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Study of dam break analysis using HEC-RAS

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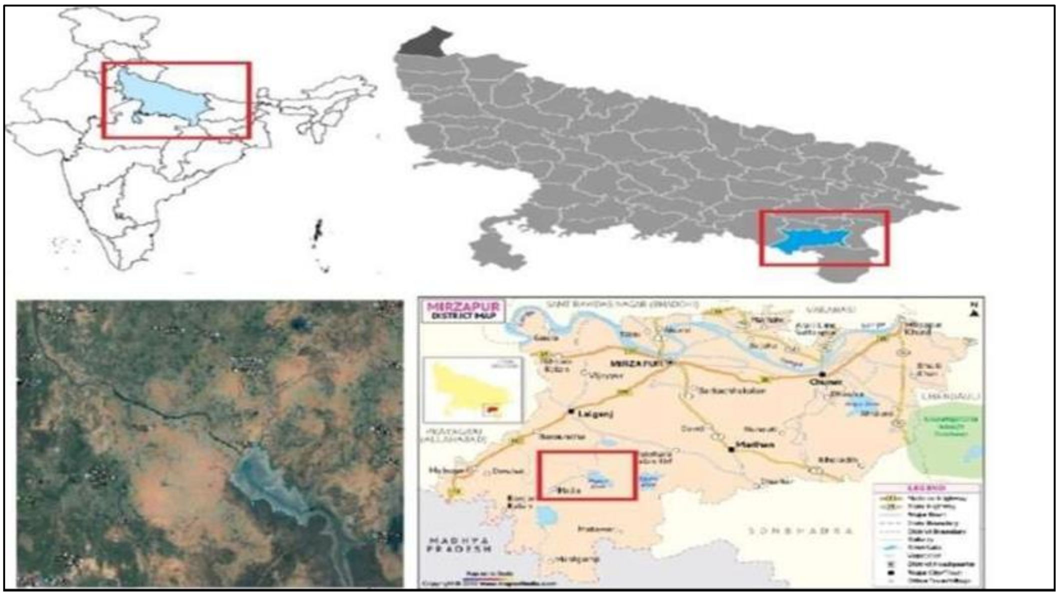
Abstract
Dams are considered as structures containing dangerous forces. Even though dam failures are comparatively rare, they can cause immense damage and loss of life and properties when they occur. Complete hydraulic simulation and analysis for a hypothetical dam break of Meja dam was performed using HEC-RAS model with river geometry derived from DEM. HEC- RAS public domain software to the application of combined flood routing and flood level forecasting. The details of water surface elevations, depth of flood, flood arrival time and velocity of flood wave at different locations of downstream gives an idea about extent of flooding. The outcome of the modeling showed that in the event of failure of Meja dam, some areas which include residential, agricultural and industrial areas were identified to have very high risk of being inundated due to the significant difference in the value of water surface elevation and ground elevation. Simulation of dam break result and resulting floods are essential for characterizing and reducing negative effects occurred on the downstream area. Development of emergency action plan requires exact estimation of inundation level and the arrival time of flood wave at the downstream point.

Keywords: HES-RAS, DEM, flood routing, RAS mapper, QGIS

Introduction
Dams are constructed to serve a variety of purposes such as supply of drinking and irrigation water, generation of electric power, aquaculture, recreation and flood protection etc. Apart from above advantages floods resulting from the failure of constructed dams have also produced some of the most devastating disasters of the last two centuries. Dams are considered as "installations containing dangerous forces". Dam failures are comparatively rare, but can cause immense damage and loss of life and properties when they occur. Dam failure results from both eternal force and internal erosion. Dam failure may arise due to different reasons ranging from seepage, piping (internal erosion), overtopping due to insufficient spillway capacity and insufficient free board and to settlement due to slope slides on the upstream shells and liquification due to earthquake (Dincergok, 2007) [4]. The main reason of overtopping is decreasing live storage capacity and increasing dead storage of dam due to silt deposition in the storage area that is transported in by lateral inflow (River flow). Dam break may be summarized as the partial or catastrophic failure of a dam which results in quick release of water from the reservoir. In the event of dam break, the energy stored behind the dam is capable of causing rapid and unexpected flooding on the downstream, resulting in loss of life and damages caused to properties. It becomes our prime responsibility to ensure safety of these dams to allay any kind of apprehension from the mind of the people. While the safety of lives and property of people in vicinity of dams is of paramount importance, Dam safety assurance is also important for protection of investment and its intended benefit as also water security of country at large. The basic computational procedure of HEC-RAS for steady flow is based on the solution of the one- dimensional energy equation. Energy losses are evaluated by friction and contraction / expansion. The momentum equation may be used in situations where the water surface profile is rapidly varied. These situations include hydraulic jumps, hydraulics of bridges, and evaluating profiles at river confluences. For unsteady flow, HEC-RAS solves the full, dynamic, 1-D Saint Venant Equation using an implicit, finite difference method.

