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ARTICLE OF PROFESSIONAL INTEREST

Flood Management in Mahanadi Basin using HEC-RAS and Gumbel's Extreme Value Distribution

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Abstract Using Gumbel's extreme value distribution and HEC-RAS hydrodynamic model, the levels of peak floods at different locations of Mahanadi River reach between Hirakud dam and Naraj (delta head of Mahanadi) for 10, 25, 50 and 100 years return period are estimated. Based on the simulation study carried out considering 36 cross sections for 310 km length of river, it is observed that the heightening of embankment system for almost all the existing bank stations both in the left and right embankments are required. In the present study, the analysis has been carried out considering 25 years return period floods (45067 cumecs), as this flood is considered as most significant and under changed climatic conditions. The results of the study show that out 36 cross sections, at 23 sections, heightening of embankment spanning from a minimum of 0.11 m to a maximum of 10.63 m in the left bank should be carried out. Similarly for right bank embankment heightening is needed from 0.09 m to a maximum of 9.94 m. This can very effectively minimize the flood hazard of the Mahanadi River system.

Keywords Hydrodynamic model · HEC-RAS · Gumbel's distribution · Flood management · Mahanadi River · Inundation depth

Introduction

Floods are the most common natural phenomenon due to relatively higher flows and unwanted higher stages of a river that temporarily submerges the land and habitation endangering both life and properties. The devastating floods not only result in loss of precious human lives, cattle and damage to public and private property resulting in huge economic losses, but also create a sense of insecurity and fear in the minds of people living in the flood plains. Emergency Events Database (EM-DAT) maintained by the Centre of Research on the Epidemiology of Disasters at Brussels (CRED) reported that in the last decade of the twentieth century floods have taken the lives of about 1 lakh and affected over 1.4 billion people [1]. So, for minimizing the losses due to floods, proper sustainable scientific flood management strategy needs to be adopted [2]. It is again important to mention that the return period of major floods which was 100 years earlier, may now start to happen in every 20–30 years due changed climatic scenario. The flood season may become longer and there will be flooding in the places where there were no floods earlier. So, risk of flooding looks greater than ever all over the world.

Flood inundation models play a central role in both real time flood forecasting and in flood plain mapping. All flood inundation model work with discharge and water level as upstream, downstream or as internal boundary conditions. Large numbers of works have been reported in literature to model flood in Mahanadi River [3–6] which helps flood management experts and water resources engineers to develop suitable flood management strategy to reduce the havoc of flood in the deltaic regions. However, suitable structural measures in the form of embankment heightening and channel modification to reduce losses due to floods by way of flood mitigation are not available in literature.

In view of the above, the present study attempts to develop a hydrodynamic model to suggest suitable structural measures by way of channel and embankment

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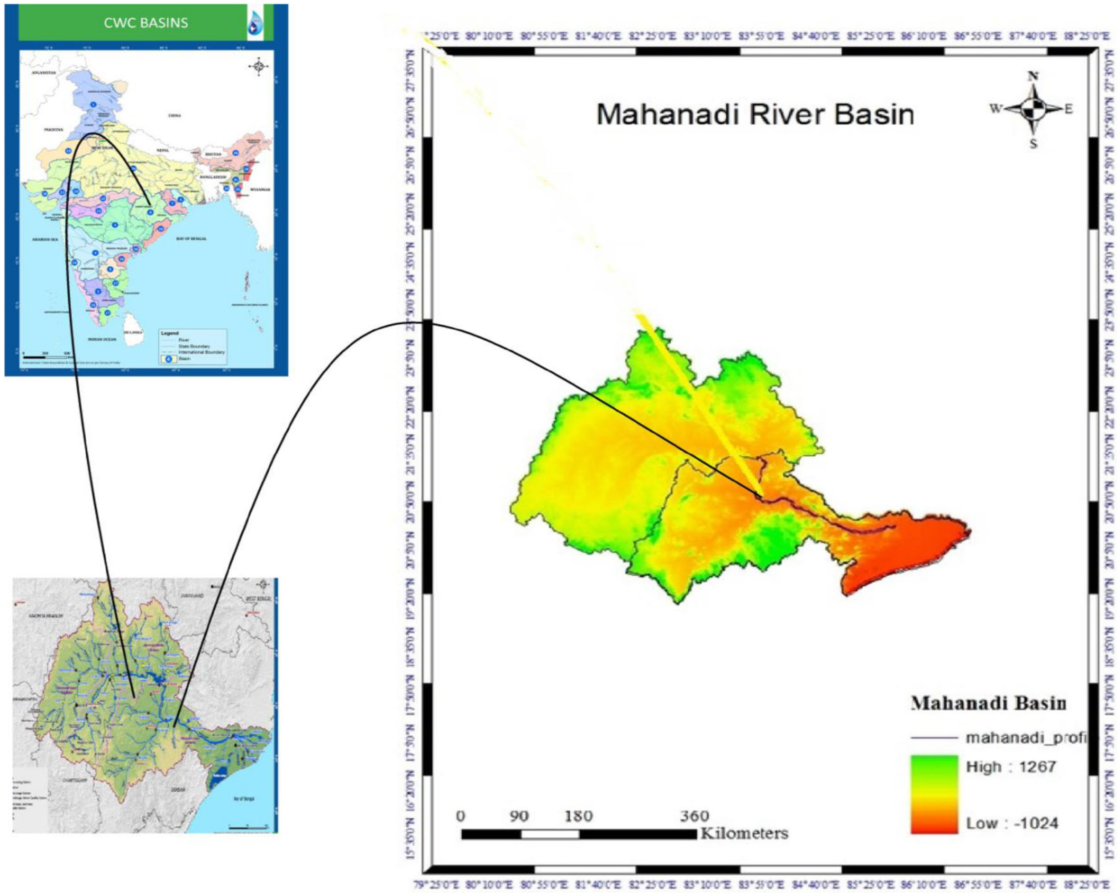

