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PREPARING EVACUATION PLAN FOR DEVELOPMENT OF EMERGENCY ACTION PLAN – A CASE STUDY OF KONAR DAM

ABHISHEK SHUKLA
Executive Engineer (Civil), Damodar Valley Corporation, Dhanbad, Jharkhand, India

ABSTRACT

Dams are important structures that serve multiple purposes. Failure of a dam is characterized by an abrupt uncontrolled release of stored water and would lead to catastrophic consequences in most cases. Preparation and implementation of an Emergency Action Plan (EAP) for a dam is crucial to minimize such consequences. For an effective EAP, planning for evacuation becomes a vital component. Guidelines for Developing EAPs for Dam, Central Water Commission (CWC), 2016, recommends using inundation maps for evacuation planning. As these maps are to be used by the Disaster Management Authorities (DMAs), simplicity and clarity of evacuation plan is essential. As per the guidelines, DMAs are to be provided with multiple inundation maps for planning evacuation which might not be convenient for them, especially during an emergency.

The paper discusses about the simplified evacuation plan prepared for EAP of Konar dam. The information provided in multiple inundation maps, individually showing time of arrival, velocity, depth and maximum water level corresponding to the flood waves, were clubbed into one single inundation-cum-evacuation-map for each failure scenario, with all relevant information, using GIS platform. A separate evacuation table was also prepared to supplement the information shown in prepared map. The author proposes preparing simplified map for distribution to the DMAs rather than multiple inundation maps in an EAP document.

Keywords *: Dam failure, Inundation maps, Emergency Action Plan (EAP), Evacuation plan, GIS*

1. INTRODUCTION

India, with 5,745 large dams including 411 dams under construction [1], ranks third in the world in terms of dam construction. The collective storage from these large dams is over 300 billion cubic metre which facilitate flood control, water supply, hydroelectric power generation, irrigation, etc. Therefore, their health and safety are of paramount importance for sustainable utilization of these valuable assets, besides protecting people, property, and the environment.

One of the key requirements of any dam project, which unfortunately has not been given its due weightage, is dam safety. Modern dam safety practices involve holistic approach which can primarily be classified into three aspects (1) Preventive – which includes dam monitoring and surveillance, comprehensive dam safety evaluation, maintenance against ageing etc. (2) Actionable – which includes repair and rehabilitation methods (3) Emergency Planning in case of dam failure.

Dam Safety Act – 2021 [2], passed by Indian Parliament in December 2021, defines "dam failure" as any failure of the structure or operation of a dam which leads to uncontrolled flow of impounded water resulting in downstream flooding, affecting the life and property of the people and the environment including flora, fauna and riverine ecology. The act also obligates dam owner to prepare Emergency Action Plan (EAP) for the specified dam, which shall set out the procedures to be followed for the protection of persons and property upstream or downstream of the specified dam in the event of an actual or imminent dam failure or to mitigate the effects of the disaster.

A carefully conceived and implemented Emergency Action Plan (EAP) shall comprehensively cover requirements for operational procedure / actions during emergency, notification, identification of emergency conditions, preparation of inundation maps, evacuation planning, warning procedures, etc. Such document would be used for efficiently managing the likely adverse situations due to dam failure specially to avoid loss of human life. Thus, planning for evacuation of human, livestock etc. is an essential aspect for preparation of EAP.

The implementation of an EAP requires coordinated efforts of both dam owning/operating agencies and Disaster Management Authorities (DMAs) at district / state / national level to save lives, minimize damages to property, structures and inhabitations and to minimize environmental impacts. Therefore, the set of procedures to be laid down in the document shall have to be simple and clear for all concerned officials without compromising on the informational aspect.

An inundation map is the result of consequence analysis of a dam failure and is used to delineate the areas that would be flooded because of such failure or unusually large spillway releases, these maps are required for identification of areas that shall be evacuated during emergency. They also indicate the critical areas requiring necessary evacuation, relief and rescue operations. A set of four different inundation maps for each failure condition is prepared showing affected settlements. These maps are divided into 1) Time of arrival of wave front, 2) Maximum depth of inundation, 3) Maximum velocity of flow and 4) Maximum water surface elevation. Additionally, a vulnerability map, created from information captured from depth and velocity map, is also attached for prioritizing the evacuation.