Materials and Methods
Description of the Study Area Meja dam is located 63 km south of Mirzapur city, in Mirzapur district of U.P., India. The dam is famous for its rich fauna.

It is situated on the Bealan River



Location of Study Area

Software Used

HEC-RAS 5.0.3 The program was developed by the US Department of Defence, Army Corps of Engineers in order to manage the rivers, harbours, and other public works under their jurisdiction. HEC-RAS is a computer program for modeling water flowing through systems of open channels and computing water surface profiles. HEC-RAS finds particular commercial application in floodplain management and flood insurance studies to evaluate floodway encroachments. Some of the additional uses are: dam breach analysis, bridge and culvert design and analysis, levee studies and channel modification studies. The basic computational procedure of HEC-RAS for steady flow is based on the solution of the one-dimensional energy equation. Energy losses are evaluated by friction and contraction. The momentum equation may be used in situations where the water surface profile is rapidly varied. These situations include hydraulic jumps, hydraulics of bridges, and evaluating profiles at river confluences. Fr unsteady flow, HEC-RAS solves the full, dynamic, 1-D Saint Venant Equation using an implicit, finite difference method.

St. Venant's Equations

Continuity equation

Momentum equation

Where

x = space coordinate along the channel axis.

t = time

A = cross-sectional area of the flow at location x Q = discharge

g = acceleration due to gravity

So = bed slope

Sf = friction slope

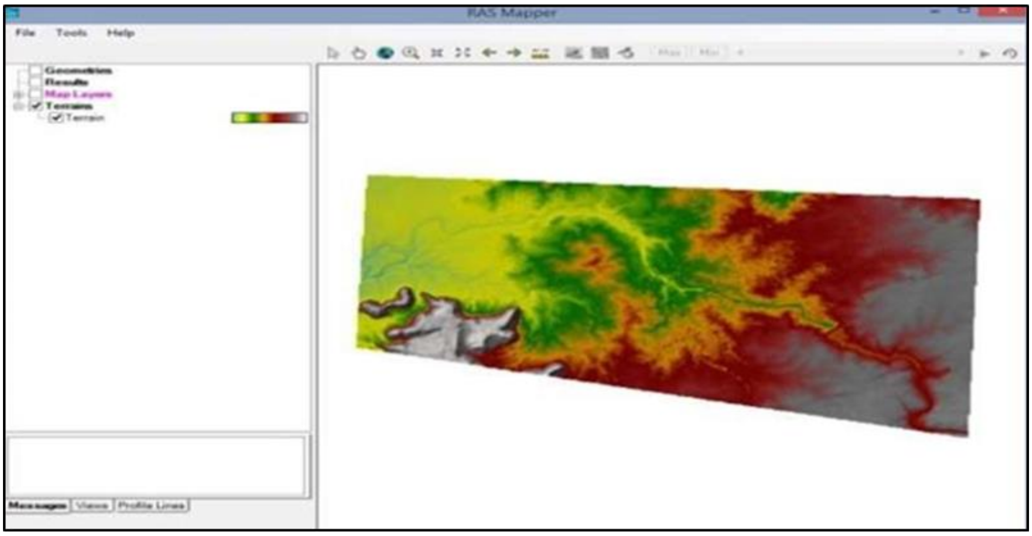
ArcGIS Arc GIS is a geographic information system (GIS) for working with maps and geographic information. It is used for creating and using maps, compiling geographic data, analyzing mapped information, sharing and discovering geographic information, using maps and geographic information in a range of applications, and managing geographic information in a database.

Methodology

The methodology involves field and desk works. The field work involves carrying out reconnaissance survey to have first-hand information about the site condition, identification of physical features of the study area (dam, river and downstream area) and the type of failure to which the dam is prone to as a result of the repeated high intensity rainfall. Collection of geometry data of dam and terrain information for the main channel and overbank flood plain areas such as dam body volume, catchment area, reservoir volume and height of dam from foundation, height of the dam from river bed, daily discharges, and spillway capacity. Desk works involves the simulation of dam break event using HEC-RAS.