Fig. 1 Detailed location of the study area

improvements using HEC-RAS for the Mahanadi River in Odisha, India for various return periods using Gumbel's extreme value distribution.

Materials and Methods

Study Area

The Mahanadi River basin is the 8th largest basin and a major river of east central India, having total catchment area of 141,589 km^2 which is nearly 4.28% of the total geographical area of the country. The Mahanadi basin extends over states of Chhattisgarh and Odisha and relatively smaller portions of Jharkhand, Maharashtra and Madhya Pradesh. The geographical extent of the basin lies between 80°28′ and 86°43′ east longitudes and 19°8′ and 23°32′ north latitudes. In the present study the river comprised of 310 km long from Hirakud Dam to the Naraj Gauging site, near Railway Bridge covering an area of 48,700 km^2. In the present study for computation of return period of flood, 35 years data have been used. Hence the present study combines the statistical technique (Gumbel Distribution), Arc-GIS, Hydraulic Modeling (using HEC-RAS) to assess the risk and hazard of flooding in Mahanadi River in Orissa, India. Figure 1 shows the location of the study area in the Mahanadi River Basin.

Flood Frequency Analysis

Frequency analysis is used to predict how often certain values of a variable phenomenon may occur and to assess their liability of the prediction of an event. The frequency analysis is commonly used to predict the reoccurrence interval or the return period of a hydrological event or water resource applications. The calculation of 'T' years flood peak discharge is used to indicate the estimation of flood peak magnitude with a return period of T-years or flood magnitude observed once in every T-years on average. The most commonly used extreme value distribution method includes the Gumbel's distribution which was first introduced by Gumbel [7] and is one of the most widely used extreme value distribution functions for the prediction of flood peaks, maximum rainfalls, maximum wind speed, etc. In the present study Gumbel's extreme value distribution function is used to estimate the peak floods for

Table 1 Estimated peak discharge of Mahanadi River for various return periods using Gumbel's method

Return period (T years)	Peak flood discharge in (m^3/s)
10	37,535.03
25	45,067.45
50	50,656.19
100	56,203.24

return periods of 10, 25, 50 and 100 years for Mahanadi River. For the present study, 35 years data have been used to compute the flood frequency analysis as well as for the computation of the return periods of floods. Table 1 shows the predicted values of the peak flood discharges of Mahanadi River using Gumbel's method.

HEC-RAS Model

HEC-RAS is a hydraulic model developed by the Hydrologic Engineering Center (HEC) of the U.S. Army Corps of Engineers, which is capable of modeling sub-critical, super-critical, and mixed-flow regimes for streams consisting of a full network of channels [8]. This is a hydrodynamic model and can be used for the determination of water surface profiles for different flow scenarios. In the present study the River Analysis System (RAS) layers representing the cross-sections and other data that describe the river and its surrounding terrain are used. This helps to determine the water surface layers corresponding to floods of different return periods (10, 25, 50 and 100 years), which in turn suggests the needs of heightening the embankment or improvement in the channel sections under different flooding conditions.

