FORMULATION OF AN EMERGENCY ACTION PLAN FOR A DAM BREAK SCENARIO

N. MOHAMMED JUNAID, R. BALAMURUGAN AND B.V. MUDGAL
Centre for Water Resources, Anna University, Chennai, Tamil Nadu, India

ABSTRACT

Dams are constructed to serve various purposes such as supply of water for drinking, irrigation and other domestic and industrial purposes, generation of hydroelectric power, recreational purposes, protection of downstream areas from flooding etc. However, they are also prone to failure which may cause catastrophic flooding and result in severe losses to life, property and economy.Where an existing dam is found to have safety issues, immediate action should be initiated to frame an Emergency Action Plan (EAP). It would be obligatory on the part of dam owner to plan disaster preparedness, including Dam Break Analysis and framing an EAP to meet the unlikely event of a failure. This study deals with formulation of emergency action plan for a dam break scenario of Sothuparai dam, located in Theni district of Tamil Nadu, India. Two-dimensional dam break analysis is performed using HEC – RAS (2D). Using the daily rainfall data, the Probable Maximum Precipitation is calculated with Hershfield's method and the corresponding Probable Maximum Flood is found out by performing hydrologic modelling using HEC-HMS. The dam breach parameters are calculated using Froelich's equations. Theresults are interpreted in the form of inundation maps with maximum depth, maximum velocity, flood arrival time and water surface elevation using GIS platform. Flood hazard map is also created. On the basis of inundation maps, a suitable emergency action plan is formulated and also the emergency evacuation plan showing safe routes, shelters are prepared.

1. INTRODUCTION

Dams are structures constructed across the rivers for providing socio-economic and environmental services such as drinking water, irrigation, hydroelectric power generation, flood protection and recreation etc., In spite of all these benefits, the floods resulting from dam failure have also produced some of the most devastating disasters,resulting in huge loss of lives and major damages to property as most of these dams are constructed in the vicinity of highly dense habitations, such as traditional villages and fully developed townships. India, with approximately 5,334 large dams in operation and 437 under construction has the third highest number of large dams in the world after China and the United States. Hence, more emphasis should be given on better flood management by preparing emergency action plan and designing early warning system to minimize damages rather than prevention of flood. In this context, the Government of India with the assistance from World Bank initiated the Dam Rehabilitation and Improvement Project (DRIP), which mainly focuses on improving the structural and non-structural safety measures of the existing dams to assist the dam owner/operator in issuing early warning and notification messages to responsible downstream emergency management authorities. One of the objectives of the DRIP is of Emergency Action Plan (EAP), which is defined as a formal document that identifies potential emergency conditions at a dam and specifies pre-planned actions to be followed to minimize property damage and loss of life. (CWC, 2016).

The present study deals with the formulation of EAP Dam Break Analysis for Sothuparai Damin Tamil Nadu, India, using two-dimensional unsteady flow modelling with HEC RAS model, followed by flood inundation mapping and preparing EAP. The main objectives of the study are to perform a two-dimensional dam break analysis using HEC-RAS software, to prepare inundation maps including evacuation routes and preparation of an Emergency Action Plan (EAP) by incorporating Participatory Rural Appraisal tools (PRA tools).

2. STUDY AREA

The Sothuparai Dam is a gravity type masonry dam constructed across the River Varahanadhi, at a distance of 12 km North west of Periyakulam town in Theni district of Tamil Nadu. It is located at Latitude 10º25' N and Longitude 77º16' E. River Varahanadhi is one of the tributaries of Vaigai river. It originates in the Western Ghats from Berijam Lake in Kodaikanal, Dindigul district and flows through the dense forest of Palani Hills. Varahanadhi river traverses a length of about 30 km from the dam flowing through villages namely and confluences with Vaigai river near Gullapuram village, Theni.The dam construction was commenced during 1982 to 2001 and commissioned for irrigation from 2001.

The storage from the reservoir is used for irrigation and providing water supply. It provides irrigation for an ayacut of 972 ha in Kharif and 420 ha in Rabi it provides drinking water supply to the township. The dam is 345m long and 57 mhigh from the foundation. It covers a catchment area of 56.20 km^2. It is provided with Ogee type uncontrolled spillway designed for maximum discharge of 807.48 m^3/s and 1 vent. The maximum water level of the dam is 407.640 meters. gross capacity of the reservoir is 2.831 Mm^3. The average annual rainfall is 829.80 mm, with the North East monsoon contributing around 382.4 mm yearly. The index map of study area is shown in Figure 1 below.

