which is very necessary for accurate floodplain mapping under the study area [25]. Geographic Information System (GIS) and Analytical Hierarchy Process (AHP) techniques can be used to identify flood vulnerability and flood risk mapping [27]. Water level and discharge information have been acquired from C.W.C (Central Water Commission), Surat and cross-sections information of Purna River have been gotten from the irrigation department, Navsari region.

A. Arc-GIS software

ArcGIS is a geographical information framework for working with maps and geographic data. It is utilized for making and utilizing maps, accumulating geographic information, investigating mapped data, sharing and finding geographic data, utilizing maps and geographic data in the scope of uses, and managing geographic data in a database [26].

B. HEC-Geo RAS

HEC-GeoRAS is a set of measures, apparatuses, and utilities for preparing geospatial information in ARC-GIS utilizing a graphical interface. The interface permits the readiness of geometric information for bringing into HEC-RAS and procedures simulation results sent out from HEC-RAS [27].

C. HEC-RAS (Hydrologic Engineering Center River Analysis System)

HEC-RAS is a program that representations the hydraulics of water move through common streams and different channels. It is a computer-based program for modeling water moving through frameworks of open channels and calculating water surface profiles. HEC-RAS discovers specific viable application in floodplain mitigation measures [27].

IV. METHODOLOGY

Conceptual diagram of 1 D hydrodynamic flood methodology is shown in Figure 4.

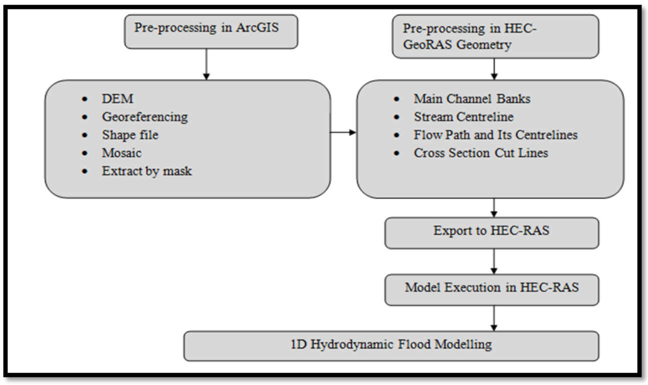

Fig. 4. Conceptual diagram of 1 D hydrodynamic flood

Phase 1- Pre-processing of Data (ARC-GIS & HEC-GeoRAS)
Phase 2- Model Execution (HEC-RAS)

A. Pre-processing (Arc-GIS & HEC-GeoRAS)

Arc-GIS and HEC-GeoRAS programming are utilized for pre-processing of the information for flood mapping. HEC-GeoRAS is an augmentation utilized in Arc-GIS. It is explicitly proposed to process geospatial information that are utilized with the Hydrological Engineering Center River Analysis System (HEC-RAS). It permits the formation of HEC-RAS import record, containing geometric property information from a current digital elevation model (DEM) and correlative informational collections.

DEM (Digital Elevation Model): It is 3 D image of territory surface, ordinarily, of a planet (for example Earth, moon) made from a terrain's elevation data. DEMs are freely available on "bhuvan.nrsc.gov.in" which are in the form of tiles as shown in Figure 5.

Georeferencing: It is the technique assigning three-dimensional directions to information that is spatial in nature. Four point of Georeference are as appeared in Figure 6.

Shapefile: It is a well-known geospatial vector information position for geographic data framework programming. Shapefile of Navsari area and Purna stream are as appeared in Figure 7.

Mosaic: It is a process of merging two or more adjacent DEM image into one entity, so that multiple DEMs can be seen as a single DEM. Mosaic image of all merged DEMs are as shown in Figure 8.

Extract by mask: It is an ArcGIS geoprocessing tool that *extracts* the cells of a raster corresponding to the area defined by a *mask*, which gives the results of Navsari district and Purna River with DEM image as shown in Figure 9. The red color indicates the higher elevation and blue color indicates the lower elevation. **(Source: Arc GIS Desktop).**

Above five steps are pre-processing steps which have been used in Arc GIS environment with proper methodology, in order to apply HEC-GeoRAS geometry in Arc GIS environment.