As recommended by guidelines [3], all these maps shall be included in the EAP so that the concerned DMAs can plan for evacuation as well as carry-out the rescue operations. However, planning for evacuation through multiple maps may not be convenient for DMAs, particularly during emergency where evacuation is a priority. One contrary, a single inundation map having additional information like evacuation route, shelter points for each settlement, supplemented by priority-based evacuation table would be clearer for DMAs to understand and take actions.

This paper discusses about procedure of developing such inundation-cum-evacuation map and priority-based evacuation table prepared for EAP of Konar dam.

2. DESCRIPTION

Konar dam, owned and operated by Damodar Valley Corporation (DVC), is situated across river Konar, one of the major tributaries of river Damodar. The dam, located amidst the picturesque surroundings of the forests of Hazaribagh & Bokaro district of Jharkhand, was completed in 1955. It is an earth-cum-concrete dam about 3682 m in length including concrete gravity structure of 277 m. The ogee type spillway consists of 9 crest gates each of 10.36 m (wide) x 9.91 m (high). The reservoir is expected to attain Maximum Water Level of 429.77 m while passing the revised Probable Maximum Flood (PMF) of 9551 cumec. Fig. 1 shows the location map of the dam.

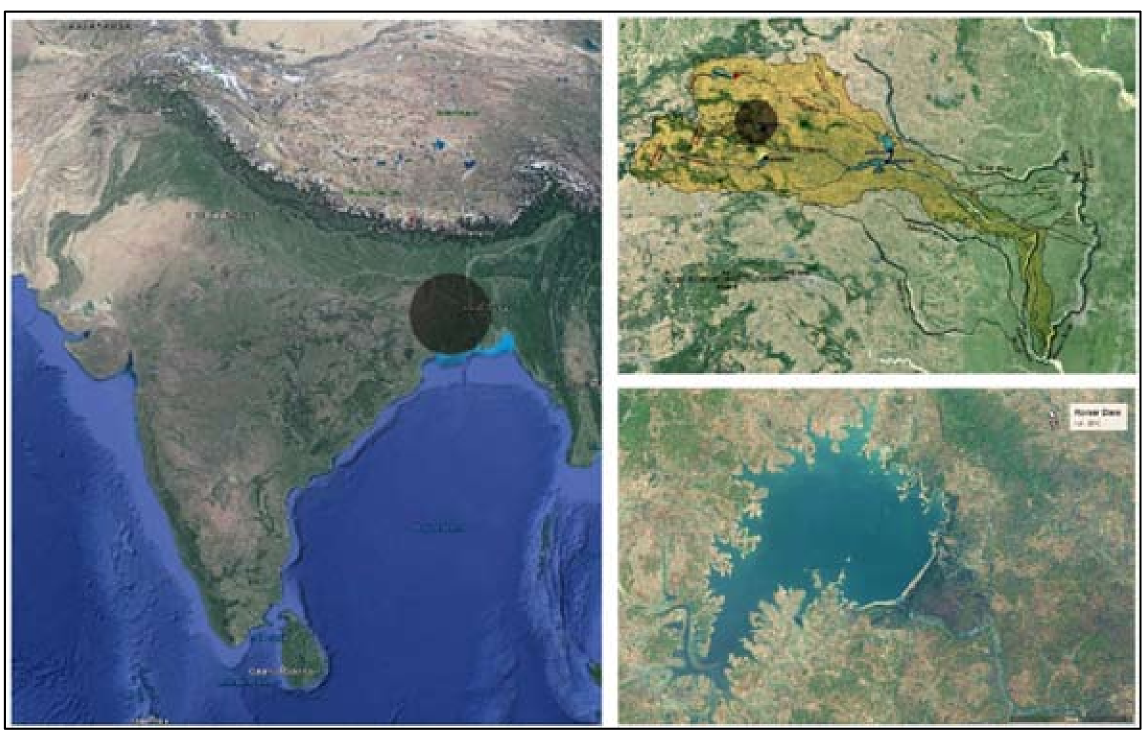

Fig. 1 : Location Map of Konar Dam

The dam has a well-established flood management operation procedure, monitoring arrangement as well as maintenance system as per the existing Damodar Valley Reservoir Operation Manual and O&M manual. However, in addition to ensuring safety by proper upkeep of the dams, it is also important that the dam authorities are prepared to face any emergencies caused by a dam failure.

