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Dam Break Analysis of Khadakwasla Dam by Using HEC-RAS

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Abstract: ***A dam is a structure constructed across river which stores water and supplies water for various purposes. Though the dams have many benefits, there is always a threat of dam break floods which are devastating in nature. Hence, it becomes essential to analyze and simulate dam failure scenarios to understand the severity of dam break flood and identify areas under threat which helps in land use planning and developing emergency response plans. This study attempts to carry out dam break/breach analysis for the Khadakwasla dam using a one-dimensional hydraulic model called Hydraulic Engineering Center's River Analysis System (HEC-RAS). HEC-RAS tool is utilized to determine the breach outflow hydrograph and hydraulic conditions at critical downstream locations. Further, the breach outflow hydrographs are routed using dynamic flood wave routing. Further, HEC-RAS model is simulated for breach parameters derived from five different empirical methods, and the results are compared.***

Keywords: ***HEC-RAS, Khadakwasla Dam, Dam Break, Digital Elevation Model (DEM), Flood Inundation Mapping, 1-D Modelling***

I. INTRODUCTION

Dams are man-made or artificial barriers usually constructed across a stream channel to impound water. Dams are typically provided with spillway systems to safely pass a broad range of flows over, around or through the dam. A dam failure or dam burst is a catastrophic type of structural failure characterized by the sudden, rapid, and uncontrolled release of impounded water or the likelihood of such an uncontrolled release. Between the years 2000 and 2009 more than 200 notable dam failures happened worldwide. Dam failures can range from fairly minor to catastrophic, and can possibly harm human life and property downstream from the failure. Dam failures can be extremely harmful, especially because dams are considered "installations containing dangerous forces" under International Humanitarian law. This is because of the immense destruction that can occur with a dam breach. Throughout history, a large number of dam failures have caused immense property damage when floodwaters destroy infrastructure. In addition, ecosystems and habitats are destroyed as a result of waters flooding them. Along with this, dam failures over the years have taken thousands of lives. The older that dams get, the more potential exists for catastrophic dam failures.

The Khadakwasla Dam is a critical infrastructure component serving the city of Pune. A dam break scenario, though unlikely, could have catastrophic consequences. This project aims to utilize HEC-RAS software to simulate a dam break event at Khadakwasla dam and assess the potential downstream impacts. This project will provide valuable insights into the potential consequences of a dam break at Khadakwasla Dam.

The results can be used for:

1) Emergency planning and preparedness for dam safety.
2) Identifying vulnerable areas downstream and prioritizing mitigation strategies.
3) Informing evacuation plans and public awareness campaigns.
4) Guiding future dam safety assessments and potential dam improvement works.

By analyzing a hypothetical dam break scenario, this project aims to contribute to the safety and well-being of downstream communities.

II. LITERATURE REVIEW

Several research papers were reviewed to study how the HEC-RAS can be used for its applications. Reviewing papers helped in determining and limitation and the scope of the study. In literature study, the results forecasted in the research papers were also compared with the real incidents that had happened in recent years, ascertaining the accuracy of the software. The results in research paper on Dam Break Analysis of Khadakwasla dam using HEC RAS found matching to recent reports of C.W.P.R.S. shared to us.

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III. METHODOLOGY

The two primary tasks in the analysis of Dam Break Studies are the prediction of the dam break flood hydrograph and the routing of that hydrograph through the downstream valley. Predicting the outflow hydrograph can be further subdivided into predicting the breach characteristics (e.g., shape, depth, width, rate of breach formation) and routing the reservoir storage and inflow through the breach. The routing tasks through the breach and through the downstream valley are handled in most of the widely used computer models with various one-dimensional routing methods. However, the programs differ widely in their treatment of the breach simulation process. Many models do not directly simulate the breach; rather, the user determines the breach characteristics independently and provides that information as input to the routing model. Following methodology has been adopted in the present study:

1) Study and understand the problem, review information about dam operation and other details.
2) Review of salient features of all the four dams in the Mutha River System i.e., Khadakwasla dam.
3) Estimation of breach parametersDam Break Analysis and flood routing with dam at FRL (Level Pool Routing) impinched over and above full reservoir levels of dam using 1-Dimensional mathematical model.
4) Estimation of inundation levels at different locations at downstream of dams for different scenarios of breaching using estimated water surface profile.
5) Preparation of inundation map which can be used for preparation of Emergency Action Plan.

A. Dam Break Analysis of Khadakwasla Dam:

Khadakwasla dam was constructed on River Mutha in the year 1880. It is a gravity dam with capacity of 86 Mm it was partially breached in the year 1961 to form safe passage for flood generated due to breaching of Panshet dam. The breached part was reconstructed in the year 1973 Ogee spillway with 11 numbers of radial gates is provided for the outflow discharge on the left side of the dam. The breaching section with earthen material is also constructed next to spillway unit on the left side of the dam for providing safe passage to floods without damaging dam structure under emergency situations. Dam Break study for Khadakwasla dam was carried out by developing 1-D mathematical model using HEC-RAS under level pool scenario. The breaching of earthen part of the dam due to overtopping was considered for the studies. The routing of dam break flood was carried out through the downstream reach of river Mutha upto the Navi Peth. The breach parameters for the present study were estimated as per the guidelines given in the manual of HEC-RAS for Dam Break Analysis. The details of the breach parameters considered are mentioned in the table 1.