Fig.5. DEM images

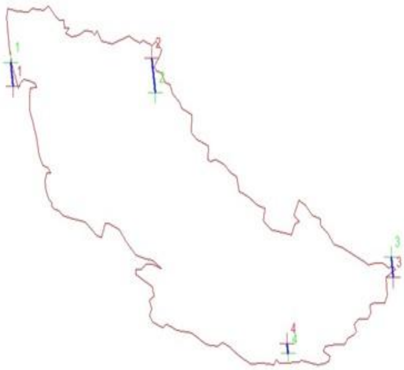

Fig.6. Georeferencing

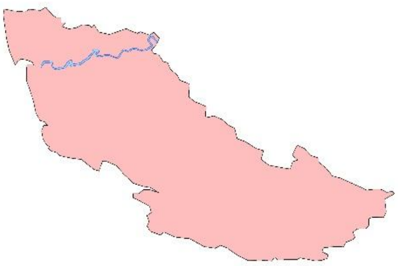

Fig.7. Shapefile

Fig.8. Mosaic

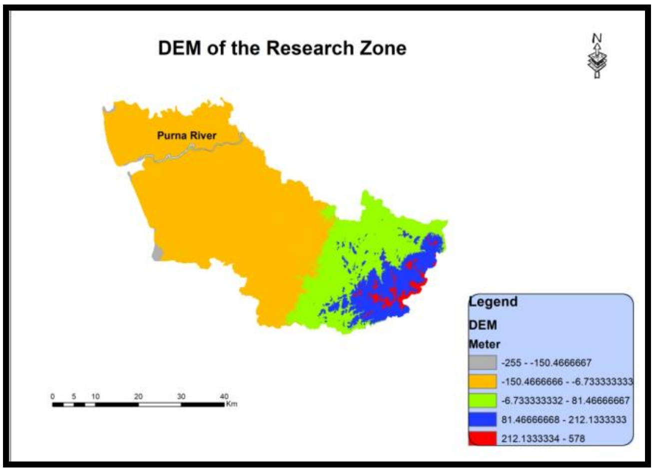

Fig.9. DEM of the Research zone

B. Pre-processing of data in HEC Geo-RAS

RAS Geometry is an information document setup in the HEC-GeoRAS condition, which have been utilized for geometric information development and extraction of the floodway waterway catchment. There are two major themes of classifying geometric data available which are namely polygonal theme and line theme. In this paper, only line themes are of our interest, and the Line themes that have been created for the study area are as follows.

Main Channel Banks: Main channel banks are utilized to separate the primary stream from the left bank or right bank of the floodplain territories inside which the stream is contained. Stream Centerline: The river is characterized by the stream centerline theme.

Flow Path and Its Centerlines: Stream way has been made toward stream from upstream to downstream.

Cross Section Cut Lines: The cross segments taken are opposite to the direction of the stream. While the cut lines portray the planar position of the cross-section, the rise station information has been separated along the cut line from the Digital Elevation Model.

As Figure.10 demonstrates the color notation of theme in which blue color indicates the 'Stream centerline', red color indicates the 'main channel bank' and yellow color indicates the 'flow path' of Purna river from upstream to downstream. Moreover, cross-section cut lines and RAS Geometry are as shown in Fig.11. Finally, Geometry data is exported from ARC-GIS to HEC-RAS for model execution.