3. CONSEQUENCE ANALYSIS AND EVACUATION PLAN

3.1. Dam-break modelling

One of the biggest advances in dam safety practices has been the evolution of computation technology for flood routing for dam break scenarios as well as availability of free and accurate topographic data and satellite imaging along with improvement of the software and methods of modelling. Assessing, modelling, and mapping of a dam failure flood is carried out using these data set and methods. The level of analysis correlates with the sophistication and accuracy of the analyses as well as the scale and complexity of the dam and downstream area under investigation. In general, as the sophistication of the modelling increases, so does the level of effort, time, and cost needed to conduct the analysis. In case of Konar dam, dam break studies were carried out by CWC under Dam Rehabilitation and Improvement Project (DRIP) for the following three scenarios [4]:

1. A dam failure caused by overtopping from the inflow design flood leading to breaching and uncontrolled release of impounded water.
2. A non-flood dam failure caused by internal erosion (piping) with the reservoir at full supply level (often called a "fair-weather failure") leading to breaching and uncontrolled release of impounded water.
3. A large controlled-release flood without dam failure.

Dam failure floods resulting in breaching from overtopping by floodwaters and from internal erosion (piping) were simulated by solving numerically the two-dimensional, depth-averaged flow equations on an unstructured computational mesh using the HEC-RAS computer program [5]. Breaches were modelled as trapezoidal openings that form at the crest of the dam and then grow in size, first vertically downward until the specified breach bottom elevation is reached, and then horizontally as outflows continue to widen the opening. Flooding caused by a steady large controlled release (LCR) from the reservoir was simulated to provide an idea of the hazard owing to non-failure event.

The digital elevation model (DEM) used to prepare the two-dimensional computational mesh to simulate flooding was derived from the Japan Aerospace Exploration Agency (JAXA) global digital surface model (DSM) dataset with a horizontal resolution of approximately 30 meters (1 arc-sec). Freely available Land Use / Land Cover raster data were used to assign roughness coefficients to the computational mesh.

3.2. Development of Inundation Maps

The results of the dam break-analysis for overtopping failure showing depth, velocity, water-surface elevation, and time of arrival of flood in HEC-RAS were exported as map layer. While saving map-layer, Unsteady Profile was selected as "Maximum" for depth, velocity and water-surface elevation and "Minimum" for Arrival time (Fig. 2). The process was repeated for other two scenario viz. Piping failure and LCR.

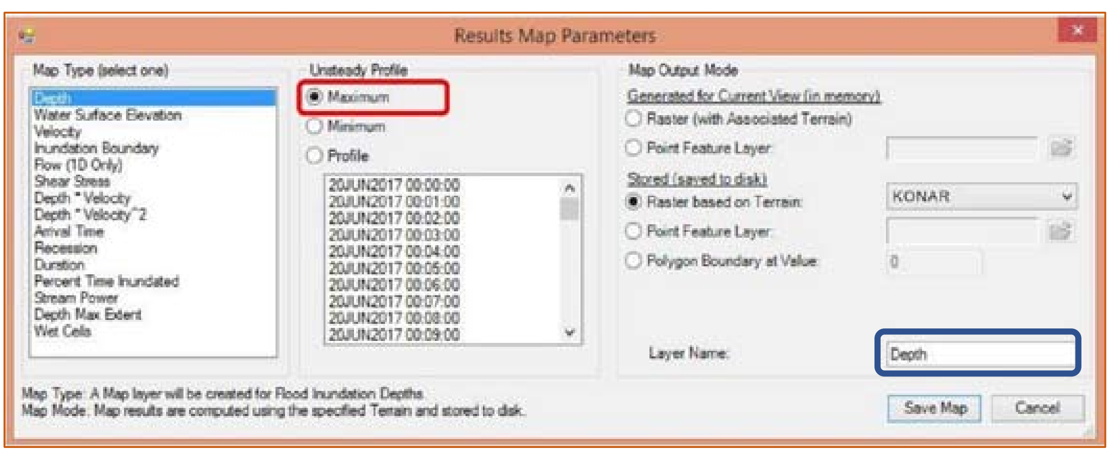

Fig. 2 : Saving a map-layer for importing to GIS platform

Mapping involves superimposing the inundation area outline on an existing map, aerial photograph, or satellite image with general features like roads, railways, state boundaries etc. Since the exported map-layer is geo-referenced, they can be imported in GIS platform (ArcGIS) for capturing additional information for developing the inundation maps. Location of human settlements can be marked in ArcGIS using Google-hybrid base map or exporting the map-layer as Keyhole Markup Language (kml) for adding settlement location in Google Earth Pro.

