A Dam Break Analysis Using HEC-RAS 2D Hydrodynamic Modeling for Decision-Making System

Kishanlal Darji and Dhruvesh Patel

Abstract Flood is the disastrous phenomenon of the nature, especially, when it is associated with large dams. The large dam is constructed for multipurpose use, however the major objective to operate to reduce the flood threat at downstream. In recent climatic uncertainty and extremity, dam operation is the challenging part for flood resilience. In addition, old dams have chances to break under extreme condition. To strengthen the resilience condition and improve the decision-making system, recent state-of-art to utilize a dam break analysis for prior threat detection. This is the case of dam break analysis, it has been developed for Madhuban large dam in Gujarat. The Hydrologic Engineering Center's River Analysis System (HEC-RAS) 5.0.7 version of hydrodynamic model in 2D environment is developed for studies. The digital elevation model, flood hydrograph and elevation capacity curve of dam has been utilized for building the model. The entire approach is simulated under the unsteady flow condition. The water surface elevation, water depth, velocity, arrival time, and inundation maps have been prepared under the guideline of Dam Rehabilitation and Improvement Project (DRIP). Probable future catastrophe has been identified and addressed for future resilience. The case will help to produce the flood mitigation strategies associated with dam break case in Gujarat.

Keywords Dam break analysis · HEC-RAS · Flood · Overtopping failure

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1 Introduction

Approximately 5745 large dams, and several thousand small dams in India, are providing basic social, economic, and ecological services such as flood control, water storage for society, industrial, and agricultural use, river navigation, mining, hydropower generation, industrial waste management, and recreation. However, due to lack of consideration dams have started getting lower priority for maintenance. So, the dams constitute a serious threat to life, property and the environment, due to their potential to fail and cause disastrous flooding. According to [1] Costa reports more than 11,100 people losing their lives due to just three dam failures in the entire world: (1) Vajon dam, Italy (2) Johnstown dam, Pennsylvania, and (3) Machhu II dam, India [2]. In each of these cases, warning signals were not provided to a large number of populations. So, it is required to produce warning signals and emergency action plans of dams to reduce loss of life. The dam offers us a lot of benefits for our society but a result of the floods, caused by the failure of the constructed dams has led to some of the most devastating natural disasters in the last two centuries [3]. Dam break analysis has been carried out in order to investigate the behavior of high floods, as a result of the dam breaking and taking control of the area from flooding. This is very useful for the preparation of an emergency action plan for the evacuation of the people, and the minimized loss of the property [4]. Hurricanes, floods, cannot be avoided, however, by the adoption of appropriate evacuation methods, the losses can be minimized [5, 6]. Particular attention should be paid to effective power management through the development of an emergency evacuation plan to deal damage to a minimum.

Dam failure is generally defined as an incident to, from any structural problems, including accidental releases, or to control the outbreak of the impounded water or the incidents, which could result in the loss of the dam [7]. Different case studies express that dam failure arrives due to several reasons such as flood event, piping/seepage, foundation failure, earthquake, landslide, structural failure, equipment malfunction/failure (such as gates, etc.), upstream dam failure, the rapid drawdown of the pool, sabotage, etc. 25% of all dam failures are due to overflowing. 25% of the earthen dams and 12% of the concrete dams break in link with overtopping [8]. While HEC-RAS hydraulic computation is generally limited to overtopping and piping failure mode, all other failure modes can be simulated with one of these two methods.

The study reviews several literatures in the domain of dam break modeling using HEC-RAS software [3, 9–14]. Dam break modeling involves the prediction of breach parameters (shape, time, and size of failure) and using them to estimate breach outflow hydrograph, which is then routed to downstream of a river reach and then hydrograph at different downstream sections up to the point considered on the river are predicted. The HEC-RAS 2D modeling was toward performing unsteady flow calculations with the intent of determining the outflow hydrograph and peak discharge at various stations and to provide detailed information about a failure such as warning time available, maximum water surface elevation, and velocities at downstream locations.