Table 1. Breach Parameters for Khadakwasla Dam

Sr. No.	Breach Parameters	
1	Center station	975 m
2	Bottom width	960 m
3	Bottom elevation	568 m
4	Left side slope	1
5	Right side slope	1
6	Breach weir coefficient	1.44
7	Breach formation time	0.1 hour
8	Failure mode	Overtopping
9	Trigger failure at	W. S. elevation at FRL 582.47 m

DEM of the study area was validated with reference to the deepest bed level at dam site mentioned in the salient features of the Khadakwasla dam. The total reach of River Mutha of length 12 km was considered for the Dam Break studies. The total 20 cross sections for the study reach or River Mutha were extracted from DEM using HEC-RAS software and extended beyond their natural banks for demarcation of flood inundation area. The details of the cross sections of River Mutha with their respective chainages are stated in table 2.

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Table 2. Location Details of Cross Sections for Khadakwasla Dam Break

Sr. No.	Cross section (m)	Chainage from dam (m)	Sr. No.	Cross section (m)	Chainage from dam (m)
1	12698	110	11	6379	6424.5
2	11450	1348.6	12	5935	6869.5
3	10958	1840.2	13	5541	7199.3
4	10452	2345.6	14	4862	7877.2
5	10013	2784.2	15	4092	8648.7
6	9574	3222.3	16	3430	9312.6
7	8767	4033.3	17	2828	9915.8
8	8108	4694	18	2108	10634.4
9	7539	5260.4	19	1338	11402.7
10	6955	5848.2	20	780	11962.8

1D mathematical model was developed using HEC-RAS software for study reaces of River Mutha. The details for the inline structure and reservoir were extracted from the salient features (Annexure I) and AEC curve (Annexure V) supplied by the project authority. The schematic of Khadakwasla dam and downstream reach of River Mutha as shown in figure 1.

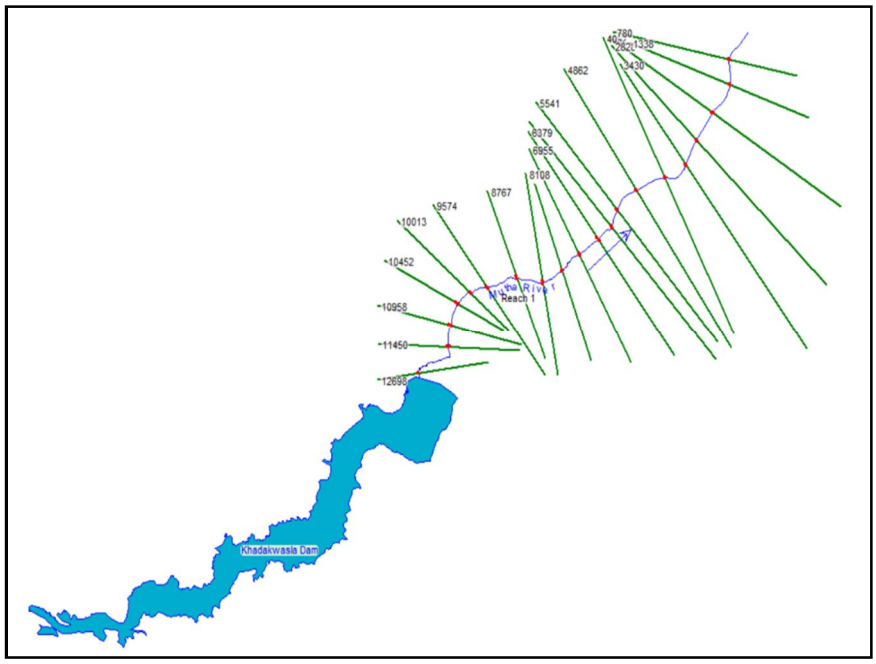


Fig. 1. Schematic of Downstream Reach of River Mutha

B. Mathematical Model Studies for Khadakwasla Dam:

Mathematical model runs were carried out for study reach of River Mutha under the scenario as mentioned in previous section. Khadakwasla dam was assumed to be breached due to overtopping as it is a gravity dam. In this study, the flow contribution of river Mutha was estimated using salient features of Panshet dam and Warasgaon dam and it was added as point discharge on the upstream cross section of river Mutha.

The preliminary model runs were carried out for all scenarios with time to breach of 1 hour. A rectangular breach shape with bottom width 960 m and breach bottom elevation RL 568 m was considered for Dam Break simulation under all scenarios as per the HEC-RAS manual. A uniform initial flow has been assumed at all cross sections for initiation of model run. The details of the breach section considered for Khadakwasla dam is shown in figure 2.