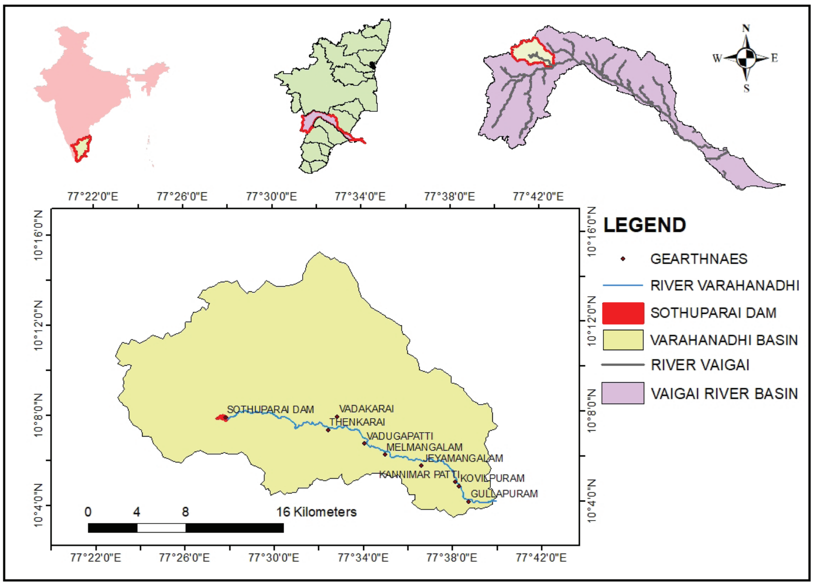

Figure 1 : The Sothuparai Dam within Varahanadhi river watershed

3. DATA USED

The basic data used in this study are the hydraulic particulars of the dam, the inflow and outflow data which was obtained from PWD office, Periyakulam. The daily rainfall data was collected from the following departments: Department of Economics and Statistics, Institute of Water Studies, Chennai and PWD office, Manjalar Sub Division, periyakulam, Theni.ALOS World 3D-30m (AW3D30) dataset, the global digital surface model (DSM) dataset with a horizontal resolution of 30meter mesh (1 arcsec. latitude and longitude) generated from 5mresolution DSM was acquired. Toposheets of scale 1:25000 was obtained from Survey of India (SoI).

4. METHODOLOGY

The methodology adopted in this study in order to formulate the Emergency Action Plan (EAP) is discussed in detail in the following flowchart as shown in Figure 2.

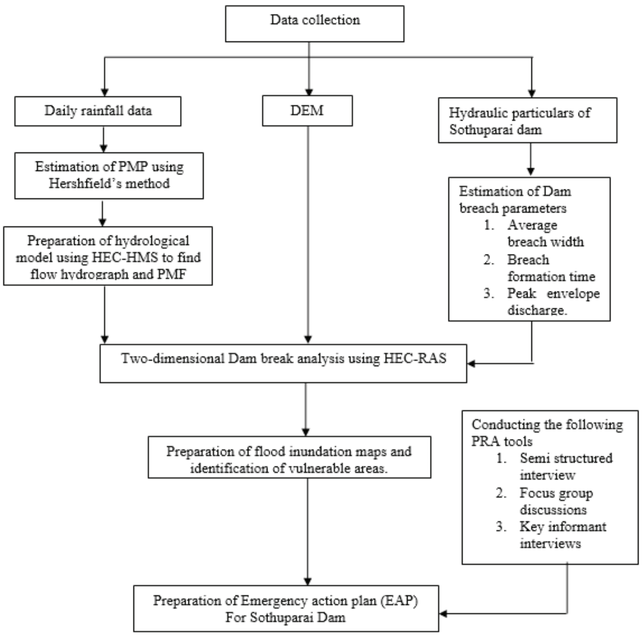

Figure 2 : Methodology flowchart of the study

4.1 *Estimation of Probable maximum precipitation Using Statistical Method*

The procedure as developed by Hershfield in 1961 and later modified in 1965. It is based on the general frequency equation of Chow (1961). It uses the parameters viz., mean, standard deviation and the frequency factor for the series of annual maximum rainfall. Thus, the mathematical representation of Hershfield method for the PMP can be estimated from the equation below

$$PMP = \bar{X} + (K_m \times \sigma)$$

Where,

PMP = Probable maximum precipitation

$\bar{X}$ = Mean of Annual daily maximum rainfall (ADMR) series.

