# DAM BREAK FLOW SIMULATION MODEL FOR PREPARING EMERGENCY ACTION PLANS FOR BARGI DAM FAILURE

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**ABSTRACT**

Study of dam breach analysis is necessary because of the tragic consequences that can result in dam failure. After dam had breached, it is difficult to prevent the flood. Therefore engineers focused more over the flood management for the protection of the population at downstream of dam. This can be done by knowing different types of dam failure, by calculating the consequences of each type of failure, and by evaluating the risk associated with that failure type. In India till now 37 dam's failure has been reported. Bargi Dam or Rani Avanti Bai Lodhi Sagar Dam comes under the category of large dams constructed across Narmada River and breaching of this dam can cause disaster in Madhya Pradesh as well as Gujarat. This study is focused over the overtopping failure of the earthen part of the Bargi Dam. The present work comprise of three objectives: (1) case study of Bargi Dam failure using hydrodynamic model MIKE11, (2) Bargi dam failure impact on Narmada River and Jabalpur city, (3) preparation of inundation map for Bargi dam failure. Further, the present research also presents the applicability and usability of MIKE11-DB developed by the Danish Hydraulic Institute.

***Keywords: Bargi dam, Breach parameters, Flood inundation map, Overtopping failure, MIKE11***

## 1. INTRODUCTION

A structure used for impoundment of water is generally known as dam. It can also be defined as a barrier that is used to restrict or stop the water or stream flow beneath the ground. Dams create reservoirs that are used to fulfil the following basic needs of the society such as electricity, human consumption, irrigation, industrial use, navigability and aquaculture and also it is the major factor in flood protection. The emerging knowledge of construction engineering and technology is helpful to engineers in constructing dams with more suitable design and safety factor, in spite of this nature is more powerful. Many dams that were previously considered to be safe are now facing maximum flow uncertainty which causes overtopping during high flood events that leads to safety concerns. Dam failure results in economic damage and loss of life that totally depends on the magnitude of velocity of water, water depth, warning time and population density at the time of the event. In flood prone areas, early warning is essential for saving lives. People believe that due to construction of dams, flood are totally controlled due to which an increase in urbanization and development in industrialization in the floodplains are taking place. Hence, damage by flood caused due to structure failure might be much greater as compared to the damage that would occur in the absence of it.

Document no. 13 of U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Centre (HEC) has listed the causes of dam failure such as landslide, piping, earthquake, extreme storm, structure damage, equipment malfunction, foundation failure and others. Nevertheless all these almost every dam failure starts with the formation of breach. Breach is basically a gap formed in the body of dam that causes failure of dam and this event leads to the flow of accumulated water at upstream to the downstream. In spite of these entire factors the main failure mode is overtopping or piping. Also, as we know that the continuous change in the climate has drawn an uncertainty in flow within the dam life span [FEMA 2001]. Dam preventive measures as soon as possible. Therefore analysis of dam failure and preparation of inundation map is necessary.

Dam failure analysis purpose is to demonstrate the propagation and attenuation of flood wave beside the river. Dam break analysis consist of three distinct parts: (i) dam-break outflow hydrograph estimation, (ii) dam-break hydrograph routing of downstream valley and (iii) damage and inundation level estimation at downstream structures. U.S. Bureau of Reclamation has categorised the method of analysis in four different types: (i) Physically based methods; (ii) Prediction models;
(iii) Parametric models; (iv) Comparative analysis. Physically based dam break models work on the principle of hydraulics and sediment transport for the simulation of the breach developed. Prediction models use the data such as the breach outflow hydrographs from the past events and then put it in the routing models that are presently available to predict the data for the future events. Parametric models generally parameterize the breach (such as maximum breach size, shape of breach and many more) so its advancement through time could be depicted in relative basic mathematical models to calculate the enlargement process of the breach (for example: linear increment of breach dimensions with time). Comparative analysis includes comparing the outcomes of historical failures of a dam to a similar study area. According to these types of analysis, many softwares have been developed such as NWS FLDWAV, FLO-2D, HEC-River Analysis System (HEC-RAS), DAMBRK, MIKE-11, SMPDBK, FLDWAV, BREAK and many more for the analysis of dam break.
Reservoir outflow hydrograph prediction and hydrograph routing through the downstream valley are the two major tasks in the hydraulic study of a dam failure. Dam break simulation model in MIKE ZERO i.e. MIKE-11 is use to simulate the flood wave propagation correlated with a potential failure of the dam. The objective of this paper is to use MIKE-11 for the analysis of dam failure based on given geometrical and hydrological data.