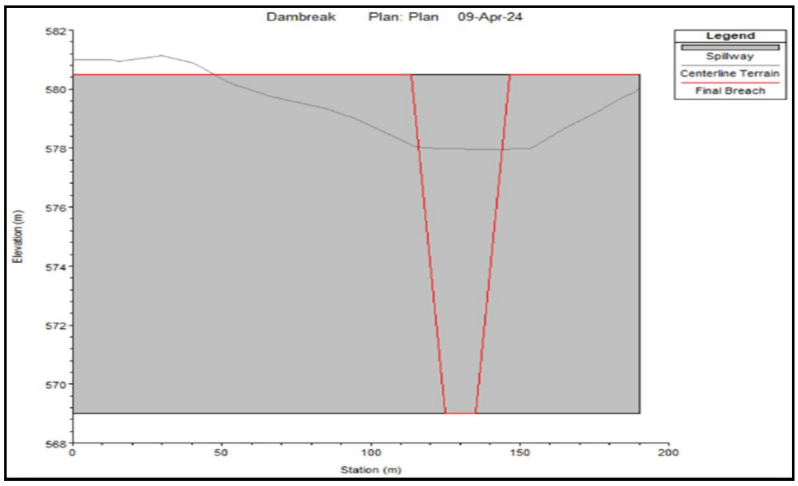


Fig. 2. Breaching Section for Khadakwasla Dam

A uniform initial flow has been assumed at all cross sections for initiation of model run. Dam break flood hydrograph for each run was estimated. The maximum peak value of dam break flood hydrograph had noticed for dam break simulation carried out for the breach time 1 hour. The water surface profile, velocity curve, flow curve, rating curve and volume curve for the Dam Break simulation carried out with breaching time 1 hour was estimated.

IV. RESULTS OF ANALYSIS

A. Analysis of Results:

The details of study results estimated under the normal pool scenario are presented in table 3., table 4. and table 5. The following table 3. shows the flow area in m^2 and top width of spreaded water to the upstream side of the dam to the LOB, channel and ROB of the river Mutha.

Table 3. Details of Flow Area and Top Width for Khadakwasla Dam Break

River	River Station	Chainage from dam (m)	Flow Area (m^2)			Top width (m)		
			LOB	Channel	ROB	LOB	Channel	ROB
Mutha	12698	110	2687.75	72.61	20529.77	341.41	6.30	1479.75
	11450	1348.6	11055.31	1608.14	8545.38	878.63	61.40	920.90
	10958	1840.2	10284.58	1315.71	12228.17	1025.78	53.50	1485.14
	10452	2345.6	10467.79	1961.83	15043.06	1086.36	76.70	1264.70
	10013	2784.2	11118.91	1011.76	15899.78	925.58	37.20	1231.50
	9574	3222.3	12157.82	1354.11	17362.25	914.64	52.60	1410.37
	8767	4033.3	14457.94	1607.85	14715.10	1289.81	66.00	1290.04
	8108	4694	19967.25	1222.99	11554.81	1187.32	52.60	951.47
	7539	5260.4	16473.84	751.96	15254.29	1148.94	29.50	1488.70
	6955	5848.2	5591.13	1461.23	18461.57	342.64	48.20	1556.41
	6379	6424.5	6309.79	2069.14	8905.59	707.14	86.60	1064.39
	5935	6869.5	18771.84	782.67	12143.37	1874.61	32.00	1271.88
	5541	7199.3	16855.06	812.80	11868.82	1494.67	31.20	1276.23
	4862	7877.2	9613.29	808.65	14979.28	881.34	29.50	1431.69
	4092	8648.7	16622.71	785.76	13240.57	1865.66	30.00	828.30
	3430	9312.6	19792.29	1009.44	6649.72	2414.57	33.10	785.61

	2828	9915.8	14891.99	742.00	3043.50	1992.71	32.80	247.95
	2108	10634.4	15559.41	867.57	7976.98	1512.93	33.90	679.42
	1338	11402.7	13253.20	939.00	6932.73	1136.38	38.00	696.79
	780	11962.8	7353.60	854.72	11624.38	800.63	32.10	1478.89

The following table 4. shows the velocity, velocity head and average velocity to the LOB, at channel and to the ROB with respect to the cross sections of the river Mutha. The maximum velocity to be experienced was of 4.05 m/s at the cross-section of 6379.

Table 4. Details of Velocity, Velocity Head and Average Velocity for Khadakwasla Dam Break

River	River Station	Chainage from dam (m)	Velocity (m/s)	Velocity head (m)	Average Velocity (m/s)		
					LOB	Channel	ROB
Mutha	12698	110	3.01	0.48	2.03	4.48	3.13
	11450	1348.6	3.30	1.05	3.01	8.43	2.70
	10958	1840.2	2.94	0.81	2.59	8.09	2.67
	10452	2345.6	2.55	0.64	2.05	6.72	2.35
	10013	2784.2	2.50	0.47	2.31	6.66	2.36
	9574	3222.3	2.27	0.39	2.19	5.74	2.05
	8767	4033.3	2.27	0.43	2.05	5.90	2.09
	8108	4694	2.14	0.29	2.20	4.67	1.77
	7539	5260.4	2.16	0.32	2.29	5.75	1.83
	6955	5848.2	2.74	0.71	2.87	7.46	2.33
	6379	6424.5	4.05	1.79	3.43	9.75	3.17
	5935	6869.5	2.21	0.36	2.19	6.34	1.98
	5541	7199.3	2.37	0.44	2.33	6.98	2.11
	4862	7877.2	2.76	0.56	2.35	7.44	2.76
	4092	8648.7	2.28	0.36	1.93	5.98	2.51
	3430	9312.6	2.55	0.76	2.16	8.90	2.73
	2828	9915.8	3.75	1.38	3.22	11.51	4.45
	2108	10634.4	2.87	0.67	2.59	8.16	2.83
	1338	11402.7	3.31	0.91	3.16	8.94	2.84
	780	11962.8	3.53	1.37	3.45	11.39	3.00

The following table 5. shows the water surface elevation, maximum channel depth and water depths at banks to the LOB, at channel and to the ROB with respect to the cross sections of the river Mutha.