In the instant case, the settlements were identified in Google-Earth pro and results were imported back into ArcGIS. Finally, the inundation maps were prepared for each scenario showing settlements along with necessary map elements such as a base-map, scale, north-arrow, legends, location map and other information. The outcome of the dam break models as well as inundation maps, with (1) maximum water depth, (2) maximum water velocity, and (3) maximum water-surface elevation and (4) minimum time of arrival of flood, were shared with DVC for development of Tier I EAP in the year 2016 [4]. Fig 3 shows one such Inundation map shared with DVC.

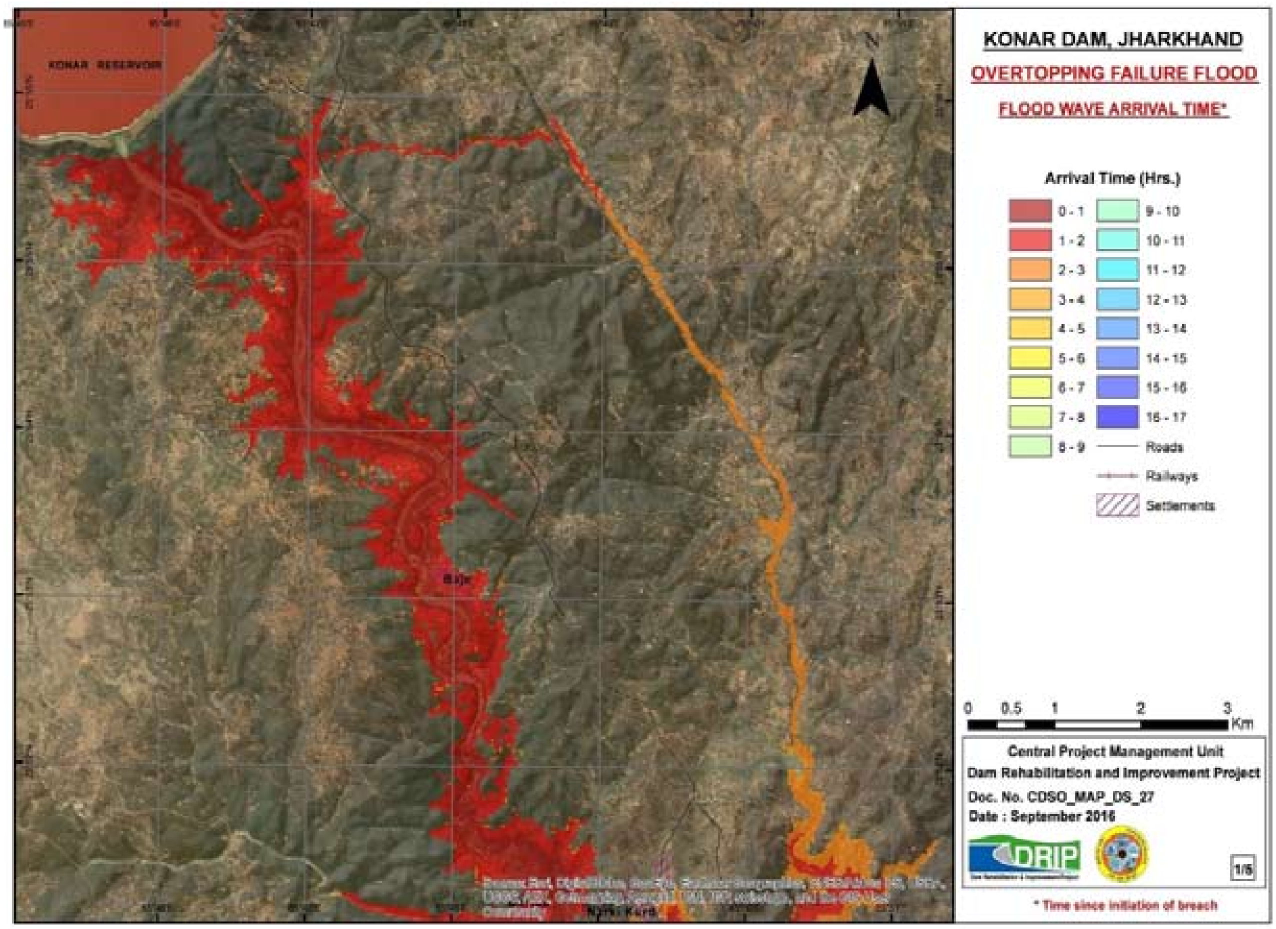

Fig. 3 : Inundation Map for Overtopping Failure showing flood wave arrival time.