## 2. STUDY AREA

Bargi dam also known Rani Avanti Bai Lodhi Sagar dam is located at 22°56’30”N longitude and 79°55’30”E latitude. It was among the first completed dams out of the 30 major dam projects on River Narmada. Construction of this dam was started in the year 1974 and completed in the year 1990. Main dam is constructed near Bargi village, close to National Highway-7 (connects **Jabalpur- Nagpur**) due to which it has been named Bargi Dam.
In terms of river network, Narmada River rises in the Mikel range in Shahdol district near Amarkantak at an elevation of 1050m. Flowing generally in south western direction in a narrow valley the river takes a northerly turn near Mandla after passing through Jabalpur, the river flows through a deep narrow channel through the famous “Marble Rocks” of Bhedaghat. The Narmada River after emerging from the gorge and continuing west enters the fertile Narmada Valley which is a long and a narrow strip walled by Vindhyas on the north and Satpuras on the south. Coming out of the gorge the river enters the plains of Gujarat and finally discharges in the Gulf of Khambat. The Narmada river carries 0.67Mham (5.45 M.A.F) water at 75 % dependability up to the Bargi Dam. The Bargi Dam visualises a canal head use of 0.39Mham (3.20 M.A.F) and the storage capacity had designed accordingly.
The Rani Avanti Bai Lodhi Sagar Dam head works comprises of composite masonry and earth dam with central spillway. The masonry dam consists of 209.69m left NOF and 231.74m right NOF. The central spillway is 385.72m long with maximum height of 69.8m. The top width of service road and bridge over spillway is 7.2m. The earth dam is 4.53 km long. The left earth dam is 2.77km and right earth dam is 1.76km long and maximum height is 29m. The top width is 7.62m. Bargi dam reservoir is almost 75km long and 4.5km wide, spread over an area of about 267.97 $km^2$


**Figure 1: Narmada Basin**

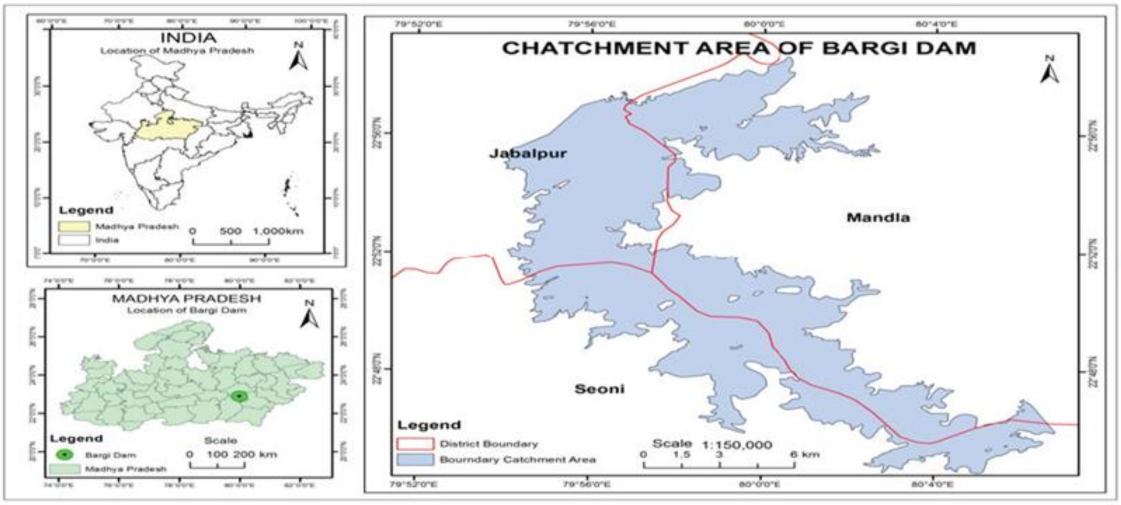


**Figure 2: Catchment area of Bargi dam**

## Table 1: Salient features of Bargi dam

| GENERAL | | | | RESERVOIR DATA | |
|---|---|---|---|---|---|
| Lat. & Long. | 22°56’30”N & 79°55’30”E | | | Minimum Drawdown Level (MDDL) | RL 403.55 m |
| Catchment | 14,556 Sq.km | | | Full Reservoir Level (FRL) | RL 422.76 m |
| PMF | 51,510 Cumecs | | | Maximum Reservoir Level (MWL) | RL 425.70 m |
| **DAM** | | | | Top of Dam Level (TBL) | RL 426.90 m |
| **Type** | **Length (m)** | **Maximum height (m)** | **Top width (m)** | Dead storage capacity at MDDL | 740 M.Cum. |
| Masonry | 827.0 | 69.8 | 7.2 | Gross storage capacity at MWL | 4806 M.Cum. |
| Earth | 4540 | 29 | 7.62 | Spillway Crest Level | 407.5 m |