σ = Standard deviation of ADMR series.

K_m = Frequency factor for PMP.

Frequency factor (K_m) is obtained from the Equation

$$K_m = \frac{(X_{max} - \overline{X_{n-1}})}{\sigma_{n-1}}$$

Where,

X_{max} = Largest values of Annual daily maximum rainfall (ADMR) series.

$\overline{X_{n-1}}$ = Mean of the ADMR omitting the largest value from the series.

σ_{n-1} = Standard deviation of the ADMR omitting the largest value from the series.

Daily rainfall data from the influencing rainfall stations were collected and was processed to find the Annual Daily Maximum Rainfall (ADMR) and the parameters discussed above to find the PMP using Hershfield's method was found out which is shown in Table 1 below.

Table 1 : Statistical parameters for Hershfield's equation

Parameters	Symbol	Rainfall (Mm/Day)
Mean of maximum rainfall series	$\bar{X}$	124.34
Standard deviation of maximum rainfall series	σ	65.609
Largest values of maximum rainfall series	X_{max}	370
Mean of maximum rainfall series omitting the largest value from the series	$\overline{X_{n-1}}$	117.8
Standard deviation of maximum rainfall series omitting the largest value from the series	σ_{n-1}	51.7

By substituting the above values, the PMP is calculated by using Hershfield's method and was found out to be 44.5 cm.Asper the report on design flood studies for Sothuparai Dam by CWC, in addition to this value, by using method of transposition, the one day PMP is found out to be 57.66 cm and the same is adopted as the design storm for this study.

4.2 Estimation of Probable maximum flood (PMF) using HEC HMS

HEC-HMS model, developed by U.S Army corps of Engineers, is used in this study to find the PMF for corresponding PMP. Before running the HEC-HMS model, the schematic containing the sub basins, river and reservoir is created using ArcGIS extensions namely HEC-GeoHMS and Arc Hydro tool. HEC-GeoHMS transforms the drainage paths and watershed boundaries into a hydrologic data structure that represents the watershed response to precipitation. The schematic created using the above-mentioned tools is shown in Figure 3.

The various parameters used in HMS model are as follows.

- Loss method : Initial and constant.
- Initial loss : 0 mm
- Constant loss rate : 0.1 mm/hr (as per CWC report on design flood studies of Sothuparai Dam)
- Baseflow : 3.7m^3/s(as per CWC report on design flood studies of Sothuparai Dam)
- Transform method: SCS unit hydrograph
- Time of concentration (T_c) : 1.41 hours (calculated using Kirpich formula)

Using the following data, the basin schematic is created and the computations are carried out using HEC HMS.

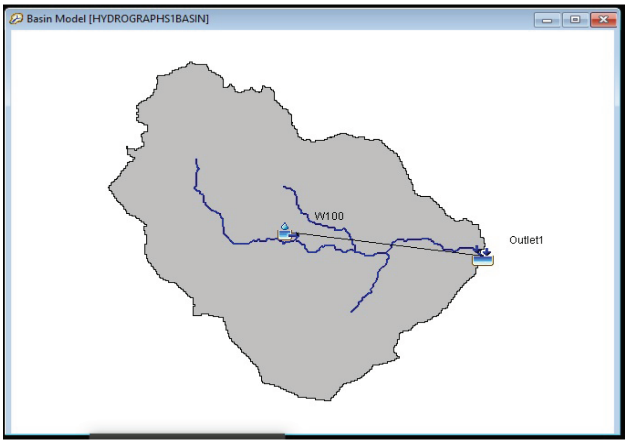

Figure 3 : Schematic representation of watershed in HEC-HMS model

4.3 Dam breach parameters

The characteristics of flood hydrographs resulting from a dam breach essentially depend on set of parameters like breach geometry, time of breach formation, which are collectively known as dam breach parameters. These parameters are necessary as they affect the outflow discharge, extent of inundation and warning times at downstream locations. Guidelines for Mapping Flood Risks Associated with Dams, developed under the Dam Rehabilitation and Improvement Project (DRIP), CWC recommends Froehlich regression equations for estimating dam breach parameters of concrete/masonry dams. The formulae for calculating average width of the final breach (B_{avg}), Breach Formation Time. (t_f), Peak Envelope Discharge. ($Q_{P_{max}}$) developed by Froelich (2017) and their corresponding values are shown.