Results and Discussion

Unsteady Flow Simulation

Unsteady flow simulation was carried out using HEC-RAS [8] for 310 km lengths of Mahanadi lower reach starting from downstream of Hirakud Dam to Naraj gauging station taking 36 cross-sections. The total relief under the study reach was found to be 144.55 m, which causes very high velocity of flow towards the downstream reaches, leading to a great damage to the embankment systems. The simulation was also carried out for floods of return periods 10, 25, 50 and 100 years. For the purpose of simulation of HEC-RAS model for Mahanadi River, the flood hydrograph of the year 2008 was incorporated as upstream boundary condition and normal depth has been considered as downstream boundary condition.

The simulation results show that the water surface profile computed at 310 km (just at the downstream of Hirakud Dam) for 10, 25, 50 and 100 years return period

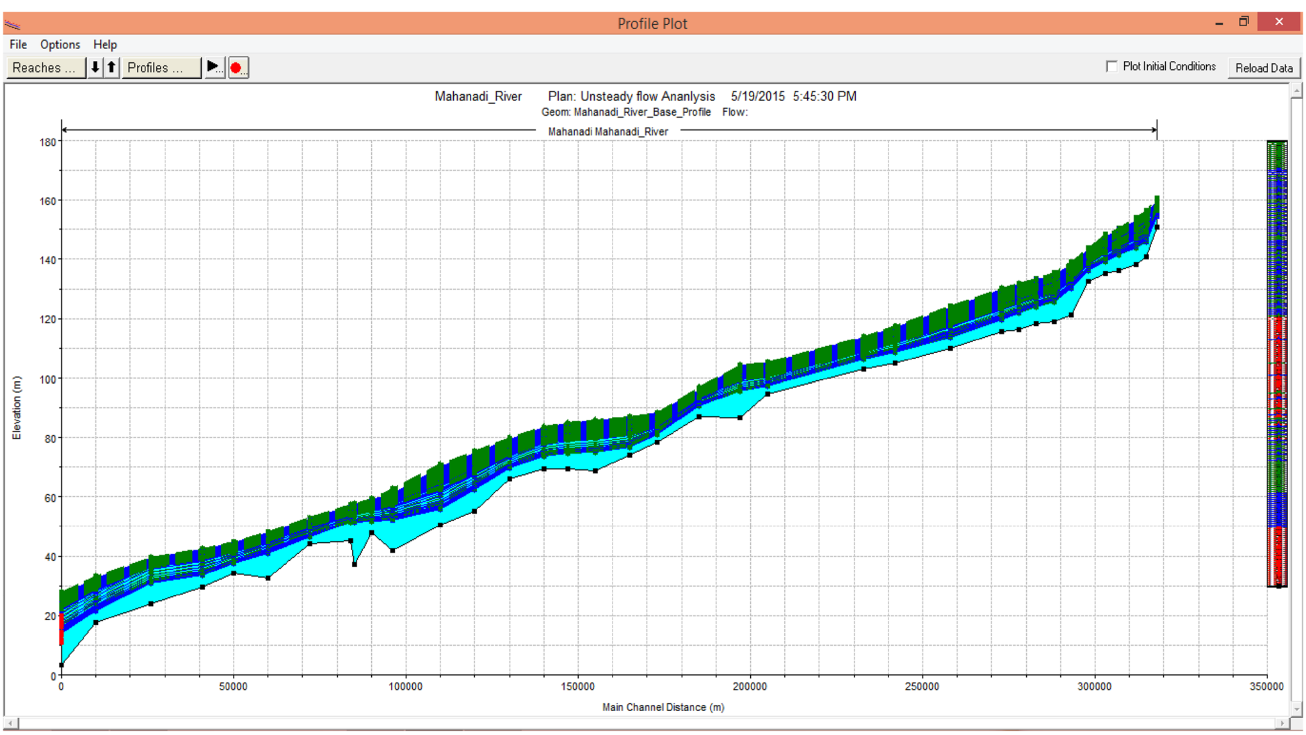

Fig. 2 Water surface profile of Mahanadi for 25 years return period flood under unsteady flow conditions

respectively indicates the water surfaces as 158.07, 159.55, 160.01 and 160.74 m. Accordingly the water surfaces corresponding to different sections of the river may also be computed. However, the simulation for flood having return period of 25 years has been analyzed in details in the present study for the Mahanadi system, as with changed climatic conditions, it is the most important return period. Accordingly, the water surface profile computed shows that it varies from reduced level (RL) of 159.55 m at downstream of Hirakud dam to a RL of 27.56 m at Naraj, the head of delta. Figure 2 shows the water surface profile in the complete channel length of 310 km under unsteady flow conditions of 25 years return period. Further, Table 2 shows the water surface elevation under unsteady flow condition of 25 years return period and top of left and right bank elevation of the Mahanadi River. It is clear from Table 2 that a maximum of 10.63 m in left bank (at 200 m downstream from Hirakud dam) and 9.94 m in right bank