## 3. METHODOLOGY

This study comprises of dam break analysis of Bargi Dam also known as Rani Avanti Bai Lodhi Sagar Dam by using MIKE11. The MIKE software was developed by the Danish Hydraulic Institute (DHI). MIKE-11 is 1-D model that uses the Dambreak (DB) module to simulate a dam breach. From this dam breach, the outflow hydrograph can then be fed any other flood routing software and then the floodwave downstream routing can be done. MIKE11 is a software package that consists of many different modules. These modules are stated under the following headings that are hydrodynamic module (HD), advection-dispersion (AD), and water quality (WQ). This study is basically focused on the use of hydrodynamic module (HD).

The hydrodynamic module uses an implicit, finite difference scheme, to calculate unsteady flows in rivers and estuaries. Depending on the local flow conditions, it can describe supercritical as well as subcritical flows within the river or estuary. Other computational models can be included within the HD module to describe dam breaks or flow around structures.

For dam break analysis following data is needed in MIKE-11:

- Shape files of Narmada River and its tributaries.
- Various time series such as Probable maximum flood values with respect to time, water level and discharge values and many more.
- A 90m DEM file of Narmada catchment area which is generally processed in ArcGIS for extraction of data.
- Text files with cross-section data which is derived from the DEM file.
- Narmada catchment topographical image.

Before working with the dam failure analysis tool, it is essential to grasp the knowledge about the critical breach parameters. These parameters are of four types:

1. Estimation of breach parameters such as breach size or shape and failure time.
2. Peak discharge during breach and estimation of breach hydrograph.
3. Routing of breach flood, and
4. Hydraulic conditions estimation at critical location.

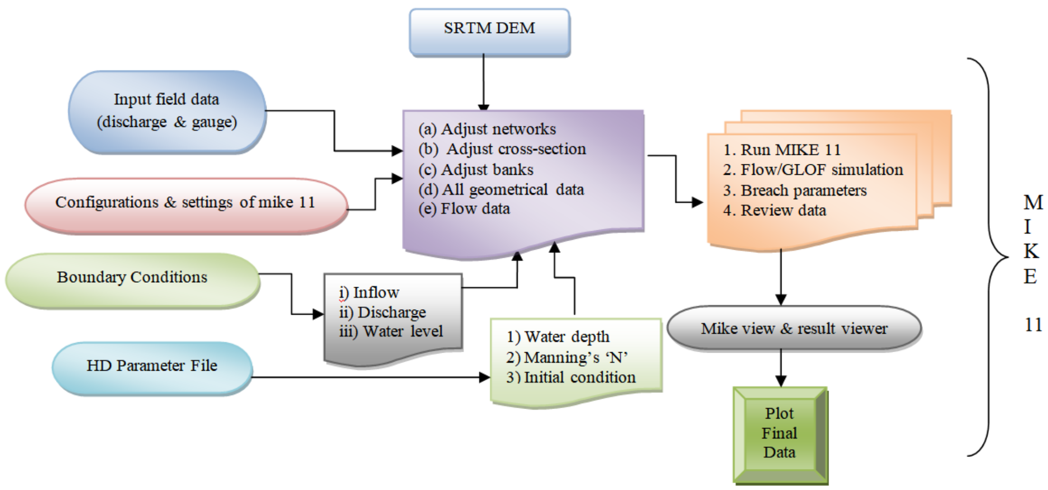


**Figure 3: Flow chart of methodology used in Bargi dam break simulation**

### 3.1 Empirical method

For the prediction of time of failure, breach geometry and peak discharge during breach empirical methods are practiced. Empirical approach is based on statistical analysis of data which is attained from recorded failures. There are four mostly used empirical equations or empirically derived enveloping curves for the prediction of dam breach parameters. They are listed below:

1. MacDonald & Langridge – Monopolis (1984)
2. U.S. Bureau of Reclamation (USBR-1988)
3. Von Thun and Gillette (1990)
4. Froehlich (1995a, 1995b, 2008)

In this study Froehlich (2008) is used for the estimation of dam breach parameters as it is considered as one of the most endorsed empirical tool under the Guidelines for dam break analysis. Froehlich (2008) depends only on the reservoir volume, breach height and the assumed side-slope of the breach. This method can also differentiate between overtopping and piping failure. Froehlich (2008) equation stands substantial because with his assumptions dams with more prominent stature tend to deliver shorter failure time for a given volume of reservoir.