The HEC-RAS has ability to simulate the break of an inline and lateral structure such as dam and levee [6]. The main aim of this study is to apply HEC-RAS model for Damanganga dam break analysis based on given geometry data. Dam breach simulation studies may be required for preparing emergency action plan (EAP) to reduce loss of life at a time of failure of the downstream area of Damanganga dam which includes the Sillvassa, Vapi city as well as Vapi industrial area, Daman, and many villages. This paradigm analysis will be very useful to the dam owner to strengthen the decision-making system.

2 Study Area

The Damanganga River is also known as the Dawan River which is located in western part of India. The Damanganga River originates from the Western Ghats range, and it flows west into the Arabian Sea (Fig. 1). This river flows through Gujarat, Maharashtra, Union territory of Daman, and Union Territory of Dadra and Nagar Haveli. The industrial area of Silvassa and Vapi located on the north side of the Damanganga River, and the Daman dominates both sides of the river mouth. Damanganga River has a total of 1813 km^2 catchment area, out of this 376 km^2 in Gujarat, 119 km^2 in U.T. of Dadra, and Nagar haveli, and 1318 km^2 in Maharashtra. The average weighted rainfall of the Damanganga catchment is 2382 mm.

Damanganga reservoir also known as Madhuban dam is the current key project on the Damanganga River located at Madhuban village in Dharampur taluka of Valsad city of Gujarat as shown in Fig. 1. Damanganga reservoir is the inter-state multifunctional project of the Government of Gujarat and Union Territory Daman and Diu and Dadra and Nagar Haveli. Madhuban dam was constructed from 1972 to

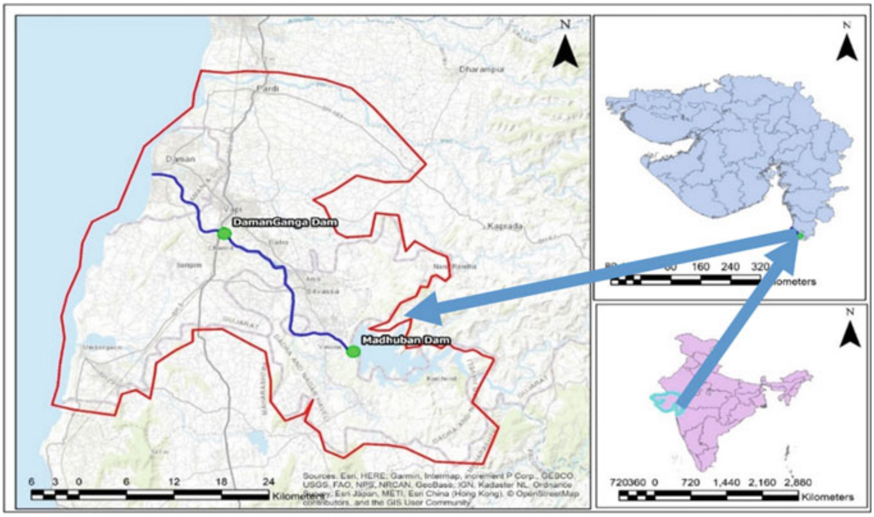

Fig. 1 Location map of the study area

1998. It is a composite dam of saddle dam, earth-fill dams, and masonry. The total length of the Madhuban dam is 2870 m in which 353-m masonry dam, 130-m saddle dam, and 2388-m Earth-fill dam. The maximum height from the deepest foundation level to the top of the roadway is 49.84 m for masonry, 6.3 m for a saddle, and 58.6 m for an earth-fill dam. Madhuban dam was designed up to 9.48 lakh cusecs flood. The gross storage capacity of the dam is 524.86 MM^3 and the live storage capacity is 478 MM^3. The spillway, with a roller bucket for energy dissipation, which is planned to rout a probable maximum flood (PMF) discharge of 7.78 lakh cusecs managed by 10 radial gates each of dimensions 15.55 * 14.02 m.