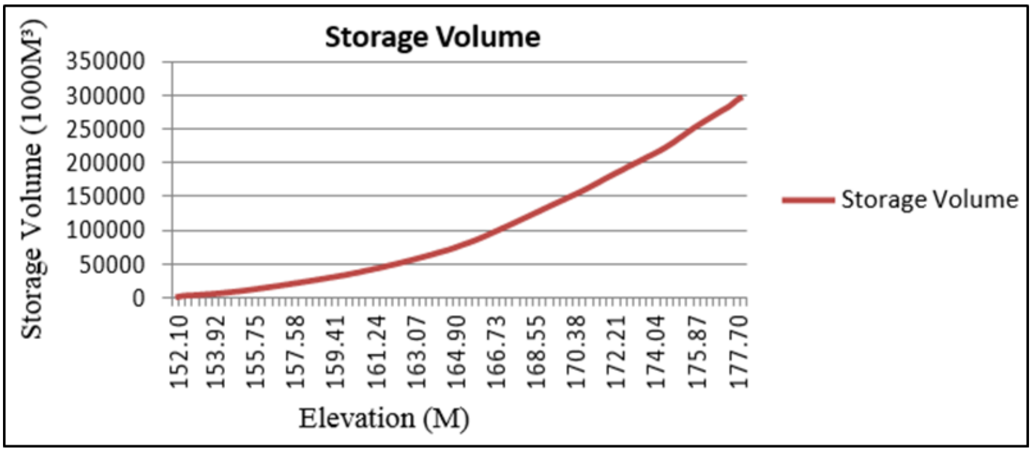
Procurement of Digital Elevation Model (DEM) file: Digital Elevation Model (DEM) is a representation of the land surface elevation of our area of interest with respect to any reference datum. DEM file is necessary to conduct 2D dam break analysis using HEC-RAS. DEM file (Entity_ID-ASTGDEMV2_0N24E082) has been downloaded from the Earth Explorer portal (earthexplorer.usgs.gov) of United States Geological Survey (USGS), NASA/METI. Then, the DEM file is clipped for our area of interest using spatial analyst tool of Arc Toolbox in ArcGIS.

Dam Break Analysis using HEC-RAS: Firstly set projection file (prj.) then loaded DEM file (tif.file) with rounding precision 1/1024 in RAS-Mapper. RAS Mapper is a GIS extension within HEC-RAS. Satellite imagery (Google Hybrid) is also loaded for reference.



Visualization of DEM in HEC-RAS

Putting geometric data: Geometric data such as location of reservoir, downstream and dam are specified. Elevation v/s volume curve of reservoir is given as input. The downstream area is divided into 94788 cells with a cell size of 70m x 70m.



Volume V/S Elevation Relationship of Reservoir

Gate Parameters: Gate specification of the dam such as height, width, invert, number of gates, location of gate, type of gate and user defined curves or discharge coefficient are specified.

Estimation of Dam Breach Parameters: The estimation of the breach location, size, and development time are critical in order to make accurate estimate of the outflow hydrographs and downstream inundation. Once the breaching parameters are estimated, the HEC-RAS can be used to compute the out flow hydrograph from the dam breach and perform downstream routing. The user is required to enter information like: failure location, failure mode, breach development time, breach shape, weir and piping coefficient and trigger mechanism into HEC-RAS model to define a dam breach. To numerically reproduce the progression, two main parameters have to be determined: breach geometry (width) and breach formation time. Due to high number of parameters involved, the formation of a breach is a complex process, hardly describe with mathematical tools (Froehlich 2008).

Average breach length (m) is given by:

$$Ba = 0.27 \cdot K_o \cdot V^{w\,0.32} \cdot H_b^{004}$$

Failure time (minutes) is given by:

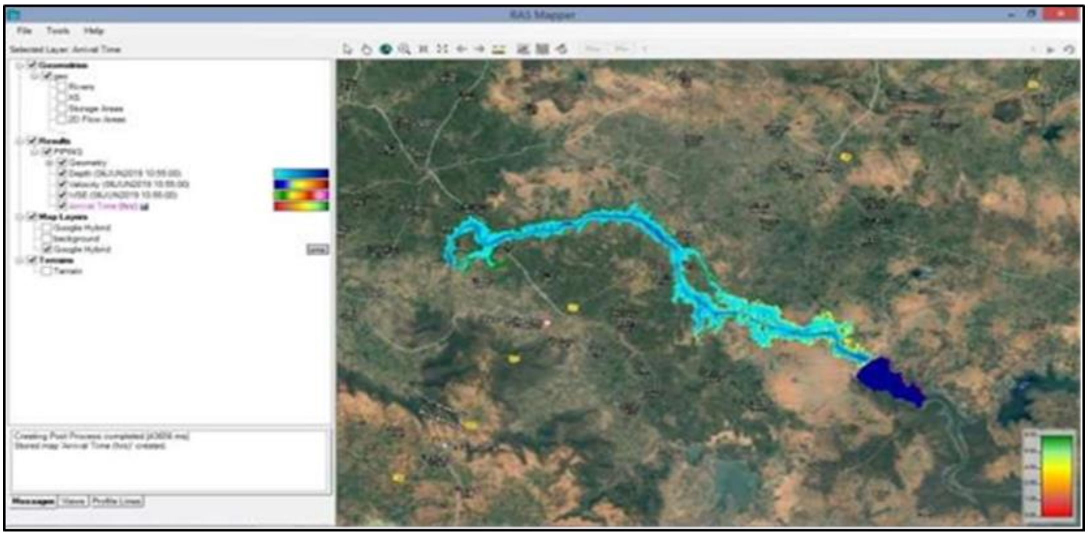
$$f = \sqrt{Vw}/\,Hb2$$

Where,
Ba = Average breach length tf = Failure time
Vw = Volume of the reservoir Hb = Breach height
g = Acceleration due to gravity
Ko = 1.3 (Overtopping), 1.0 (Other cases)

Unsteady flow data: Lateral inflow hydrograph data of reservoir and hourly precipitation data was collected from Irrigation Department Uttar Pradesh, Division Office Mirzapur.
It was put as unsteady flow data in HEC-RAS. Initial level of water parameters related to control of gates were also specified.

Unsteady Flow Simulation: Dam breach analysis is simulated as an unsteady flow simulation with a computational interval of 5 seconds and mapping interval of 5 minutes for 24 hours.

Result visualization in RAS Mapper: Flood progression in the downstream area can be visualized as an animation in RAS Mapper.
Maximum water depth, Water surface elevation, Velocity of water Arrival time can be exported as a raster layer for further processing in GIS software.



Visualization of Final Result in RAS Mapper

Results and Discussions

Dam break analysis was performed using HEC-RAS for two major types of dam breach cases, i.e overtopping and piping. Overtopping dam failure is most common type of dam failure in earthen dam.

A head-cut is formed on the top of earthen dam due to large amount of water inflow in the reservoir. Water erodes a part of dam gradually and it creates a devastating situation.

Piping dam failure occurs due to seepage of water inside the dam. The dam erodes from the inside and gradually, pipe like structures are formed inside it which leads to failure.

Parameter	Overtopping	Piping
Centre station (M)	2100	2100
Breach bottom elevation (M)	155	155
Dam crest width (M)	7.62	7.62
Slope of upstream (H:V)	3:1	3:1
Slope of downstream (H:V)	3.75:1	3.75:1
Top dam elevation (M)	180.442	180.442
Pool elevation at failure (M)	181	178
Pool volume at failure (1000M3)	362561.44	299025.4
Final bottom width (M)	194	141
Breach formation time (Hr.)	4.20	3.81
Side slope (left and right both)	0.7	1