Table 5. Details of Water Surface Elevation, Maximum channel depth and Water Depth for Khadakwasla Dam Break

River	River Station	Chainage from dam (m)	Water Surface elevation (m)	Max channel depth (m)	Water depth at banks (m)		
					LOB	Channel	ROB
Mutha	12698	110	583.25	25.66	7.87	11.53	13.87
	11450	1348.6	581.42	27.77	12.58	26.19	9.28
	10958	1840.2	581.03	26.65	10.03	24.59	8.23
	10452	2345.6	580.70	27.59	9.64	25.58	11.89

	10013	2784.2	580.53	27.40	12.01	27.20	12.91
	9574	3222.3	580.32	26.27	13.29	25.74	12.31
	8767	4033.3	579.83	26.79	11.21	24.36	11.41
	8108	4694	579.61	27.29	16.82	23.25	12.14
	7539	5260.4	579.32	29.31	14.34	25.49	10.25
	6955	5848.2	578.54	31.38	16.32	30.32	11.86
	6379	6424.5	576.74	24.85	8.92	23.89	8.37
	5935	6869.5	577.30	26.61	10.01	24.46	9.55
	5541	7199.3	576.92	27.21	11.28	26.05	9.30
	4862	7877.2	576.24	27.93	10.91	27.41	10.46
	4092	8648.7	575.86	26.72	8.91	26.19	15.99
	3430	9312.6	574.93	31.07	8.20	30.50	8.46
	2828	9915.8	573.34	22.89	7.47	22.62	12.27
	2108	10634.4	572.70	25.77	10.28	25.59	11.74
	1338	11402.7	571.49	25.18	11.66	24.71	9.95
	780	11962.8	570.08	27.30	9.18	26.63	7.86

The following results were arrived at after Dam Break analysis for Khadakwasla Irrigation System:

1) The peak floods have been estimated just downstream of the dam for the breaching time of 1 hour for Khadakwasla dam due to overtopping.

2) It was observed that the flood generated due to breaching of Khadakwasla dam under level pool condition have affected few locations on the downstream of Khadakwasla reservoir.

3) The flood generated due to Khadakwasla dam is seen to be affecting the major parts of Pune city nearby both the banks of the river Mutha. In addition, the major effect of flood was noticed in the Pune city and rural area of Pune district until the studied area.

4) The affected region has spread across NDA campus to Dattawadi (mid urban area of Pune city) which includes, Kondhawe-Dhawade, Shivane, Nanded City, Sinhagad Road, southernmost part of Warje-Malwadi, Karve Nagar and some region of Swargate respectively.

5) The maximum velocity at the cross section for the studied area was estimated. It was noticed that the mid region of the studied area may experience high velocity flow. The maximum velocity observed was 4.05 m/s at the cross section 6379 which is the area of Ram Nagar.