The 24 villages in U.T. Dadra Nagar Haveli, 112 villages in the Valsad district, and 26 villages in U.T. Daman are irrigated by Damanganga reservoir. The Damanganga reservoir provides 58 million gallons each day for domestic and industrial water demands and also has a minor power plant of capacity 5.6 MW. The budget of the Damanganga reservoir project was distributed between the sharing states as per the Inter-State Agreement of 1992.

3 Data Collection

Meteorological data of the study area were collected from the State Water Data Center (SWDC), flood control cell of Damanganga reservoir (https://swhydrology.gujarat.gov.in), and the Government of Gujarat and Indian Meteorological Department (IMD) (http://www.imd.gov.in/). Thematic maps were prepared from the published literature (https://www.gsi.gov.in/, http://cgwb.gov.in/) of the different agencies in conjunction with the interpretation of the Landsat images, Google Earth images, and SRTM DEM using remote sensing and GIS technology. Salient features and capacity area table of Damanganga reservoir are collected from the Damanganga project division no.1 office.

4 Methodology

The method followed for dam breach analysis is as mentioned as shown in flow chart (Fig. 2).

Required data for model simulation:

- Salient features of Madhuban dam.
- Elevation capacity curve of the Madhuban dam.
- Design flood hydrograph or probable maximum flood as the upstream boundary condition.
- Upstream sectional elevation of a dam.
- Manning's roughness coefficient for a site for a downstream area.

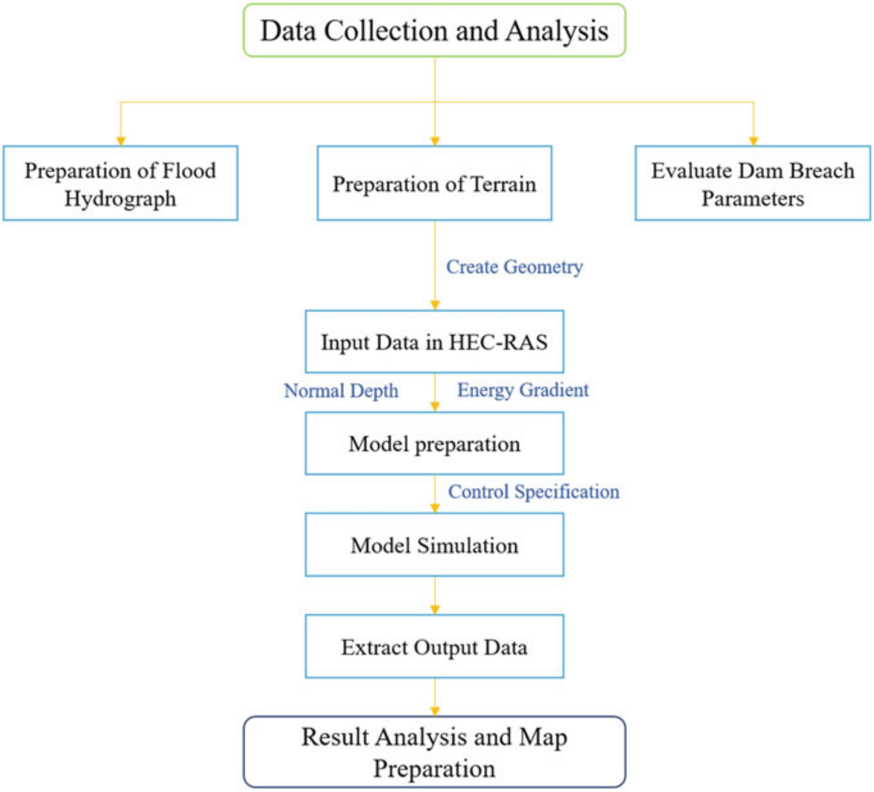

Fig. 2 Methodology flow chart

- The normal depth of the river downstream of Damanganga reservoir.
- Digital elevation model (DEM)—Terrain of the study area.