3.3. Consequence analysis and Flood Hazard Reference Value

The severity of the area for a particular failure scenario can be determined from the outcome of dam break analysis. The Guidelines for Mapping Flood Risks associated with Dams [6], 2018 further describes the hazard curves (Fig 4) and the vulnerability thresholds related to the vulnerability of the community when interacting with flood waters (Table 1). Based on the field visits and administrative boundaries of local DMAs, the settlement locations were re-drawn and a total of seventy-one affected settlements were identified. The inundation maps were revised to incorporate the modified settlement areas (detailed under 3.4. Preparation of Evacuation Plan). Vulnerability map and Hazard Vulnerability Classification for these settlements were prepared utilizing the outcome of the dam-break analysis based on the recommendation of new guidelines [6]. Finally, the affected settlements were sorted in order of their severity with respect to the arrival time of flood wave for each of the three scenarios.

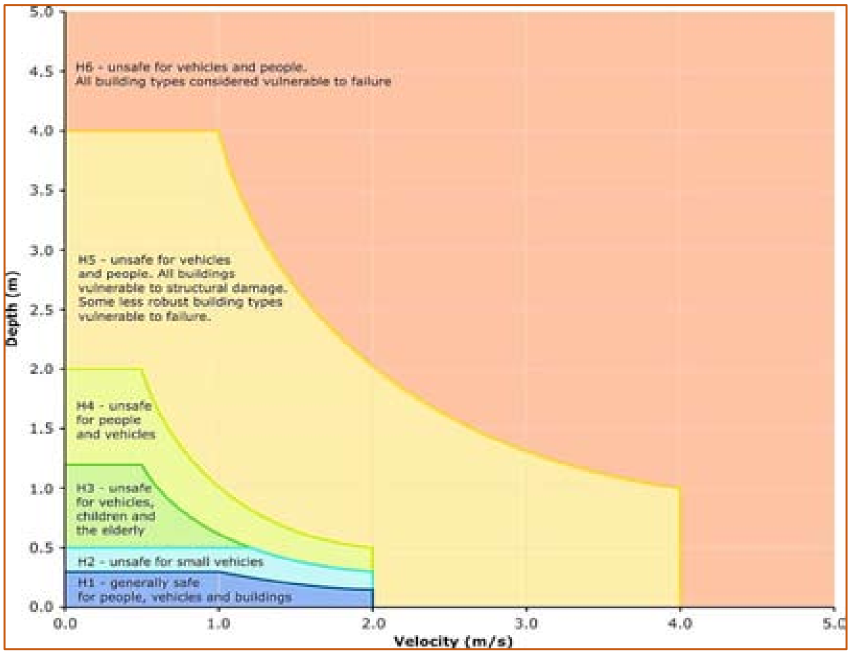

Fig. 4 : Flood hazard curves (adopted from AEMI, 2014) [6]

Table 1 : Classification limits for vulnerability thresholds of combined hazard curves [6]

Hazard Vulnerability Classification	Classification Limit (D and V in combination, m²/s)	Limiting Still Water Depth (D, m)	Limiting Velocity (V, m/s)
H1	D×V ≤ 0.3	0.3	2.0
H2	D×V ≤ 0.6	0.5	2.0
H3	D×V ≤ 0.6	1.2	2.0
H4	D×V ≤ 1.0	2.0	2.0
H5	D×V ≤ 4.0	4.0	4.0
H6	D×V > 4.0	-	-

3.4. Preparation of Evacuation Plan

The objective of an EAP is to clearly outline "WHO does WHAT, WHEN, WHERE and HOW?" without any ambiguity. The EAP document must clearly outline the roles and responsibilities of all concerned officials including DMAs as well as the process and sequence of each activity. As per the guideline [3], an EAP must include inundation maps and local authorities (DMAs) shall use these maps for evacuation planning, once notified for evacuation.

As availability of multiple inundation maps may create confusion for DMAs during evacuation process, it is critical to have an evacuation plan which shall have all the necessary information laid out in lucid manner. Continuous stakeholders' meetings, table-top exercises and mock-drills would certainly help DMAs understand the inundation maps and their roles in planning an evacuation, however, there is no substitute for a simpler evacuation plan on first place. Therefore, contrary to the multiple inundation maps, a single inundation map with additional information like evacuation route and shelter point for each settlement, supplemented by priority-based evacuation table would be much useful for DMAs for on-field rescue operations.