Breach Width and Time Development

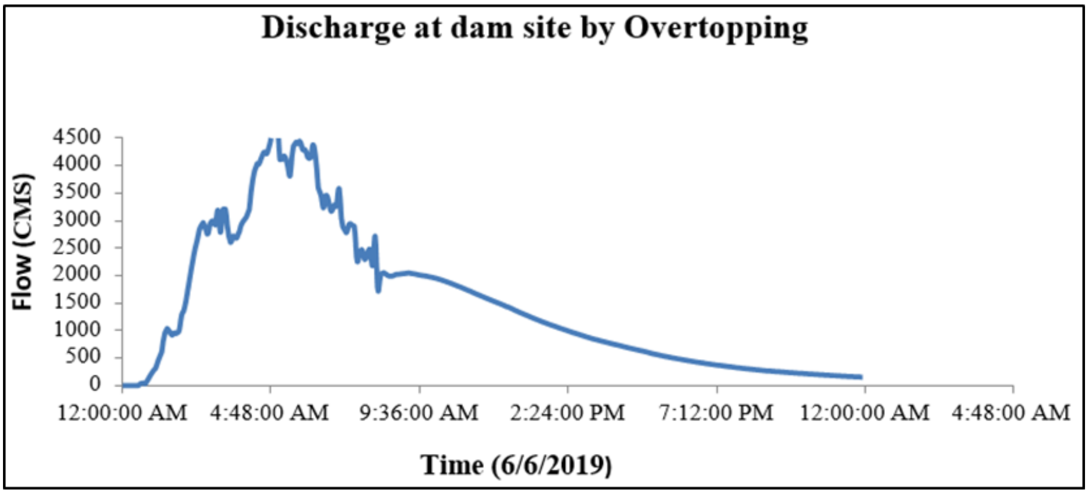
The average breach width and breach development time of dam is calculated by using the geometric information of the Meja dam through regression equation of the Froehlich (2008).

The average breach width and breach development time calculated by Froehlich (2008) are 194 m and 4.20 hr for overtopping and 141m and 3.81 hr for piping mode of failure respectively.

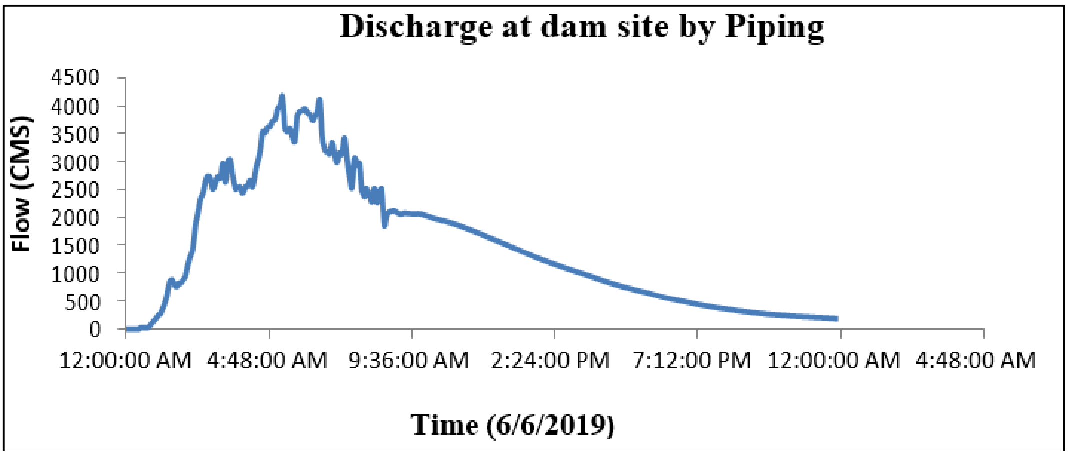
The bottom breach elevation of the dam which used as input for HEC-RAS model is 155 m for both mode of failure.

Flood Hydrograph of breached dam

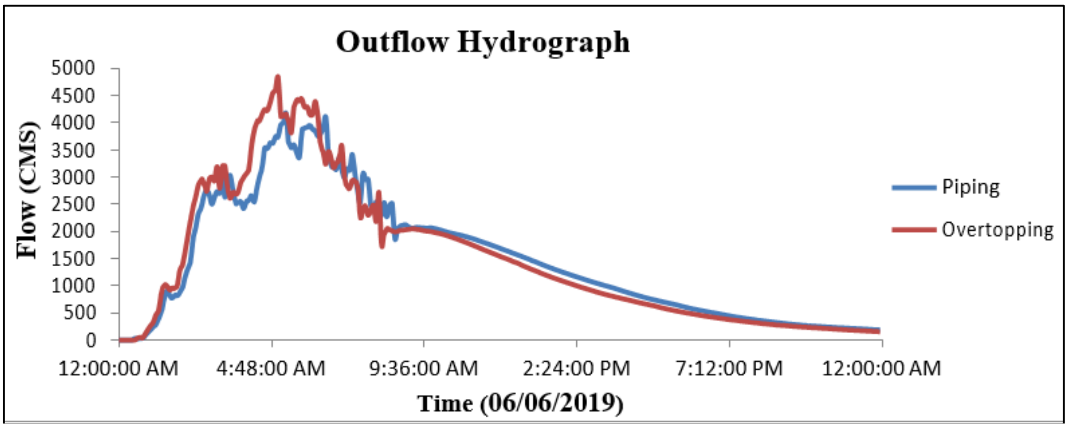
The maximum discharge flows out from the breached dam is 4836.42 m3/s (CMS) noted at 5:00 hours after dam breached due to overtopping and 4169.04 m3/s (CMS) at 5:15 hours after dam breached due to piping mode of failure. The peak discharge rate of overtopping mode of failure is greater than that the piping mode of failure. Further, the peak of overtopping failure occurs after peak of piping failure. Finally we can say that the overtopping failure more dangerous than piping failure. The fig 4.3 compared the hydrograph of overtopping failure and piping failure.