4.1 Flood Hydrograph

Flood hydrographs are displays that how a basin responds to a period of precipitation. The flood data from the dam, which affects the study area, was obtained from the Flood Cell Department of Madhuban Dam, under the Government of Gujarat for the year 2004 event as shown in Fig. 3.

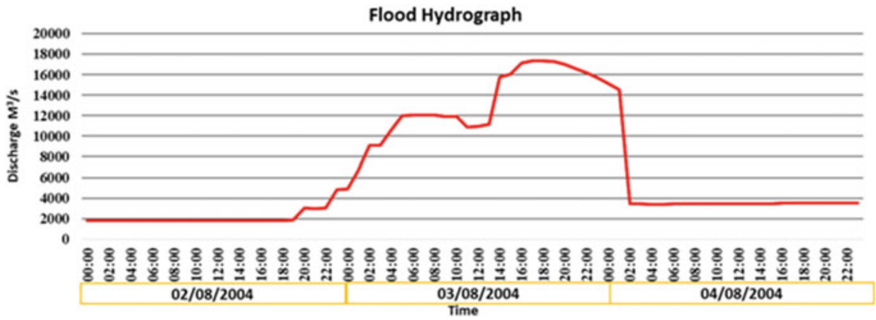

Fig. 3 Flood hydrograph of Madhuban dam of high flood event 2004

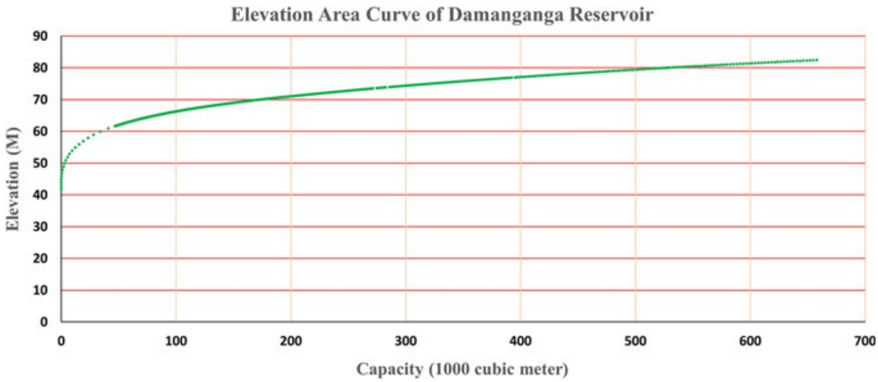

Fig. 4 Elevation capacity curve of Madhuban dam

4.2 Area Capacity Curve

Area capacity curves are generally used for reservoir flood routing, determination surface area of the water, and volume corresponding to each elevation, classification of a reservoir, and distribution of sediments in the reservoir. Elevation capacity curve of Madhuban dam was collected from Damanganga Div. project 1 office which is shown in Fig. 4.

4.3 Estimation of Dam Breach Parameters

It has been shown that the selection of dam breach parameters for dam breach modeling contains the extreme uncertainty of all phases of dam failure modeling and therefore it is necessary to evaluate carefully of dam breach parameters for better understanding and simulating the model.