Since the jurisdiction of evacuating authorities are based on the administrative boundary, data related to administrative boundaries were required for creating such maps. Geo-referenced village boundary map of Bokaro and Hazaribagh districts as well as their panchayat boundary map, block boundary map and district boundary map were obtained from the website of Jharkhand Space Application Centre (JSAC) under Department of Information Technology, Government of Jharkhand. Additionally, geo-referenced data related to schools, hospitals, police station etc. of the two affected district were also gathered from JSAC website. These data were superimposed on the imported map-layers in ArcGIS and the data was exported in Google Earth Pro. Nearby schools were selected as the shelter points and evacuation route for each settlement was drawn from the settlement to designated shelter points in Google Earth Pro. Finally, all the information (polyline / points) marked in Google Earth Pro viz. settlements, shelter points, evacuation routes, bridges etc. were exported back into ArcGIS. Further processing regarding determination of maximum water depth, maximum water velocity, maximum water-surface elevation as well as Time of arrival of flood at each settlement and bridges for each of the three scenarios were completed in ArcGIS. Using the newly processed information, Inundation-cum-Evacuation map was developed in ArcGIS (Fig. 5) supplemented with the table of Flood Hazard Reference Value cum evacuation plan (Fig. 6) indicating all relevant information useful during evacuation. Additionally, information about barricading of bridges and roads were also provided for each scenario (Fig. 7).

In comparison to the multiple inundation map, the inundation-cum-evacuation map developed for Konar dam is providing readily available information on evacuation route as well as shelter points specific to each settlement. Also, superimposing the administrative boundaries on maps helped in assigning roles and responsibilities of DMAs as per the administrative jurisdiction.

4. RECOMMENDATIONS

Going by the applicability of multiple inundation maps verses the one inundation-cum-evacuation map with required information, it is evident that the later would provide more usable information to DMAs as the same could be readily used for evacuation. Nevertheless, all the inundation maps are useful as they form the very basis of developing the final map. The Author proposes the use of one such map in the EAP with details like shelter points, evacuation routes in addition to details of roads, railways, major infrastructures, etc. to be incorporated in the revised guidelines on preparation of EAP. The other inundation maps shall not be included in the EAP document for clarity but shall be kept handy with the project officials for deriving engineering conclusions and other decisions related to mitigation of flood hazard.

The Author further proposes development of web-based GIS for evacuation planning and integrating the map and table of evacuation in mobile application, so that the evacuation process can be taken up on ground using remotely available data. Such measures, once incorporated in the guidelines, would provide detailed but clear inputs to concerned authorities. Regular update of information, meetings with stakeholders and table-top exercises for such planning is necessary and shall mandatorily be conducted without exception as per the timeline mentioned in the EAP.