$$B_{avg} = 0.27 k_o {V_w}^{0.333} (\text{Overtopping}, k_o = 1.3 \text{ \& Piping}, k_o = 1.0) \quad [1]$$

$$t_f = 0.0176 \sqrt{V_w/(g h_b^2)} \quad [2]$$

where, $K_o$ = Failure mode factor, $h_b$ = Height of breach (m), $V_w$ = Reservoir volume stored ($m^3$), $B_{avg}$ = Average breach width (m), $t_f$ = Breach development time (hr)

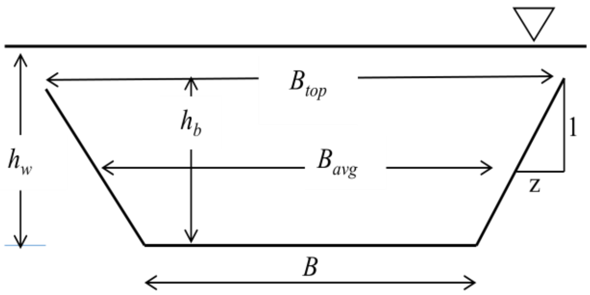


**Figure 4: Diagram showing breach parameters**

## 4. RESULT ANALYSIS

It is fundamental to comprehend the aspects of probable dam-break floods in the absolute surroundings to lessen the danger of dam-prompted surges. For the estimation of storage level in dam under the condition of total gravity dam failure according to the guidelines of the flood risk mapping, breach flow process calculation model along with the 90 m DEM data of the study area is needed. It is important to note that in this study the dam failure occurring mode is assumed to be overtopping failure only on the earthen part(height of the earthen dam is 29.62m) of the dam as the spillway(height of masonry dam is 69m) has sufficient space to prevent overtopping failure of the dam.

### 4.1 Breach parameter results

Geometrical parameters of the dam used for the prediction of breach parameters are listed below: Length of the dam = 4540 m (left flank + right flank), Total height of the dam = 29.62 m, Freeboard = 1.20 m, Total volume of the reservoir (MWL) = 4806 Mcum. By applying the Froehlich (2008) equations, the breach parameters calculated are:
Breach Slope = 1:1 for overtopping, Calculated time of failure ($t_f$) = 47,226.9 sec = 13 hrs, Calculated breach width ($B_w$) = 550 m, Breach Level = 396.7 m

### 4.2 Analysis of Simulation Results

The water level in the dam before the failure was RL 425.7m with a maximum storage of $4.80\times10^9$ $m^3$. A moderate flood of 43000 $m^3$/sec is seen over this area. After stimulation with the help of breach parameters it is clearly shown that the maximum discharge during the dam break is 114851.2 $m^3$/sec (Figure5) and it takes almost 18 hours to get the water level down in the reservoir to its dead storage level (MDDL). . Figure 6 demonstrates that with the increase of breach discharge, breach width also increases till the discharge reaches to its maximum value (114851.2 $m^3$/sec). After this event, breach width will become constant throughout and the discharge will start decreasing. This shows that breach discharge is dependent on the breach width. The level of breach during maximum discharge is RL 396.70m (Figure 7) and the velocity of the flow is 12.461m/sec. During the maximum discharge through the breach the water level in the reservoir is RL 424.84m (Figure 7) which is below the MWL of the reservoir as it breaches into the dam structure also the breach width at the crest is RL 610.4m (Figure 6) which also affects the intensity of the flow during the process of breach. The peak flood discharge occurs after 13 hrs of the starting of the breach and it take almost 4 days to put an end to the disastrous flood (Figure 5). A sharp peak is seen (Figure 5) at 59.56 hr because as the maximum value of the flood is achieved, a sudden reduction in HFL is seen. Figure 7 illustrates that with the increase in breach discharge, reservoir level increases simultaneously but breach level gets reduced. It is due to the factor that as the water breaches into the dam, the coarse construction material of the dam get washed and fissures get induced in the body of the dam due to which breach level get decreased. From Figure 7 it can be drawn out that during the time of breach reservoir was having water level of 427 m which has to be spilled out so as to prevent flooding as well as dam failure dam failure.