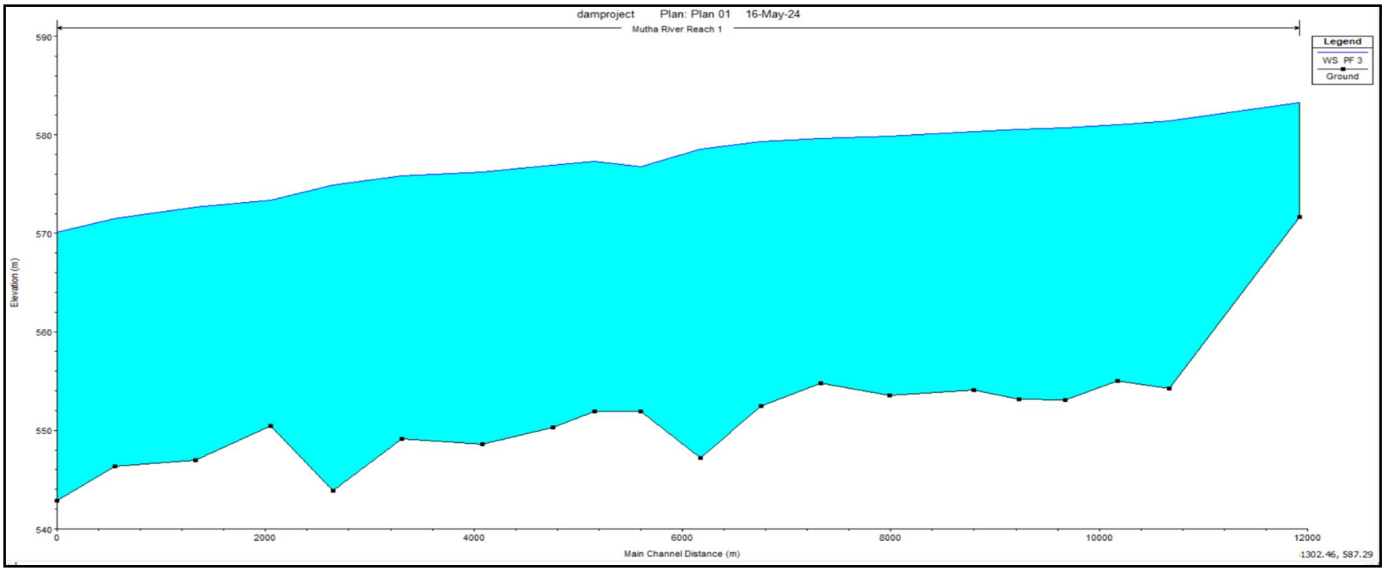


Fig. 3. Water Surface Profile for Study Reach of River Mutha

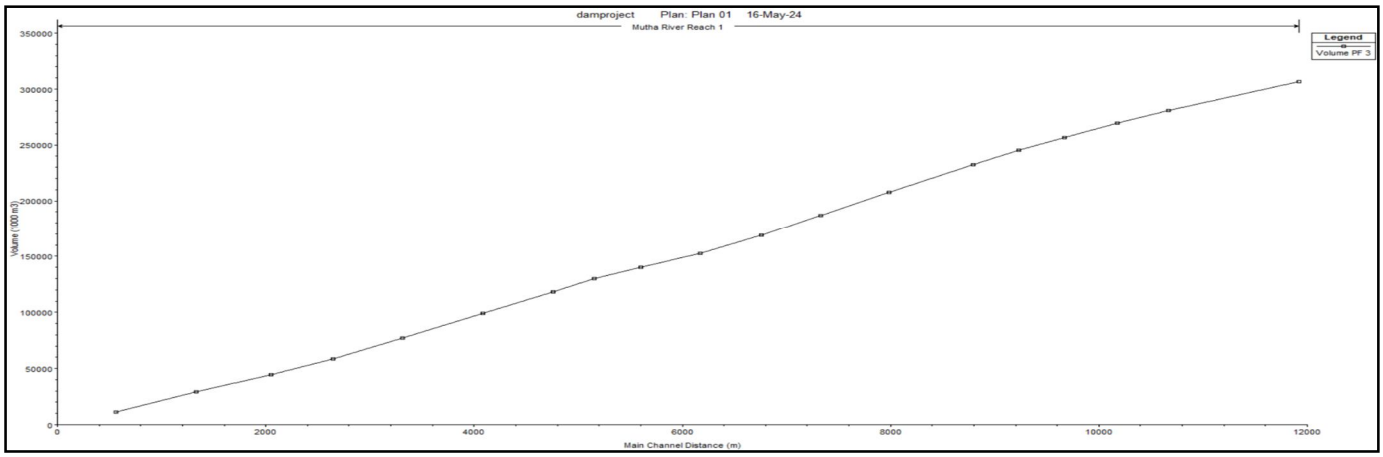


Fig. 4. Volume Curve for Study Reach of River Mutha

B. Inundation Map for Likely Vulnerable Scenarios:

Inundation map is used to present areas that may be flooded due to breaching of dam. It is used as an input in Emergency Action Plan (EAP) for identifying more vulnerable areas. They are generally supplemented with Dam break flood hydrographs and Maximum Stage profiles to identify time to flood (the time from the breach to the time that critical locations are flooded) and the time to peak flow. The aerial photographs, satellite images or best available detail maps to identify areas, including dwellings, roads, low water crossings, and other critical structures (schools, assisted living facilities, hospitals, etc.) are recommended for use as a basis for detailed inundation maps. Highly accurate Light Detection and Ranging (LIDAR) elevation data is usually used wherever available to develop Digital Terrain Models (DTM), to carry out hydraulic calculations, and to display flood inundation areas. The results estimated using 1-D mathematical model in HEC-RAS were used for the preparation of inundation map. The flood levels extracted from the water surface profiles were marked on the respective cross sections with reference to the contours extracted from DEM with 30 m resolution of study area using HEC-RAS. The flood levels were marked on the cross sections along the left and right banks of study reach of river Mutha and the inundation map was prepared for the study reach for the river. The inundation map was superimposed on Google map for identification of vulnerable areas.

In the present study, the representative key map in respect of whole study area is shown in figure 5. Approximate area covered by each cross-section is presented in table 3.