Table 2 : Parameters for estimation of dam breach parameters

Dam Breach Parameters	Formula	Values
Average width of the final breach in meters. (B_{avg})	$0.12\times 1.5^{Type} \times (\frac{V_W}{H_b{}^3})^{\frac{1}{4}} \times (\frac{L_a}{H_b{}^3})^{\frac{2}{3}} \times H_b$	58.5 meters.
Breach formation time (t_f)	$63.2\sqrt{\frac{V_w}{gH_b{}^2}}$	0.2 Hours
Peak Envelope Discharge. ($Q_{P_{max}}$)	$(\frac{L_A}{B_{Avg}})^{0.28} \times (B_{Avg}\text{-}M(H_B - \frac{4}{5}H_W))\sqrt{Gh_W{}^3}$	22,947 $\frac{m^3}{s}$.

Where,

Type = (1, for concrete dams; 0, for masonry dams),

V_W = Volume of water above the breach bottom in cubic meters (m^3),

H_b = Height of breach (total height of dam) in meters (m),

La = approach flow width (70 % of dam height), H_W = Height of Water at FRL.

For concrete/masonry gravity dams the breach side slope ratio is assumed to equal to 0 (horizontal): 1 (vertical), considering the structural characteristics of this type of dams.

4.4 HEC- RAS Model setup

River analysis system (HEC- RAS) developed by USACE has been used in this study to carry out the hydraulic modelling of the flood wave along the river resulting from dam breach .The terrain from Sothuparai dam to its point of confluence with Vaigai river has been modelled in HEC-RAS 2D, to get the extent of water spread, flow velocity and depth at different locations. Terrain model has been created in RAS mapper using ALOS DEM (JAXA) of 30 m horizontal resolution. The reservoir was created using Storage area option. The 2D flow area was created using 2D flow area and computational grids of 20 m × 20 m has been generated. For the computational grids, Manning's roughness coefficient has been assigned corresponding to the land use/land cover. Dam is modelled using SA/2D flow area editor tool and the necessary breach parameters calculated previously were given to model. Lateral inflow hydrograph was given as upstream boundary condition and the flood hydrograph generated previously using HEC-HMS is given as inflow hydrograph. Normal depth is given as 2D flow area boundary condition and the corresponding friction slope value is given. The model is run for overtopping mode of failure and the failure initiates at MWL of +407.500 m. the computational time interval is 2 seconds and output interval is 10 minutes.

5. RESULTS AND DISCUSSIONS

5.1 *Probable maximum flood (PMF) using HEC HMS*

After creating the basin schematic and giving the necessary inputs, the model is run in HEC-HMS for giving the output interval as 1 hour; the following hydrograph is generated, which is shown in Figure 4. A peak discharge of 1,168.2 m^3/s occurred in the 2nd hour.

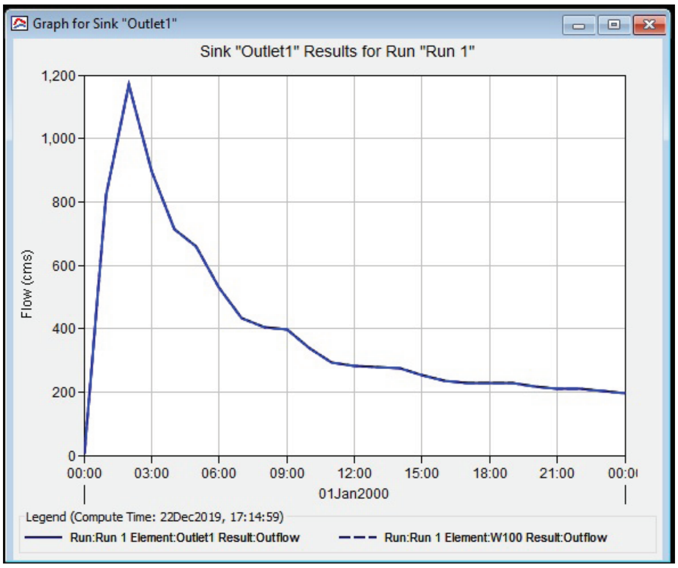

Figure 4 : HEC-HMS output (inflow hydrograph to HEC-RAS)