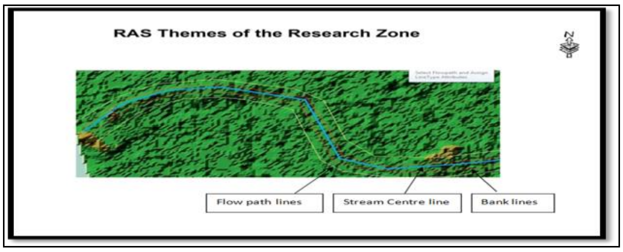

Fig. 10: RAS themes

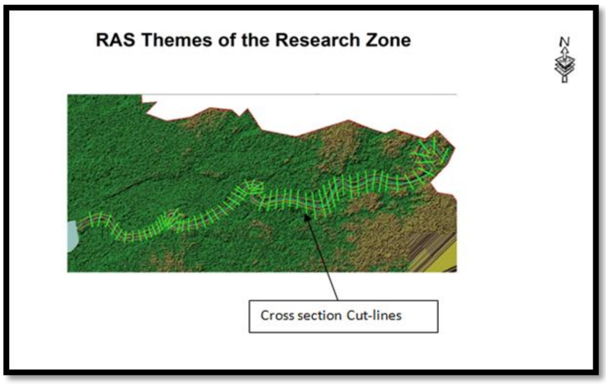

Fig. 11: RAS Geometry in Arc-GIS

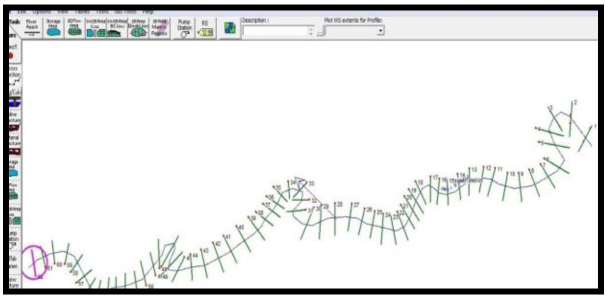

Fig. 12: GIS data file in HEC-RAS

V. MODEL EXECUTION IN HEC-RAS

In this stage, the geometry which has been made in ArcGIS is import into HEC-RAS environment through geometric data editor as shown in Figure.12.

HEC-RAS will directly give the section elevation data, but we have to add Manning's values (Roughness coefficient was obtained using the table of Chow's roughness coefficients according to bed material of river reach) for the left bank and right bank as per observed data as shown in Figure13,14.

Thereafter, from the steady flow data editor, apply two profiles say for a 50-year return period, the maximum discharge is 11500 m^3/sec and for a 100-year return period, the maximum discharge is 12800 m^3/sec as per observed data. Moreover, apply boundary conditions in which for steady flow we have to provide 'Normal depth' as slope of a value 0.001913. Finally, run the model after applying all the necessary data.

Here we have taken a total of 62 cross sections from upstream to downstream of Purna river. Moreover, we have simulated the cross sections which are more affected by flood during peak discharge.

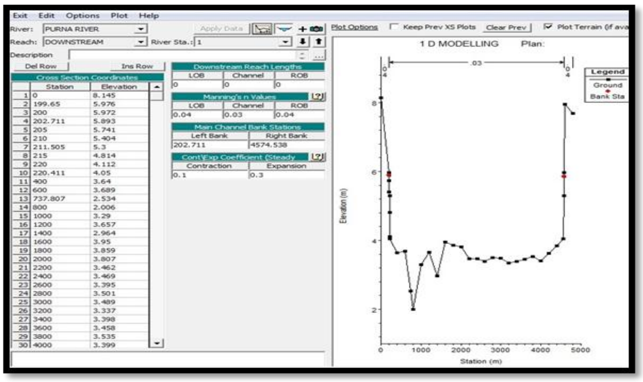

Fig. 13: Cross section-1 Geometric data editor window

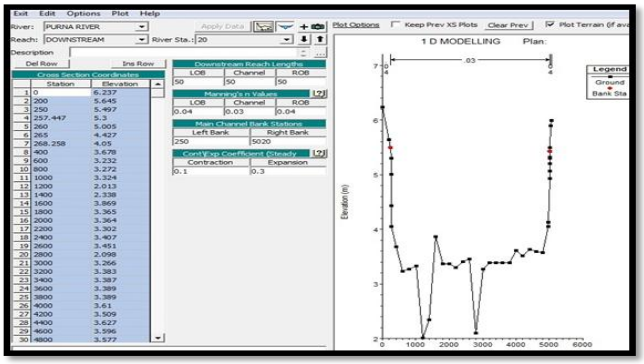

Fig. 14: Cross section-20 Geometric data editor window

VI. RESULTS OUTCOMES AND DISCUSSION

After running the model, HEC-RAS will give the results for both plans say 50 and 100-year return period in the form of water surface elevation as shown Figure.15, 16, 17 and 18, in which we observed that cross-section-1 is affected by flooding for 100-year return period but not affected for 50-year return period, for cross-section-2, the right bank is affected by flooding for 100 year and 50 year return period but the left bank is unaffected for both return periods. Cross-section-19 and cross-section-20 are affected by flooding for both 50-year and 100-year return periods.