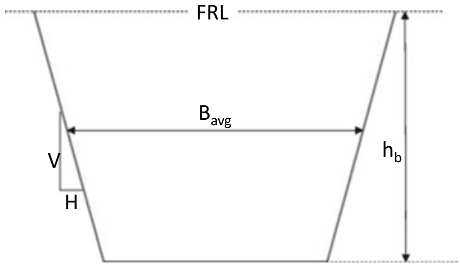

Fig. 5 Cross-section view of breach

There are several methods available for estimating dam breach parameters for use in dam breach simulation. In this study, we have used the Froehlich equation to estimate dam breach parameters which is recommended by Dam Rehabilitation and Improvement Project (DRIP). The Froehlich equation for estimation of Earthen dam breach parameters is [15] (Fig. 5):

$$B_{avg} = 0.23 \times K_m \times V_w^{\frac{1}{3}} \tag{1}$$

where B_{avg} = expected value of average width in meter,

K_m = 1.0, for internal erosion failure,

1.5, for failure by overtopping,

M = 0.6 for internal erosion failure, and

1.0, for overtopping failure,

where M = expected average breach side-slope ratio.

$$T_f = 60 \times \frac{V_w}{g H_b^2}^{\frac{1}{2}} \tag{2}$$

where, T_f = breach formation time in seconds,

V_w = volume of water above breach bottom in M^3, and

H_b = height of breach in meters.

4.4 Preparation of Terrain

Terrain preparation for the study area is done by the RAS mapper tool using the digital elevation model as input in the model. The projection of terrain is UTM Zone

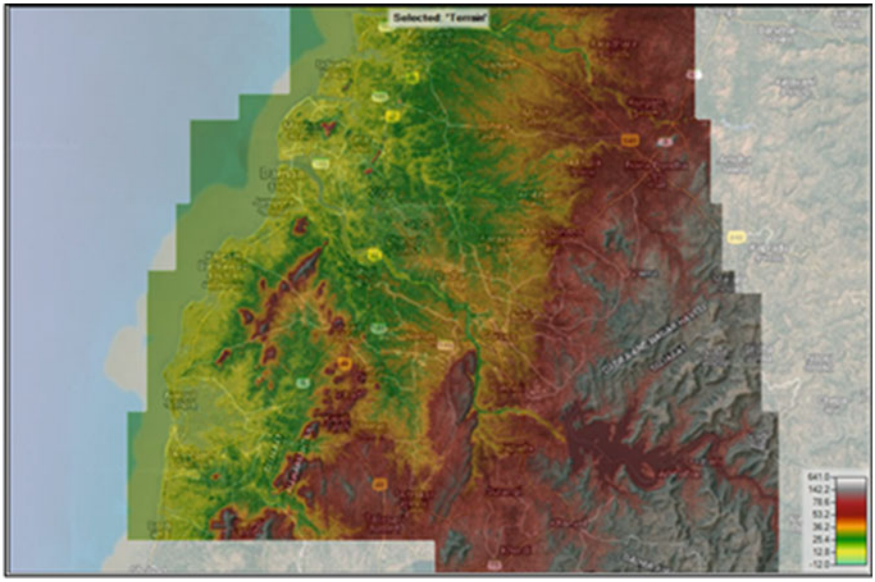

Fig. 6 Terrain of downstream of Madhuban dam

43N as per the study area. Prepared spatial referenced projected terrain is shown in the following Fig. 6.

5 Results and Discussions

HEC-RAS dam breach under unsteady flow condition is performed to simulate the events. The breach parameters are as (1) Breach bottom width is 250 m, (2) Side slope is 1:1 (H: V), and (3) Breach development time is 3.78 h.

After simulation, the dam breach model under unsteady process, flood depth, arrival time, water surface elevation, inundation area, and velocity of flood is extracted. Nearly 238 Km^2 area are under inundation in overtopping flooding condition. This is very useful information for dam wner to prepare an emergency action plan for Damanganga Dam project and reduce the life threating catastrophic event.