Outflow hydrograph of breached dam by overtopping failure



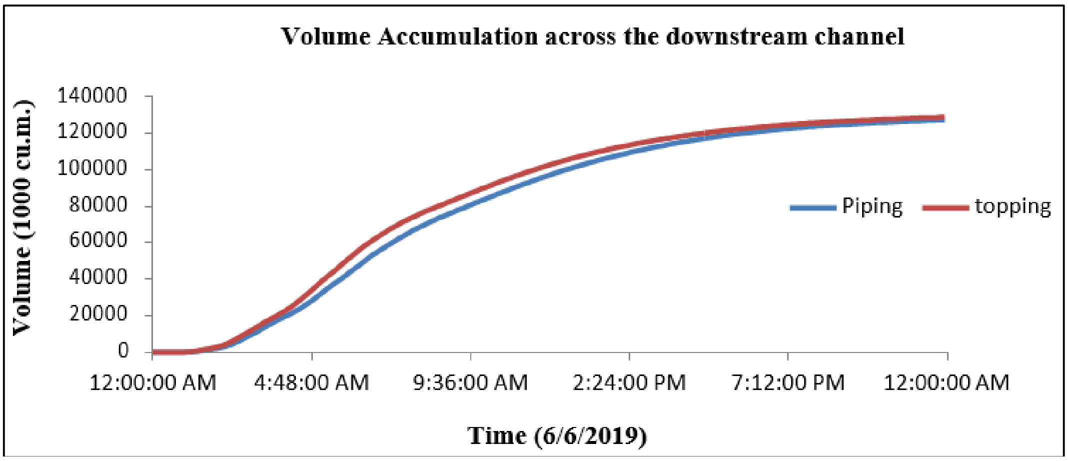
Outflow hydrograph of breached dam by piping failure



Outflow hydrograph of breached dam by overtopping failure and piping failure

Volume of water accumulation at downstream river

The maximum volume of water accumulated is 128900.8 and 127502.3 due to overtopping and piping failure respectively at end of simulation time. The flood volume accumulation along a profile line (downstream river) with respect to time is also simulated in RAS mapper.



Volume of water accumulation v/s time graph

Conclusions

The details of water surface elevations, depth of flood and velocity of flood wave at different locations of downstream gives an idea about extent of flooding. The outcome of the modeling showed that in the event of failure of Meja dam, some areas which include residential, agricultural and industrial areas were identified to have very high risk of being inundated due to the significant difference in the value of water surface elevation and ground elevation.

Due to the scenario described above, it was established that displacement of people from residential homes and commercial establishments located along the study area, such as business centers, recreational areas, industrial areas and worship places will occur. The proper analysis of the hazards associated with dam failure will assist in land use planning and in developing emergency response plans to help mitigate catastrophic loss to human life and property and the authorities should also give sufficient warnings to the downstream side inhabitants.

In an area such as downstream area of Meja dam where a dam failure either by overtopping or piping mode would endanger lives, agricultural land and other property. Dam breach simulation provides valuable information about the area most likely to be affected. The HEC-RAS output from the simulation also allows the user to make estimates of when flood waves will first arrive and when flows will be at a maximum at desired locations downstream of the dam after a failure.

This information could prove to be of great importance when creating an emergency action plan for the unfortunate event of a dam break.

One of the most important lessons learnt from the study is that the use of GIS for the undertaking of flood simulation can improve accuracy and can also prove cost-saving for floodplain delineation.

Some concluding remarks from the study are given below

Overtopping mode of failure tends to provide sharper and higher peak discharge compared to piping failure mode.

Carry out investigation of practical implementation of the results of this study in assisting to prepare an emergency evacuation plan.

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