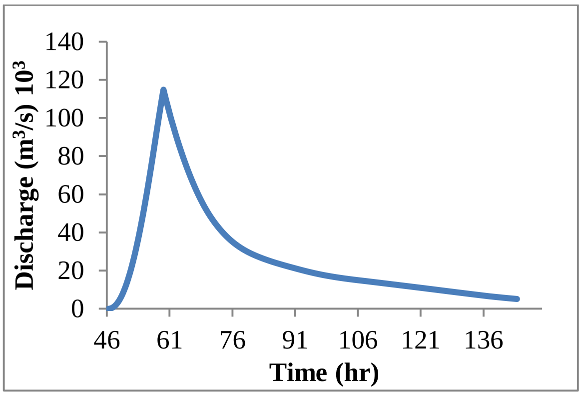


Figure 5: Dam Breach Hydrograph

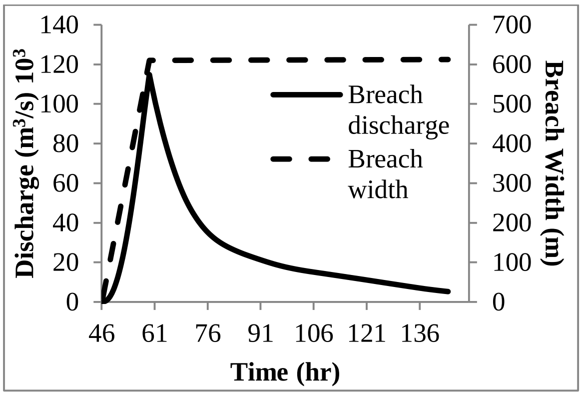


Figure 6: Breach width and discharge

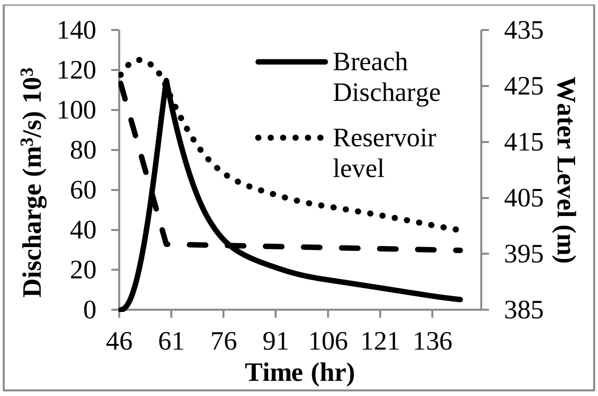


Figure 7: Relation between Breach Discharge, Reservoir Level and Breach Level

Table 2 illustrates 12 gauge stations during the dam failure. Generally the tabular study is done to know the impact of flood over various chainages at Narmada River. Out of the 12 gauge stations, Ghansore (60532.41 m) is the station that lies in the upstream of the dam. The main purpose of choosing one upstream station is to study the impact of Probable Maximum Flood over the upstream of the Bargi dam. From the study it is clear that the upstream station will be safe during flood event, as its danger level is far above the HFL received by the station. The remaining stations lie downstream of the river. From Figure 8 a clear picture can be drawn for the time of arrival of the flood in various stations. As the flood moves towards the downstream regions from the dam, water level starts reducing for the other respective stations and after that becomes uniform. In Figure 9 at upstream chainage (Ghansore), an irregular behaviour of discharge is seen due to the presence of small reservoirs near to the gauge station. In the rest of the stations (downstream), discharge reduces while moving away from the dam in the direction of the flow of water.