Here we have taken cross sections for model execution which are likely to be flooded during peak discharge. Figure.19 shows the general profile plot of 50-year and 100-year return period plans which indicate the elevation of water surface along the length of the river.

Figure.20 and Figure.21 show the XYZ-perspective view of 50-year and 100-year return period plan in which we see that cross sections 17, 18, 19, 20 are more affected by flooding during high discharge. Table 1. Shows the classification of cross sections which are experiencing flooding during high discharge.

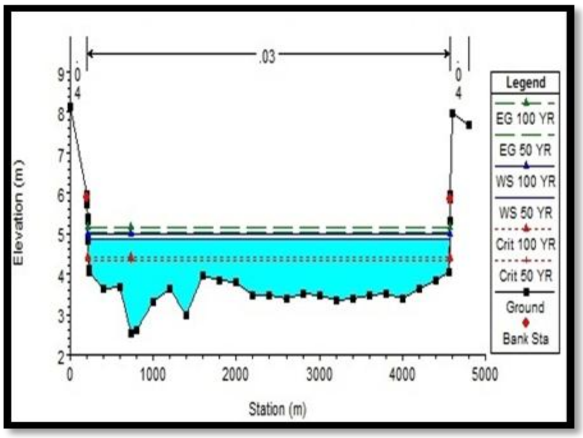

Fig.15: Water surface profile at C/S-1

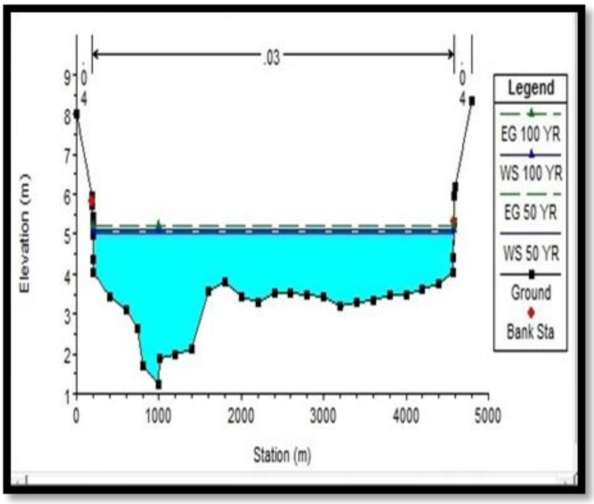

Fig.16: Water surface profile at C/S-2

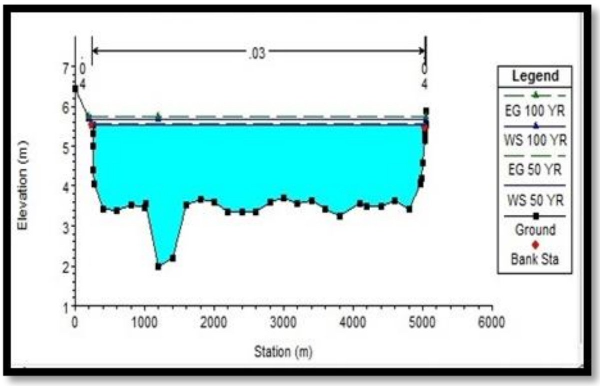

Fig.17: Water surface profile C/S-19

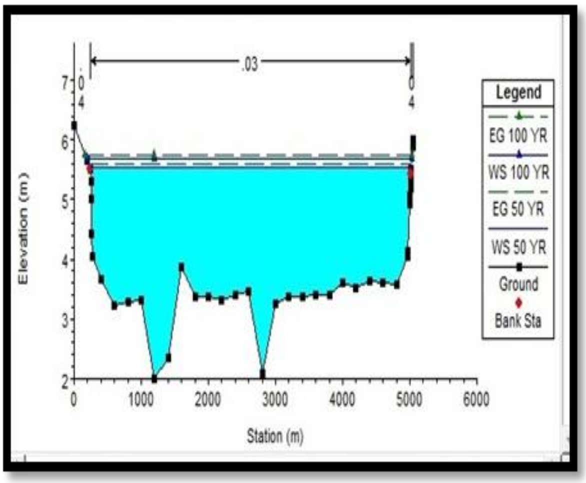

Fig.18: Water surface profile C/S-20

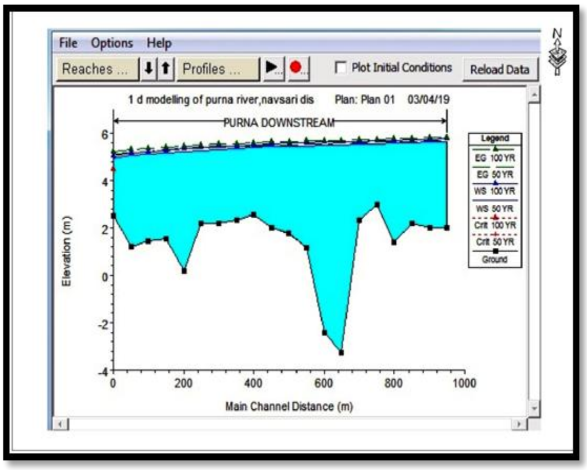

Fig.19: General profile plot

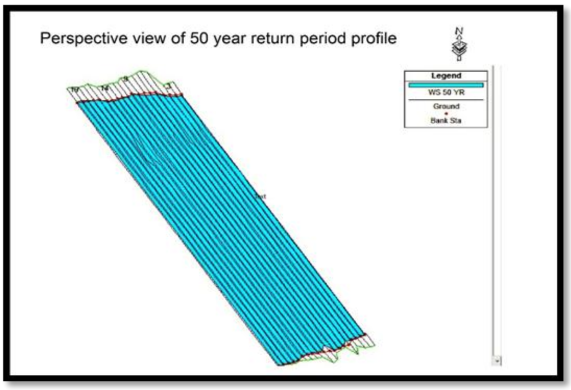

Fig.20: XYZ-perspective plot-50-year return period

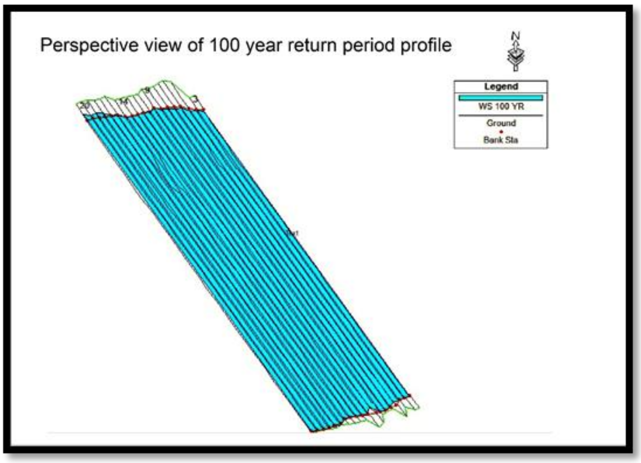

Fig.21: XYZ-perspective plot-100-year return period

Table 1. Classification of cross-sections affected by Peak Discharge

Less Affected during High discharge	Moderate Affected during High discharge	More affected during High discharge

CS-1, CS-2, CS-3, CS-10, CS-11, CS-12, CS-13	CS-8, CS-9, CS-4, CS-5, CS-6, CS-7	CS-17, CS-18, CS-19, CS-20

VII. CONCLUSION

The research examines the utility of the combination of ArcGIS and HEC-RAS software in the quantification of flooding at different cross sections which are likely to be flooded. This developed model can be used to forecast water level from Supa to Machhad village with peak discharge during flooding. Study of a flooding event in the years 1976, 1977 and 2002 have been done to measure inundation of the study area. It is strongly recommended to implement river training and riverbank protection works for Purna river by taking into consideration the past flood events at certain points along the river which would be advantageous to mitigate the flood in the surrounding regions of Navsari city, effectively and economically. The result from the scenarios indicate that cross sections 17 through 20 are affected by flood during high discharge. As per the above study, after model execution, it is apparent that future works lies in construction of embankment or raise existing wall at the cross-sections at which there are chances of water overtopping at higher discharges.

Moreover, flood map, risk map of the study area can be prepared in Arc GIS environment.

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