5.2 Dam break analysis simulation result

With the HEC-RAS model setup, discharge inflow series, the unsteady flow analysis have been carried out for PMF condition of the Sothuparai Dam. The simulation results were imported to ArcGIS and the output maps were created. The output maps are shown in Figure 5 to Figure 8 below.

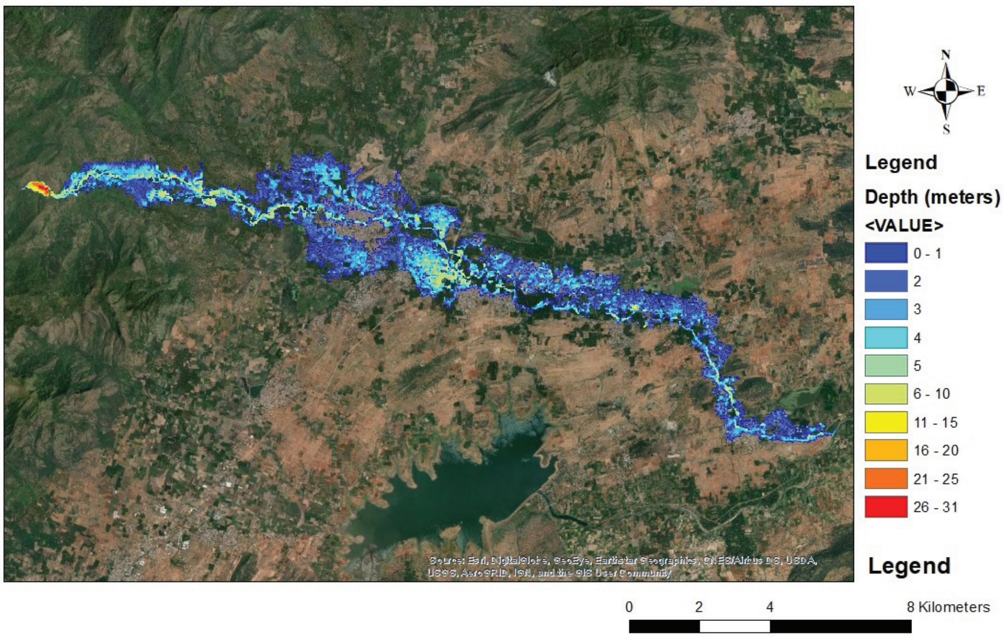

Figure 5 : Maximum Inundation depth

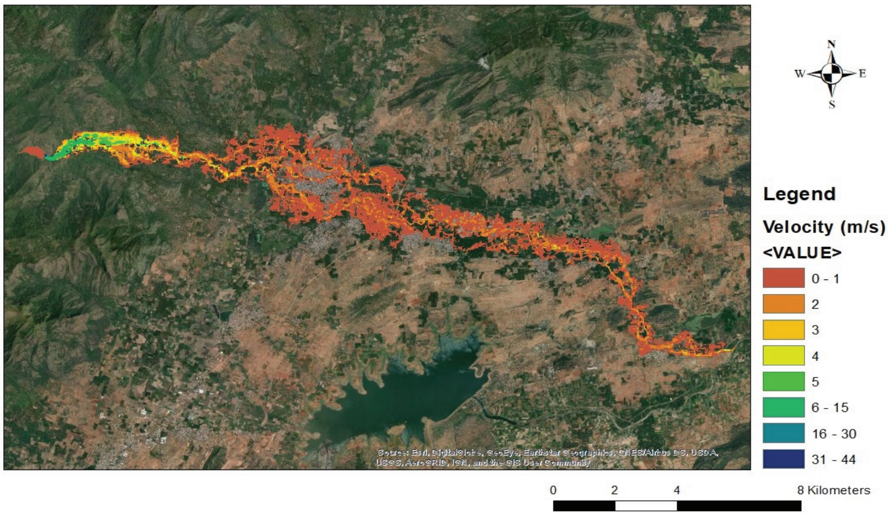

Figure 6 : Maximum Velocity

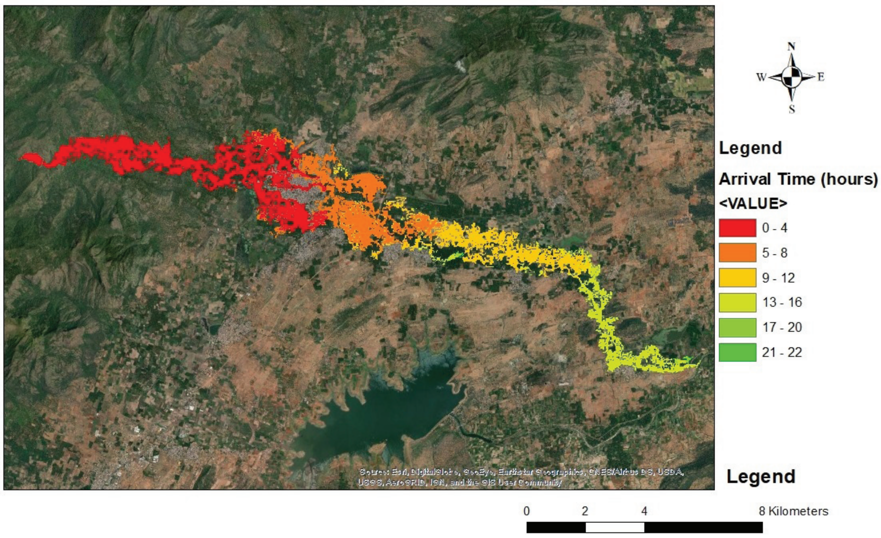

Figure 7 : Flood arrival time

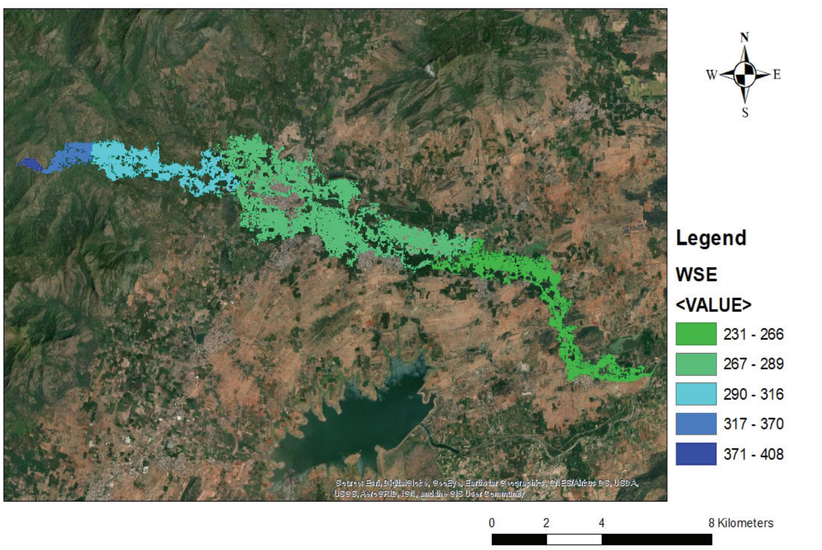

Figure 8 : Maximum water surface elevation

From the output maps, the maximum inundation depths and velocities for all towns and villages lying downstream of the dam is calculated. The maximum depth of water in Periyakulam varies around 4 – 6 meters in the river and around 1 – 3 meters in the town with velocity in the range of 1 – 3 m/s. Similarly, the corresponding depth and velocity for all the villages are found out and on the basis of the simulation results, EAP is framed out.

6. PREPARATION OF EMERGENCY ACTION PLAN

The EAP for Sothuparai Dam Failure was prepared according to the *guidelines for Developing Emergency Action Plans for Dams* (2016). As described earlier, an EAP is a written document prepared for describing a detailed plan to prevent or lessen the effects of a failure of the dam or appurtenant structures. Maximum flood level, extent of inundation and time of flood arrival were important inputs given for preparing emergency action plan during disaster. Based on the results of dam break simulation, it is observed that Periyakulam town is vulnerable, as this comes first in the line of affected places and also gets maximum flood discharge. Hence evacuation relief shelters were identified on the basis of number of people it can accommodate and also the routes for safe evacuation were planned. The nearest relief shelters and their corresponding evacuation routes are shown in Table 3 and corresponding evacuation map is shown in Figure 9 as follows.