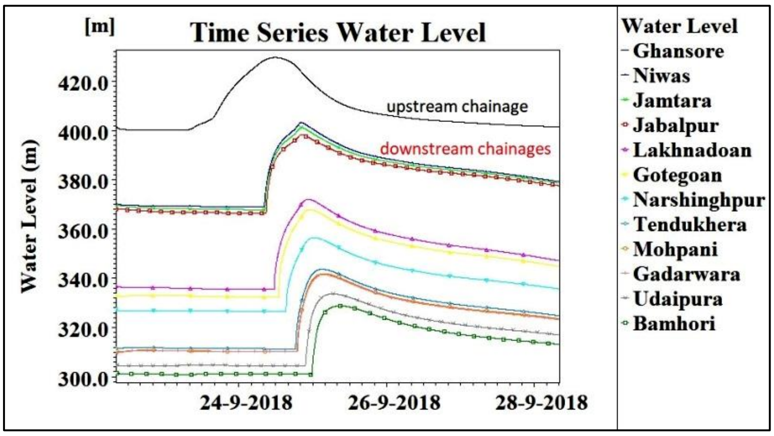


**Figure 8: Change of Water Level with time in different gauges during dam failure**

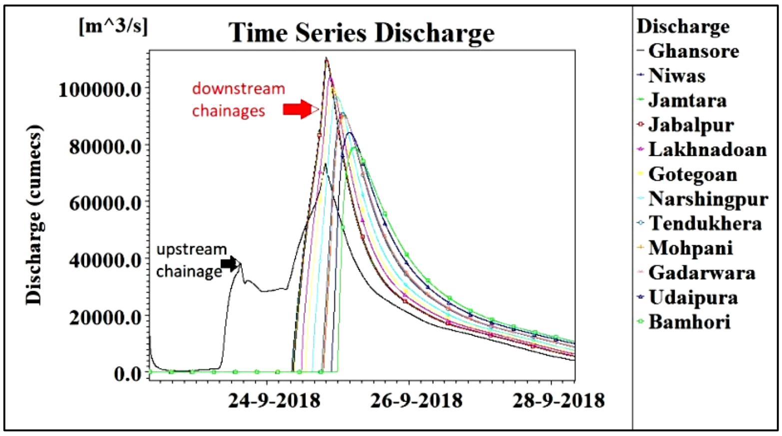


**Figure 9: Change of Water Level with time in different gauges during dam failure**

It is predicted from Figure10 that almost 8 m of water level rises in Jabalpur district due to which all the low lying regions of Jabalpur will get submerged into water as its mean sea level is 411m and also danger level of Jabalpur is 390m. According to Figure11, a sudden increase of conveyance capacity of River Narmada near Jabalpur is seen till the high flood wave arrived and after this point increase in conveyance capacity becomes uniform this shows that the velocity of the flow becomes uniform and also the boundary shear stress decreases after the flood event. Figure11 depicts the variation of water level increases uniformly after reaching high flood level (HFL) in Jabalpur i.e. RL 399m.

**Table. 2 Analysis of Mike 11 results with respect to 12 Gauge Station near Bargi Dam**

| S.no. | Gauge Station | Chainage (m) | Danger Level (m) | Mike 11 results | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | High flood | | | Arrival of 1st flood wave | | Maximum discharge ($Q_{max}$) | | |
| | | | | HFL in m | Date* | Time* | Date* | Time* | Value in $m^3$/sec | Date* | Time* |
| 1 | Ghansore | 60532.41 | 558 | 429.69 | 24/09/2018 | 11:45:05 | 23/09/2018 | 07:08:24 | 73196 | 24/09/2018 | 19:41:05 |
| 2 | Niwas | 95000 | 392 | 403.22 | 24/09/2018 | 20:13:05 | 24/09/2018 | 07:56:21 | 110444 | 24/09/2018 | 19:58:00 |
| 3 | Jamtara | 98000 | 380 | 401.24 | 24/09/2018 | 20:18:00 | 24/09/2018 | 08:27:42 | 110034 | 24/09/2018 | 20:03:05 |
| 4 | Jabalpur | 102000 | 388 | 398.43 | 24/09/2018 | 20:22:00 | 24/09/2018 | 08:42:17 | 109704 | 24/09/2018 | 20:11:05 |
| 5 | Lakhnadoan | 139000 | 583 | 372.04 | 24/09/2018 | 22:28:00 | 24/09/2018 | 11:28:34 | 103630 | 24/09/2018 | 21:20:00 |
| 6 | Gotagoan | 158000 | 344 | 367.88 | 24/09/2018 | 23:01:59 | 24/09/2018 | 12:47:20 | 99982 | 24/09/2018 | 22:09:05 |
| 7 | Narshingpur | 197000 | 323 | 354.91 | 25/09/2018 | 00:35:59 | 24/09/2018 | 15:28:33 | 96709 | 24/09/2018 | 23:35:05 |
| 8 | Tendukhera | 234000 | 346 | 343.65 | 25/09/2018 | 03:01:59 | 24/09/2018 | 18:05:36 | 91099 | 25/09/2018 | 01:31:05 |
| 9 | Mohpani | 240000 | 649 | 341.91 | 25/09/2018 | 03:30:00 | 24/09/2018 | 18:44:52 | 90194 | 25/09/2018 | 01:52:00 |
| 10 | Gadarwara | 243000 | 318 | 341.42 | 25/09/2018 | 03:35:59 | 24/09/2018 | 18:49:13 | 89754 | 25/09/2018 | 02:00:00 |
| 11 | Udaipura | 277000 | 297 | 333.66 | 25/09/2018 | 06:18:00 | 24/09/2018 | 21:26:16 | 84061 | 25/09/2018 | 03:48:00 |
| 12 | Bamhori | 304000 | 460 | 328.79 | 25/09/2018 | 08:54:00 | 24/09/2018 | 23:32:47 | 78934 | 25/09/2018 | 05:30:00 |

*note :- HFL stands for High Flood Level.
Date is in the format of date/month/year
Time is in the format of hour:minute:second