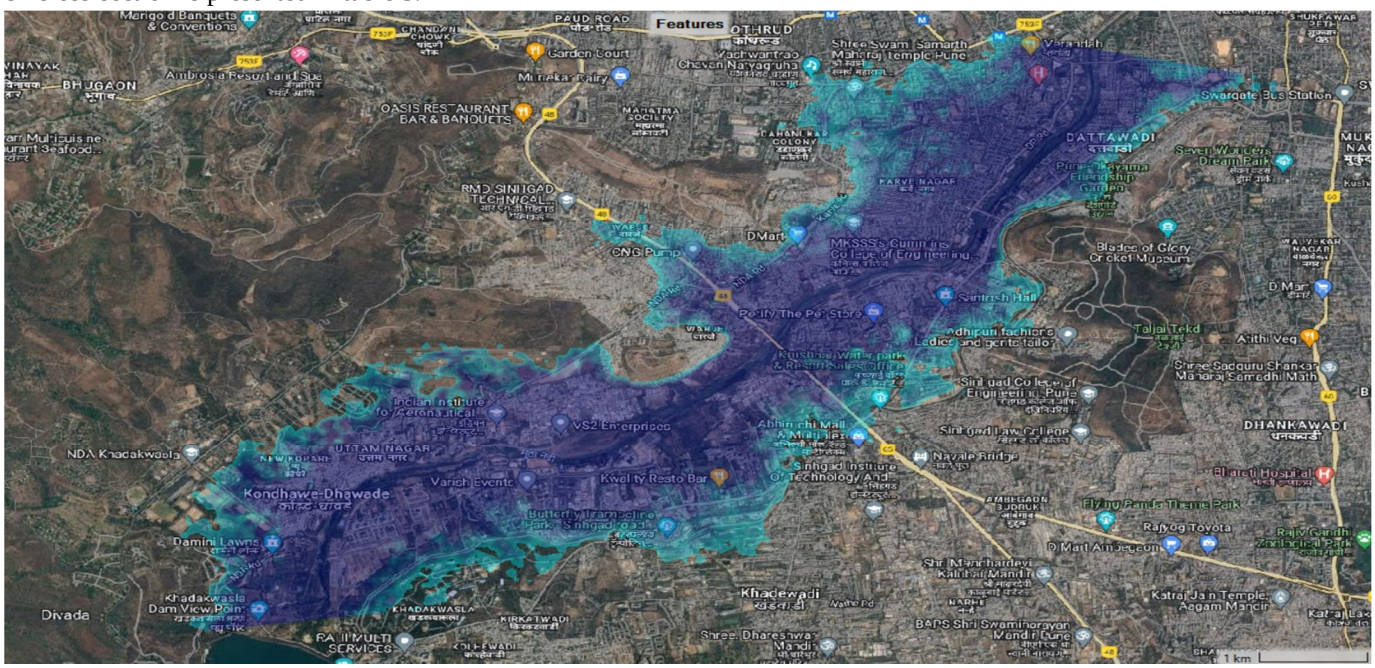


Fig. 5. Representative Key Map for Downstream Reach of Mutha River

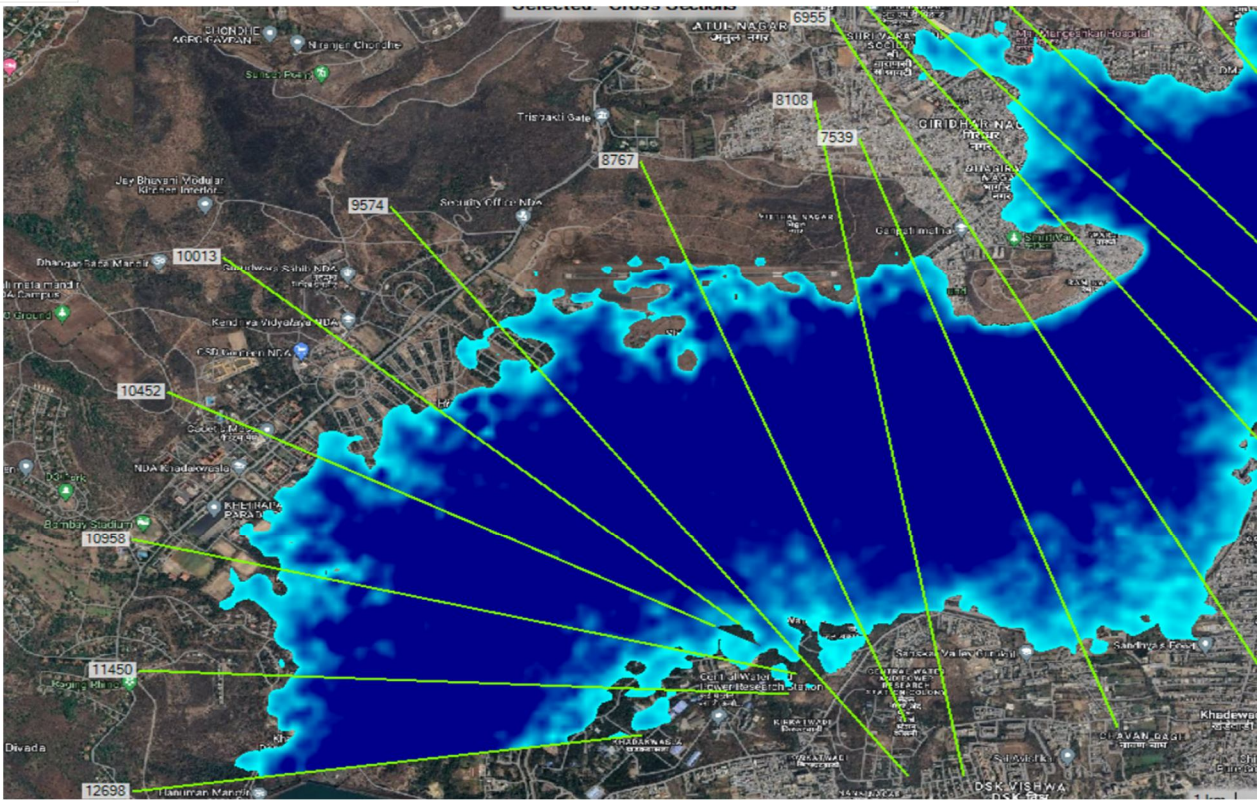


Fig. 5. (A) Inundation Map of River Mutha from Khadakwasla Dam to Ganpati Matha

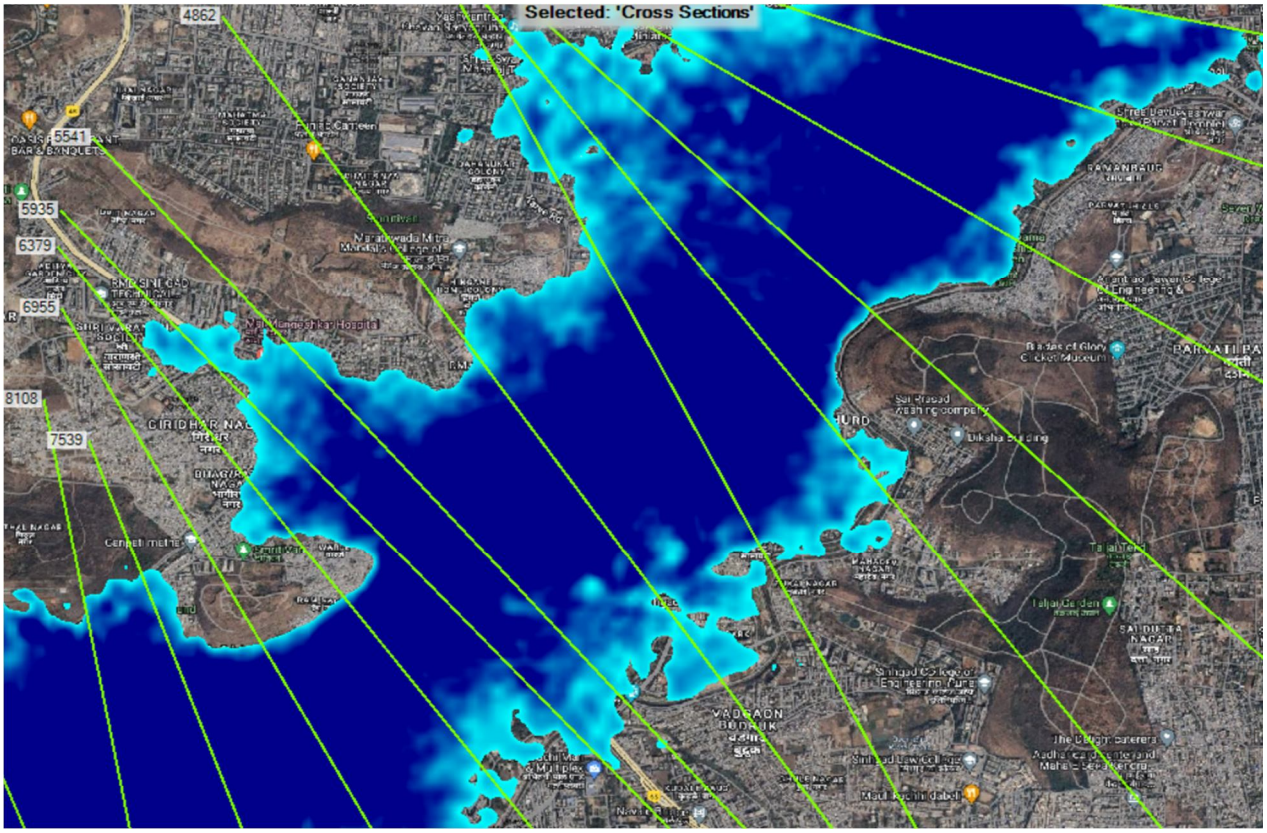


Fig. 5. (B) Inundation Map of River Mutha from Ganpati Matha to Karve Nagar

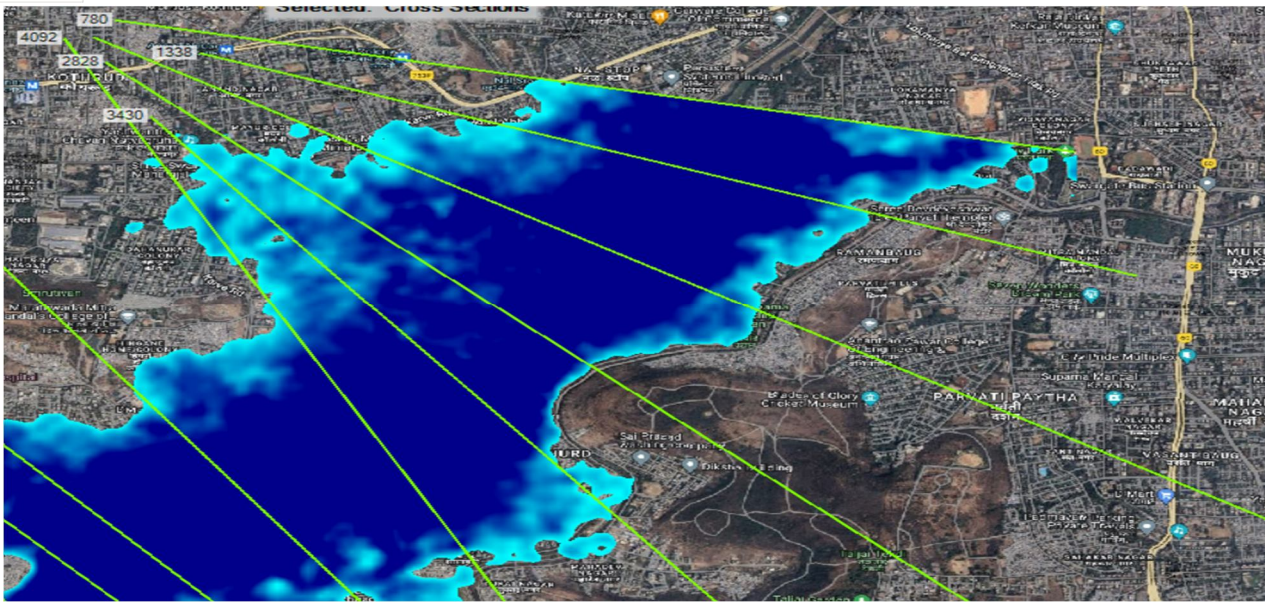


Fig. 5. (C) Inundation Map of River Mutha from Karve Nagar to Mhatre Bridge

V. CONCLUSIONS

Dam Break analysis of Khadakwasla dam was carried out for overtopping of Khadakwasla reservoir. The cross sections of the study reach of river Mutha were extracted from DEM of the