Table 2 Water surface elevation of left and right bank under unsteady flow condition

River reach	River station (km)	Max. WS elevation (m)	Existing left bank RL (m)	WS above left bank (m)	Existing right bank RL (m)	WS above right bank (m)
Mahanadi lower	310	159.55	160.83	− 1.28	161.53	− 1.98
	307	155.78	153.44	2.34	155.43	0.35
	304	153.78	164.03	− 10.25	155.70	1.92
	299	153.02	143.48	9.54	147.65	5.37
	295	147.84	142.80	5.04	137.90	9.94
	290	143.20	140.33	2.87	139.53	3.67
	285	138.20	136.54	1.66	135.96	2.24
	280	134.82	133.62	1.2	127.32	7.5
	275	133.47	130.90	2.57	134.96	1.49
	270	131.90	131.76	0.14	134.21	2.31
	265	130.22	129.61	0.61	131.59	1.37
	250	123.87	123.76	0.11	123.78	0.09
	234	117.72	117.92	− 0.7	107.9	9.32
	225	112.88	111.64	1.24	112.68	0.2
	205	105.1	106.58	− 1.48	104.13	0.97
	197	104.16	97.21	6.95	98.00	0.61
	185	96.24	94.71	1.53	93.68	2.56
	173	88.76	87.59	1.17	84.39	4.37
	165	87.47	80.32	7.15	82.98	4.49
	155	86.29	83.50	2.79	83.36	2.94
	147	85.36	80.98	4.38	80.73	4.63
	140	84.03	78.18	5.85	78.04	5.99
	130	80.06	76.98	3.08	77.03	3.03
	120	94.90	76.14	− 1.24	74.50	0.4
	110	70.36	59.73	10.63	73.26	− 2.9
	96	61.29	59.73	1.56	63.96	2.67
	90	59.16	97.45	− 3.82	101.8	− 4.62
	85	57.67	95.97	− 3.85	98.76	− 4.10
	80	57.29	96.14	− 1.54	97.85	− 4.05
	72	52.78	67.32	0.48	65.63	− 1.28
	60	47.92	47.44	1.83	49.1	− 0.21
	50	44.8	42.98	1.62	45.01	− 1.18
	41	42.78	44.91	− 2.13	44.22	− 1.44
	26	39.93	39.93	0	40.32	− 0.39
	10	33.28	33.92	− 0.63	26.32	− 3.39
	0	27.56	27.63	− 0.07		1.24

River station 310 m and 0 respectively represents downstream of dam and Naraj (head of delta of Mahanadi River) (at 15 m downstream from Hirakud dam) raising of existing embankment system is needed to prevent floods to inundate the adjoining area. It is also found from the simulation result that out of 36 stations, at 23 stations, embankment raising spanning from a minimum of 0.11 m to a maximum of 10.63 m in the left bank of river is needed. For right bank embankment, heightening of embankment is required at 20 stations from a minimum of 0.09 m to a maximum of 9.94 m.

The above results show that the existing embankments system on the left and right banks of the Mahanadi River is not sufficient to resist the floods of 25 years return period i.e. 45067.45 cumecs. Hence HEC-RAS model for estimation of flood magnitude and corresponding water surface profile shows that a maximum of 10.63 m in left bank (at 200 m downstream from Hirakud dam) and 9.94 m in right bank (at 15 m downstream from Hirakud dam) is needed to protect the inundation of the low laying areas of Mahanadi delta.

Conclusions

Following conclusions have been derived from the present study

1. Mahanadi River flow simulated under unsteady flow conditions show that the embankment system needs heightening for almost all the existing bank stations both at left and right embankments
2. In left bank, at 200 m downstream from Hirakud dam, maximum raising of 10.63 m and in right bank, at 15 m downstream from Hirakud dam, maximum raising of 9.94 m of embankment is needed as a structural measures to mitigate floods
3. It is also observed that out of 36 stations, at 23 stations, spanning from a minimum of 0.11 m to a maximum of 10.63 m in the left bank and at 20 stations from a minimum of 0.09 m to a maximum of 9.94 m in the right bank, embankment raising is required. This shows that left bank area is more vulnerable to the flood as compared to right bank.
4. As an alternative to mitigate floods channel clearance may be taken up to reduce the havoc of floods in the deltaic regions of Mahanadi River.

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