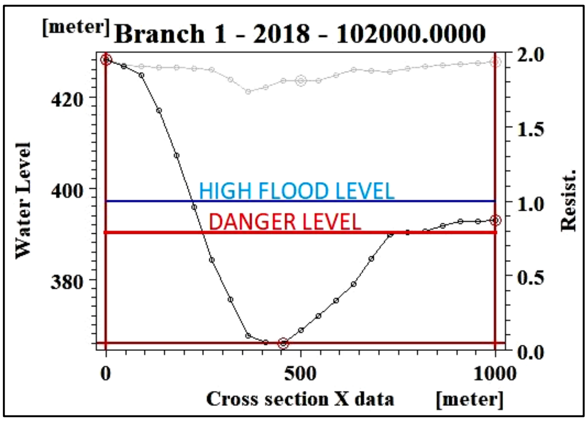


**Figure10: River Narmada Cross-section profile near Jabalpur**

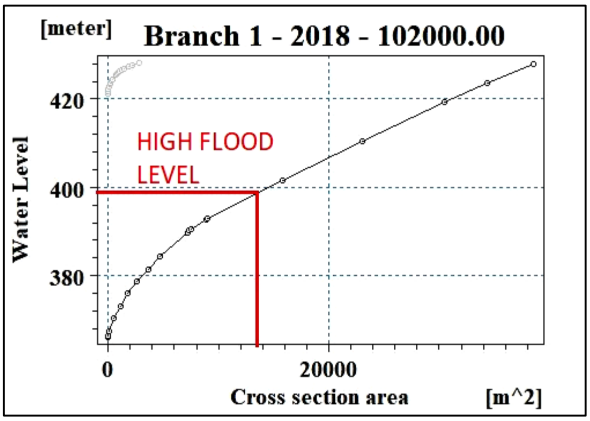


**Figure11: Variation of Water level w.r.t cross section area of River Narmada near Jabalpur**

From the result we can predict that the flood will hit the densely populated area Jabalpur (which exist at 25 km downstream of the dam site) in 10 hrs after the dam breach started (Figure12) while the maximum peak flood reached after 11 hrs from the initiation time of the flood in Jabalpur (Figure13). Research demonstrates that when alerts are issued 90 min or more prior dam break then there will be just 0.02% causalities to the population living in downstream area, but if the time of warning is less than 15 min than the causalities will increase by 50%. Therefore Jabalpur has low risk levels under an appropriate disaster warning system regardless of the 109704 $m^3$/sec of the peak flood flow (Figure13).

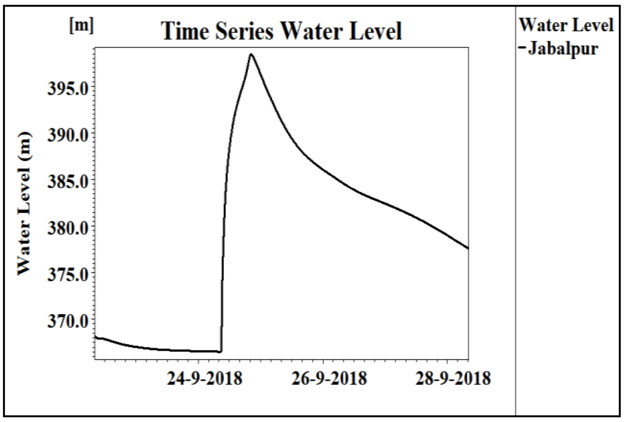


**Figure12: Variation of Water Level in River Narmada near Jabalpur with respect to time during dam failure**

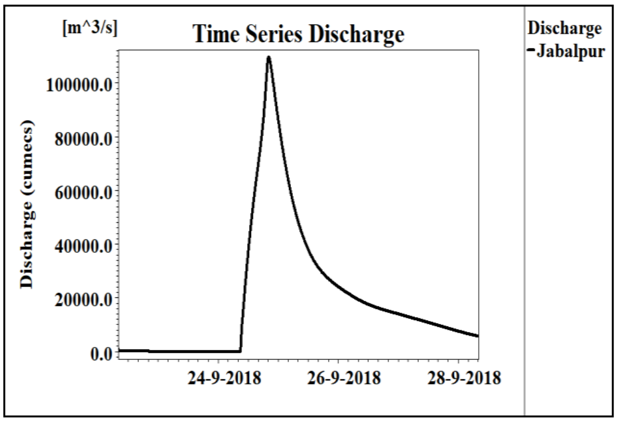


**Figure13: Variation of Discharge in River Narmada near with respect to time during dam failure Jabalpur**

### 4.3 Flood inundation map

Figure14(a) and Figure15(a) represents Narmada River and Jabalpur city before dam failure. Figure14 (b) and Figure15 (b) represents maximum water depth at various locations on Narmada River and in Jabalpur after the dam failure.