Table 3 : EAP Nearest Shelters and Evacuation Routes

Location	Distance from the Dam (km)	Nearest Shelters	Evacuation Routes
Thenkarai	7.2	St. Anne's College of education for women, Thamaraikulam	NH45
Vadakarai	7.6	Horticultural College&Research Institute, Periyakulam. and Mary Matha College of Arts & Science, Periyakulam	NH45
Vadugapatti	11.8	Government Higher secondary school, Vadugapatti.	Periyakulam Road
Kannimarapatti	19.4	College of Agricultural Technology, Theni	MDR 732
kovilpuram	19.8	College of Agricultural Technology, Theni	MDR 732
Gullapuram	20.6	College of Agricultural Technology, Theni	MDR732

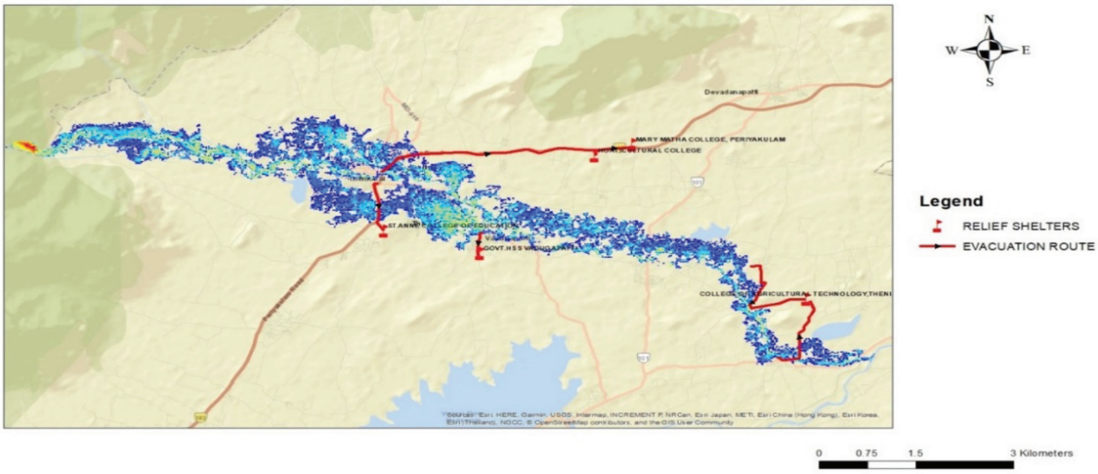

Figure 9 . Evacuation Map with Evacuation route and relief shelters

7. CONCLUSION

In this study, dam break analysis is carried out for Sothuparai approach using medium resolution terrain data. About 8 villages are found to be affected in case of Sothuparai dam breach. The people living in Periyakulam, downstream of Sothuparai dam are most vulnerable as the flood wave arrival time is less. The EAP is thus created and will be helpful in case of dam break event for ensuring the safety of the people living in vulnerable places. Though dam break is a very rare event, this EAP will be helpful for dam safety personnel to evacuate people of high flood event. It is recommended that every dam must have an EAP. Efforts are being taken for more accurate Sothuparai dam breach flood prediction by conducting river survey, ground truth verification and high-quality data products.

REFERENCES

Arlen D. Feldman (2000) Technical reference manual, U.S. Army Corps of Engineers, Institute for Water Resources, Hydrologic Engineering Center, Davis, CA.

Brunner, G. (2014). Using HEC-RAS for Dam Break Studies. U.S. Army Corps of Engineers, Institute for Water Resources, Hydrologic Engineering Center, Davis, CA.

CWC 2016. Guidelines for Developing Emergency Action Plans for Dams, Central Water Commission (CWC).

CWC 2018. Guidelines for Mapping Flood Risks Associated with Dams, Central Water Commission (CWC).

Froehlich, D.C. (2016) Empirical Model of Embankment Dam Breaching. International Conference on Fluvial Hydraulics (River Flow 2016)

World Meteorological Organization, 2009. Manual on Estimation of Probable Maximum Precipitation (PMP)