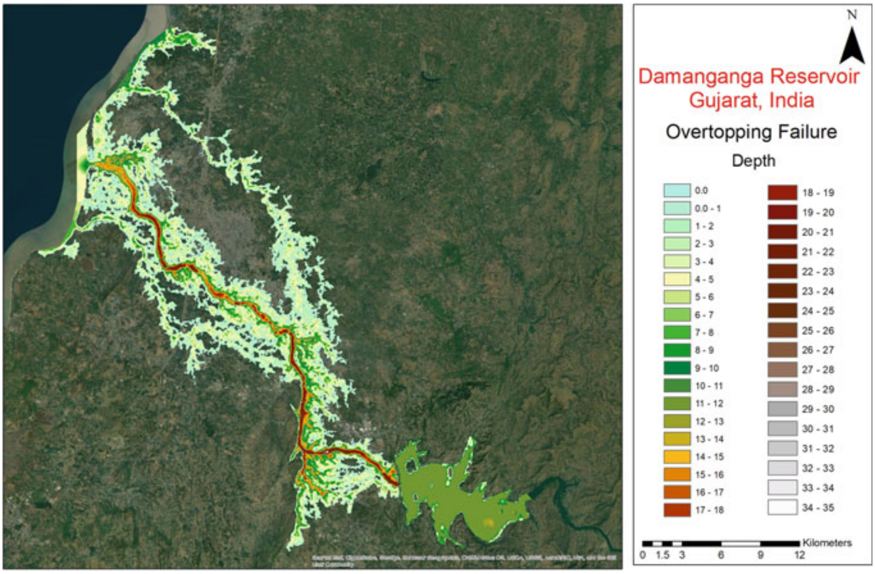

Fig. 7 Water depth map

The basic prepared maps are described as follows:

Depth map: Depth map represents the water depth from ground surface. The Silvassa, Vapi industrial area, northern part of Daman, and low lying area near River is highly vulnerable area due to dense residential and urbanization (Fig. 7).

Water surface elevation: Water surface elevation map indicates the height of the water from mean sea level which is useful to get the RL of water at a particular location (Fig. 8).

Inundation boundary: This map shows that the area of inundation during dam breach condition which is useful for evacuation team (Fig. 9).

Arrival time: Arrival time (hours) signified when the water depth reaches a specified inundation depth. This map is used to find out where to start evacuation of people, so we reduce the loss of life (Fig. 10).

6 Conclusions

Dam break for large dam is the sate-of-the art for flood risk assessment and management using hydrodynamic modeling. Present case of Damanganga reservoir project has a paradigm case analysis for dam break analysis of large dam in Gujarat. The flood depth, water surface elevation, arrival time, and inundation maps are extremely useful

