Article no. 43

THE CIVIL ENGINEERING JOURNAL 4-2022

DAM BREACH ANALYSIS AND PARAMETER SENSITIVITY ANALYSIS ALONG A RIVER REACH USING HECRAS

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ABSTRACT

A dam break is a low-probability, high risk catastrophe event that is extremely destructive and has a substantial negative socio-economic impact on downstream and nearby areas. Simulating dam breach and analyzing flood propagation downstream from those events is vital for identifying and minimizing the risks associated downstream of dam location. This study intended to anlayse the effect of overtopping failure of dam for two scenarios (a) base-case scenario (scenario with average value of dam breach parameters from their range) and (b) worst case scenario (the breach with largest geometry, shortest formation time and highest peak outflow magnitude). Further, a hydrodyanmic modelling is perfomed to investigate the sensitivity analysis (local and global) of five dam breach parameters (dam breach elevation, dam breach width, breach formation time, weir coefficient, trigger failure elevation) on breach outflow in a proposed hydropower project located in Nepal. Aeronautical Reconnaissance Coverage Geographic Information System (ArcGIS), Hydraulic Engineering Center River Analysis System (HEC-RAS) and OriginPro 2022b are utilized to analyse the effect of dam breach and parameter sensitivity.

Generation of outflow hydrograph shows that worst case scenario has devasting effect downstream with innudation of 1047 of househols and 50.83 kilometers of roads. The breach velocity was recorded as 15.16 m/s and 20.85 m/s for base and worst case respectively. The minimum depth and maximum depth of flooding downstream from dam location was found to be 24.51 m and 73.6 m for base case and 47.43 m and 106.75 m for worst case. Due to backwater effect at Bheri river, peak flow at 14 km downstream from dam reduces significantly to 124852.57 m^3/s and 244204.41 m^3/s for base and the worst case respectively. From local sensitivty analysis it has been found that, dam breach elevation is more sensitive and triggering failure elevation is less sensitive for peak outflow hydrograph. Whereas dam breach width seems more sensitive and TFE seems least sensitive for peak outflow using Monte Carlo Simulation for gloal sensitivity.

KEYWORDS

2D-HEC-RAS modelling, Dam breach, Inundation mapping, Local sensitivity analysis, Global sensitivity analysis

INTRODUCTION

Dams and waterway impoundments provide public benefits through the storage of water for flood control, recreation, drinking water, generation of hydroelectric power, stormwater management, wildlife habitat creation and irrigation [1]. A significant hazard to the downstream region is unavoidably present in the event of a dam breach event because of the enormous, stored water volumes. Concrete gravity dam failures are generally more disastrous because there are fewer visible indicators prior to failure, and collapse can occur quickly with little or no warning [2]. A dam break is a low-probablity, high risk catastrophe event that is extremely destructive and has a substantial negative socio-economic impact on downstream and nearby areas [3]–[5]. Worst of all, the collapse of such a massive dam would be a catastrophic disaster for a country like Nepal, which is economically poor [6].

Failure is unacceptable for dams since it endangers people's lives and incurs huge financial risk. Overtopping, seismic failure, internal erosion, poor management, quality problems, disasters and foundation failure are some of the several failure modes [7]. Failure modes of concerte gravity dam are overtopping, piping/seepage, foundation defects, overturning, cracking and equipment failure [8]. From the world wide historical dam failure’s database study performed by up to February 2020, 57.76 percent of gravity dams were failed, out of that 40.86 percent failed due to overtopping [9]. Overtopping failure has been found to be the most crucial cause mainly with respect to time of failure [10][11].

The estimation of dam breach geometry, which involves making decisions about variables like breach width, breach formation time, breach height, breach side slope, weir coefficient, side slope of breach, and trigger failure elevation, is a crucial step in the creation of hypothetical dam breach scenarios. The components that are included in dam breach analysis are; assessment of the dam breach parameters, estimation of the outflow hydrograph, routing of the downstream dam brach hydrograph and estimation of the magnitude and severity of the downstream flooding [12]. The availability of information about the model parameters and the complexity of the model influences the choice and use of the uncertainty approaches. Before choosing acceptable methods, it may be necessary to look at the model's parameters and complexity [13]. Hydrlogic Engineering Center-River Analysis System(HECRAS) model is widely used to simulate flow in river channels and floodplains and found to be an effective model for predicting downstream flooding impacts from an upstream event [14]–[17]. The model’s use can save time in model calibration and will be easy to route floods and anticipate flood levels [18]. The model can conduct 2D hydrodynamic unsteady flow routing using the Saint Venant equation or the Diffusion wave equation [8].

The negative impact of dam failure can be mitigated by providing the community with accurate flood inundation maps [19]. A dam failure inundation map shows the area of the downstream from a dam that could reasonably be expected to be inundated in the case of a breakdown of the dam [20]. A wide variety of end users use the maps for planning and as a tool for responding to determine the effects of dam failure in downstream communities. In addition, a dam categorization exercise considered the incremental areas flooded as a result of dam failure. Creating emergency action plan, planning flood evacuation, creating breach inundation zone mapping, choosing suitable spillway design flood are the uses of inundation studies.