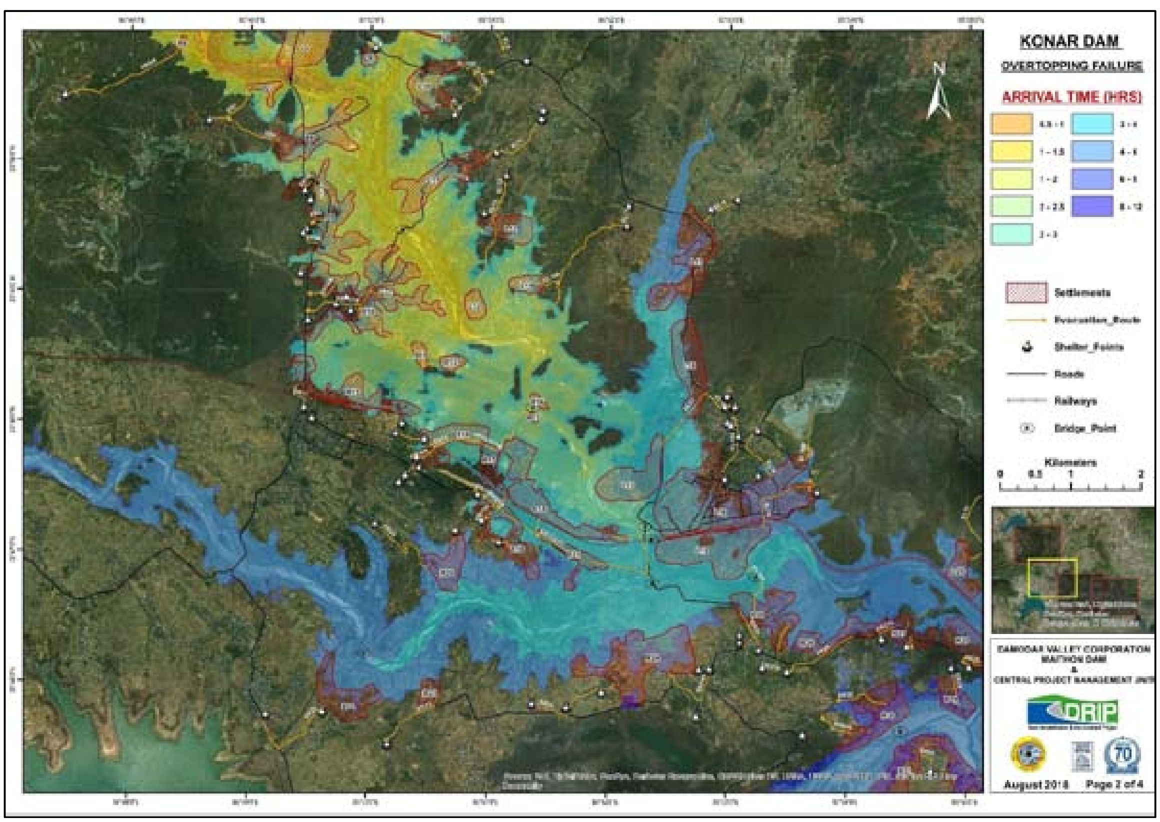

Fig. 5 : Inundation cum Evacuation maps showing settlements, shelter points and evacuation route

FLOOD HAZARD REFERENCE VALUE CUM EVACUATION PLAN

FAILURE CONDITION : OVERTOPPING (EXTREME FLOOD FAILURE)

Evacuation Window	Priority Order	Settlement id	Village name or nearby area	Block & District	Distance from Dam (in km)	Max. Water Surface Elevation (RL in metre)	Evacuation Route / Road	Remarks on Alternate Route	Shelter Points / Refugee	Responsibility of Evacuation	Contact Number & e-mail id
40 min - 1 hour	1	L4	Baja / Baje	Bishnugarh, Hazaribagh	6.0	354.8	Towards village Gajhandih for marked Shelter Point (Route EL 4 along MDR 74)		Govt. M.S. Gajhandih	Circle Officer, Bishnugrah	9934174688; cobishnugarh.1234@gmail.com
	2	L6	Narki Kurd - South	Bishnugarh, Hazaribagh	14.0	274.1	Towards village Gandake (Route EL 6 along MDR 75)	Avoid Bridge towards Karmatanr	Primary School Nerki Khurd Middle School Nerki Kalan Govt. P.S. Saitari Pindra	Circle Officer, Bishnugrah	9934174688; cobishnugarh.1234@gmail.com
	3	R4	Kari Khurd - East	Gumia, Bokaro	5.4	369.2	Towards centre of village Kari Khurd (Route ER 4)	Avoid Bridge towards Gajhandih.	Govt. Primary School Karamsirhi Govt. Primary School Baratand Govt. Rajkiyakrit Middle School Karikhurd	Circle Officer, Gomia Yashwant Nayak	9470128210 cogomia15@gmail.com
	4	L3	Alkilwa	Bishnugarh, Hazaribagh	3.4	380.1	Towards marked Shelter Point (Route EL3 & EL3A)		Govt. P.S. Kailujara, Alkilwa	Circle Officer, Bishnugrah	9934174688; cobishnugarh.1234@gmail.com
	5	R1	Dhudhmo	Gumia, Bokaro	1.0	406.6	Towards village Karma / Karmo (Route ER1)		Govt. Primary School Karmo Govt. Primary School Dudhmo	Circle Officer, Gomia Yashwant Nayak	9470128210 cogomia15@gmail.com
	6	R2	Dhudhmo - East & Karma / Karmo	Gumia, Bokaro	2.6	390.3	Towards village Karma / Karmo (Route ER2)		Govt. Primary School Karmo Govt. Primary School Dudhmo	Circle Officer, Gomia Yashwant Nayak	9470128210 cogomia15@gmail.com
1 hour - 1 hr 30 min	7	R8	Karmatanr & Chitu - East (Gomikarmanar & Hethbarwa)	Gumia, Bokaro	14.4	272.6	Towards centre of Village Chitu (Route ER8)	Avoid Bridge towards Narki Kurd	Rajkiyakrit Middle School Chitu	Circle Officer, Gomia Yashwant Nayak	9470128210 cogomia15@gmail.com
	8	R7	Chitu - North East & Karmatanr - West (Devki Stone Work)	Gumia, Bokaro	13.4	276.1	Towards centre of Village Chitu (Route ER7)	Avoid Bridge towards Narki Kurd	Rajkiyakrit Middle School Chitu	Circle Officer, Gomia Yashwant Nayak	9470128210 cogomia15@gmail.com
	9	R10	Khamhara & Sasbera (BDO Colony,Khamra Basti, Nawadari Sasbera)	Gumia, Bokaro	16.3	271.6	Towards marked shelter points (via Route ER10, ER 10 A, ER 11/12)		Pitts Modern School DPS Play Group, Sasbera Toddles Den Public School High School Gomia Dih Rajkiyakrit Middle School Gomiya Rajkiyakrit Primary School Gomiya (Kanya) KGBV Gomia, Sarhochia (Above 1st Floor)	Circle Officer, Gomia Yashwant Nayak	9470128210 cogomia15@gmail.com
	10	L11	Gandake - South & Armo - West	Bermo, Bokaro	16.4	271.6	Towards Marked Shelter Point (Route EL 11)		Govt. Primary School Nawatand	Circle Officer, Bermo Md. Moddasar Nazar Ansari	8084266714 bermoco7@gmail.com
	11	R5	Bartua - East & Banchatra East	Gumia, Bokaro	11.8	282.1	Towards Village Banchatra (Route ER 5/6)		Govt. Primary School Bhoratand, Banchatra	Circle Officer, Gomia Yashwant Nayak	9470128210 cogomia15@gmail.com
	12	R6	Banchatra - East	Gumia, Bokaro	12.4	281.1	Towards Village Banchatra (Route ER 5/6)		Govt. Primary School Bhoratand, Banchatra	Circle Officer, Gomia Yashwant Nayak	9470128210 cogomia15@gmail.com
	13	R3	Karma / Karmo - East	Gumia, Bokaro	3.2	381.4	Towards centre of village Karma / Karmo (Route ER2 / ER3)		Govt. Primary School Bhelwapani Govt. Primary School Karmo Govt. Primary School Dudhmo	Circle Officer, Gomia Yashwant Nayak	9470128210 cogomia15@gmail.com
	14	L1	Arjari - Centre	Bishnugarh, Hazaribagh	2.8	389.5	Towards marked Shelter Points in Village Laharidih (Route EL 1)		Govt. P.S. Gondalitand Govt. P.S. Lahariadih	Circle Officer, Bishnugrah	9934174688; cobishnugarh.1234@gmail.com