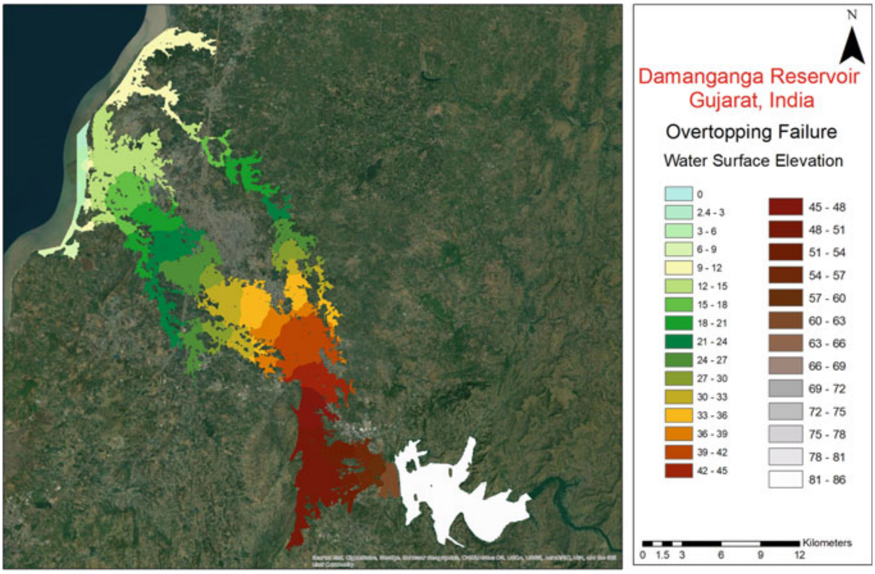

Fig. 8 Water surface elevation map

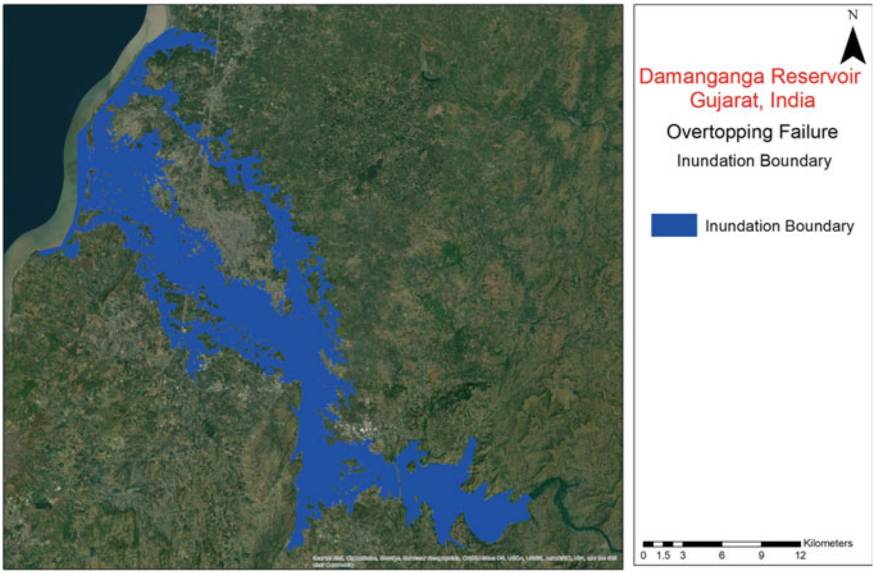

Fig. 9 Inundation boundary map

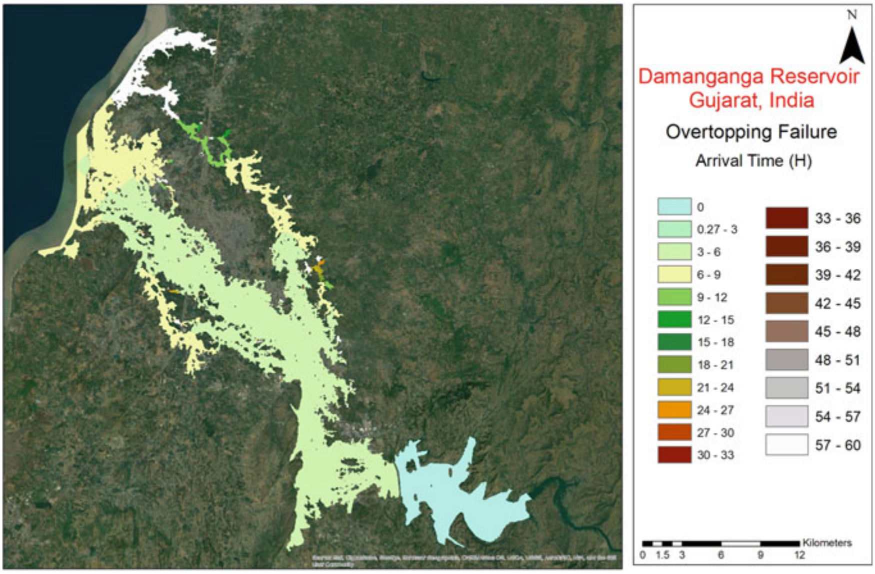

Fig. 10 Arrival time map

to the dam owner to prepare an "emergency action plan" under extreme flooding condition. The result outcomes show that 238 km^2 are under flooded in overtopping flooding condition This is very useful information to dam owner to warn and evacuate the people under any unfavorable condition and reduce the loss of life and properties.

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