study area. The breach parameters considered for the present study are estimated based on guidelines given in HEC-RAS software manual. The dam break flood hydrograph was routed through downstream river channel using HEC-RAS and water surface profile has been estimated. It is subsequently used for the preparation of inundation map as an input for emergency action planning.

The following conclusions were arrived at after Dam Break analysis for Khadakwasla Irrigation System:

1) The region affected by the breaching of dam can cause severe damage to human life. Hence, HEC-RAS is beneficial to identify these areas.

2) The HEC-RAS software provided us the overall analysis of flood occurred by dam breaching, including its affected area, inundation maps and total water coverage.

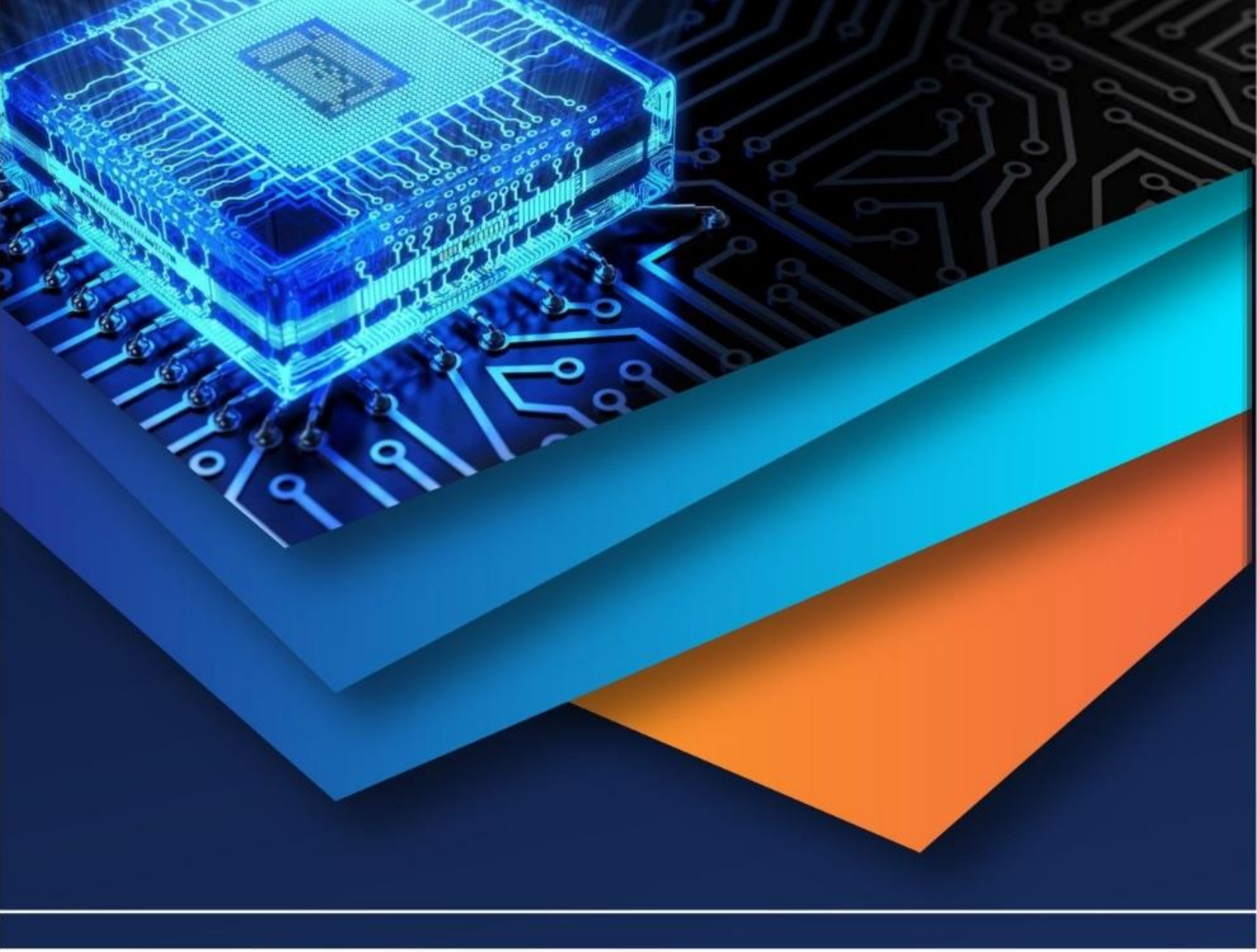
3) This analyzed data and maps can help us to create an action plan to control the living non-living life damage before the actual breaching/flooding happens.

4) The analysis of HEC-RAS also can be modified according to different weather conditions, storage capacity, river flow etc.

5) The purpose of this analysis is to create a pre plan. Also, the detailed specifications of the affected region help us implement necessary actions to each specific part.

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