Fig. 6 : Flood hazard reference value cum Evacuation Plan Table

BRIDGE DOWNSTREAM OF KONAR DAM

FLOOD HAZARD REFERENCE VALUE

Bridge Id	Bridge - Location	Distance from Konar Dam (in km)	OVERTOPPING		PIPING		LCR	
			Max. Water Surface Elevation (RL in metre)	Minimum Arrival Time (HH:MM)	Max. Water Surface Elevation (RL in metre)	Minimum Arrival Time (HH:MM)	Max. Water Surface Elevation (RL in metre)	Minimum Arrival Time (HH:MM)
Bridge 1	Local road from Gajhandih to Kari Khurd	6.0	365.7	00:25	361.5	00:56	355.8	01:11
Bridge 2	On way to Karmatanr from Narki Kurd	13.5	274.1	00:56	267.4	01:31	263.9	02:06
Bridge 3	Gandke to Khamra Basti	16.4	271.6	01:14	265.3	01:51	262.8	02:38
Bridge 4	Near CCL Canteen Phase 2 Open Cast	20.8	265.0	01:50	259.7	02:35	257.8	04:10
Bridge 5	Near Garmajuua Basti	22.2	264.6	02:42	259.6	03:36	257.3	06:30

Fig. 7 : Information regarding barricading of bridges in different failure and release scenario

5. CONCLUSION

The consequences of a dam failure are severe and may result in loss of thousands of lives and properties of unimaginable scale along with permanent damage to environment and ecology. An effective emergency plan thus plays a significant role in minimizing the scale of impact caused by dam failure. One of the key components of an effective EAP is development of an effective evacuation plan. Different Inundation maps are attached in the EAP for evacuation planning. However, as described in the paper, using different maps at the time of emergency, may not be convenient for DMAs. A single map with all the essential information required for evacuation of people would be much useful for evacuating authorities. Use of web-based GIS and mobile application for evacuation planning will undoubtably have significant impact because of remote availability of data. It is proposed to include both these aspects in future revision of guidelines for preparation of EAP.

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