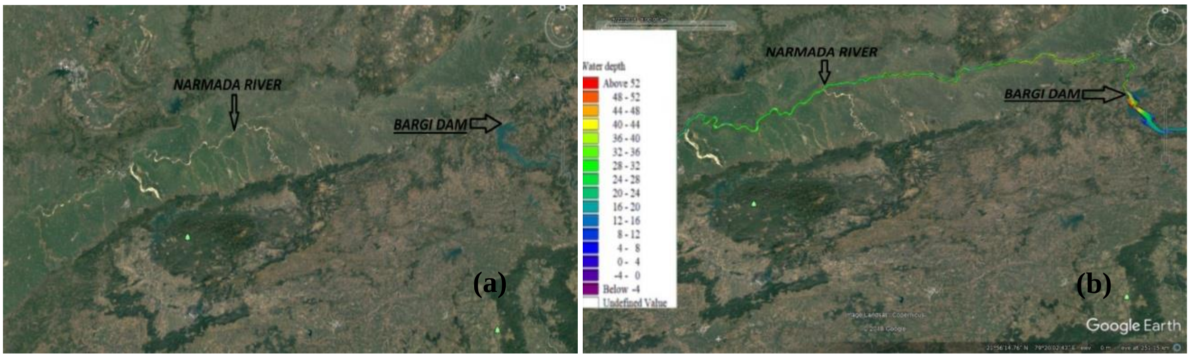


**Figure14: Flood Inundation Map over Narmada River (a) before flood, (b) after flood**

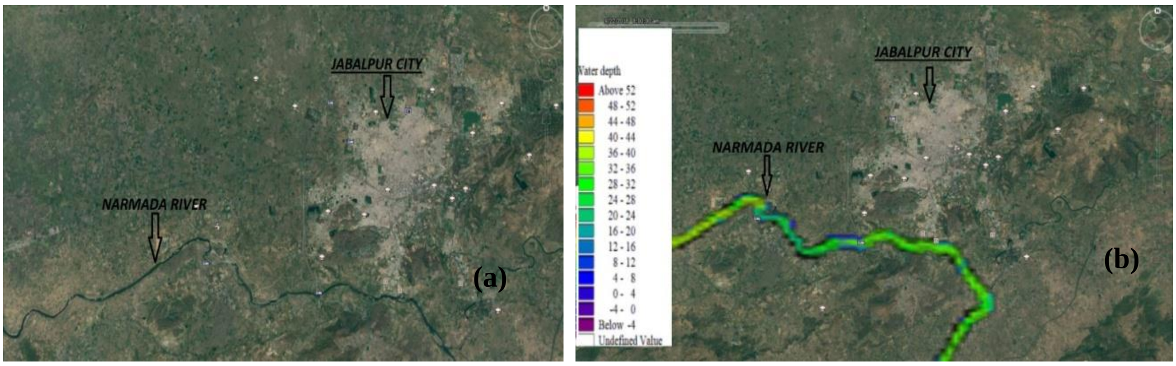


**Figure 15: Flood Inundation Map over Jabalpur (a) before flood, (b) after flood**

## 5. CONCLUSION

For the analysis of dam it is imperative to anticipate the breach parameters precisely as conditions like piping and overtopping causes failure of dam. For doing the same in this study, US National Weather Service (NWS) guidelines were chosen to figure out the dam breach parameters. This paper re-enacts the dam break flood evolution process with the help of geographical as well as hydrological data to analyse the failure condition which can further help in early warning for cataclysmic events. With the use of the hydrodynamic model for the simulation of dam break analysis it is easier to visualise the drastic effects of flood on downstream area as well as to prepare an emergency action plan to prevent any causalities.

By analysing the simulation results obtained from MIKE 11, it was found that a peak discharge flood of 114851.2 $m^3$/sec hits the dam at 59.56 hrs (from the starting of the flood) with a velocity of 12.46 m/sec. Dam breach hydrograph shows that the upcoming flood have the capability to engulf the downstream regions. It will take almost 18 hours (after the arrival of the peak flood) to reduce the effects of flood. The breach level reduces from 425.5 m to 396.7 m and breach width enlarges by 550 m i.e an opening of 1/8 times the length of dam is created in earthen part of Bargi dam. With the increase in breach width the breach discharge increases, after achieving maximum breach discharge the increase in breach width stopped and remain constant or slight increase with the decrease in breached discharge. In this study the dam break model for Bargi dam is setup in such a way that water level in the reservoir is at MWL at the time of arrival of peak of PMF.

Analysis also concludes that Ghansore (upstream gauge station) is totally saved during and after the flood event. Jabalpur (downstream gauge station) will receive the flood in 10 hrs after the dam failure and the maximum flood of 109704 $m^3$/sec will reach after 11 hrs of the initiation of the flood in Jabalpur. Hence it can be concluded that with proper management of dam safety rules, proper risk management and under proper warning system dam breach as well as flood disaster at downstream can be prevented.

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