The results of sensitivity analysis (SA) of the model output may be used to determine the degree to which the current uncertainties allow a certain mechanism to be clearly defined [21]. Sensitivity analysis is a method for predicting the outcome of a decision if a situation turns out to be different from the key predictions. The SA method evaluates how uncertainties in one or more input variables may affect uncertainties in the output variables in a numerical (or other) model. By examining the qualitative and/or quantitative responses of the model to changes in the input variables or via comprehending the phenomenon under study by the analysis of interactions between variables, this analysis helps the model's prediction or reduces it [22]. By focusing on the sensitivity close to a set of factor values, local sensitivity analysis (LSA) determines the local influence of input factor variation on model response [23]. When analyzing the local sensitivity of an input factor, the values of other input factors are held constant while the gradients or partial derivatives of the output functions are used to measure the sensitivity [23]. A study by N. B. Lucie Pheulpin demonstrates that the first order, local approach which is generally still relevant for uncertainty analysis of hydrodynamic risks remains applicable despite the nonlinearity of river flow processes, especially in the presence of significant parameter uncertainty [24]. The Global Sensitivity Analysis(GSA) is a quantitative technique that ignores models and is based on estimating the percentage contribution of each input factor to the variance of the model's output while also taking interaction terms into consideration [25].

The purpose of this study is to determine breach hydrograph due to overtopping failure of NHP dam under different scenarios and to investigate the impact of a possible failure with prediction of inundation levels (depth, velocity, WSE and arrival time) at a given location using HEC-RAS and ArcGIS. To determine the most sensitive and least sensitive breach parameter on peak outflow by using local and global sensitivity analysis is one of the major objectives of the study.

STUDY AREA

The proposed Nalgad Hydropower Project is located in Nalgad, Jajarkot district, Karnali Province, Nepal. In the Karnali River Basin, Nalgad is one of the primary tributaries of the Thuli Bheri River. The Nalgad gets its name from the Chakhure Lek, a high mountain range that runs across the Jajarkot and Jumla districts of Nepal. The project is a roller compacted concrete dam of 248 m height. The reservoir is created by the storage, which has a total storage volume of 474 MCM and a live storage volume of 350 MCM. The main dam has a spillway that allows a flood up to PMF to flow through, with a crest width of 64.2 m. The dam site of the project is located just downstream of the confluence of Andheri Khola, which is approximately 9.25 km upstream from the confluence of the Nalgad and the Thuli Bheri River and the powerhouse is located on the left bank of Nalgad River approximately 500 m upstream from the suspension bridge at Dalli.

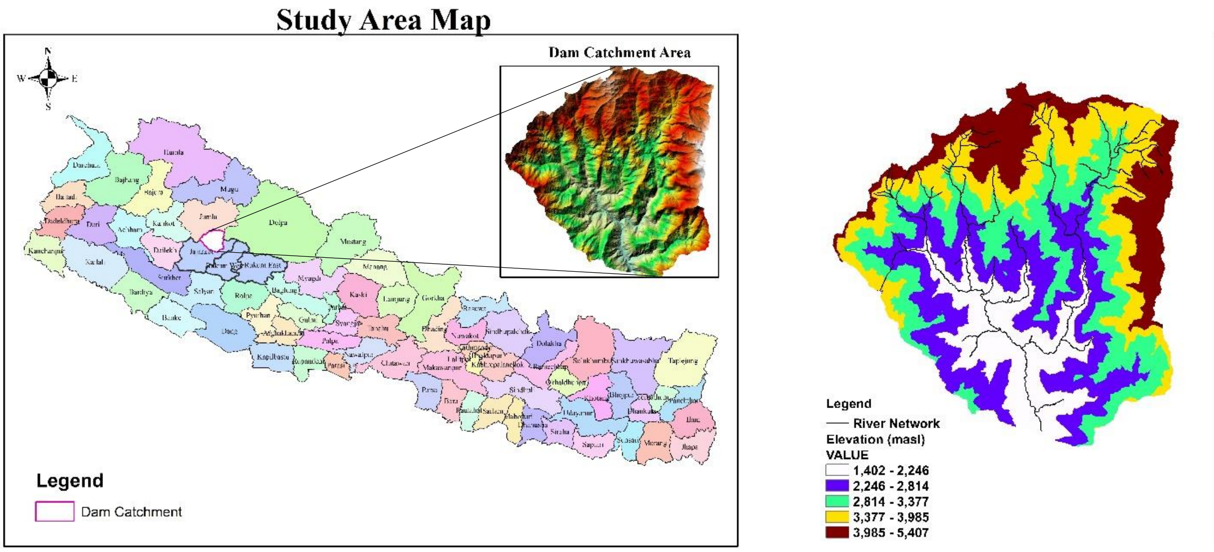


Fig. 1- (a) Map of Nepal (b) Dam catchment and river networks

The catchment area at dam location is 569 km^2. Almost half of the basin is below 3,000 m elevation. The catchment area experiences the annual rainfall of 2018 mm with average monthly flow of 27.3 m^3/s in Nalgad river. Based on the Digital Elevation Model (DEM) the elevation of the catchment varies from 1402 masl to 5407 masl. The dam do not pose a risk of Glacier Lake Outburst Floods (GLOF) [26].

METHODS

Data Collection

Most of the data was compiled from NHP office that includes updated feasibility study report (UFSR) (a study submitted by a joint venture of SMEC International Pvt. Ltd and Australia and MWH

DOI 10.14311/CEJ.2022.04.0043

International INC, USAF). Data collected for modelling was grouped into three parts, namely; hydrologic data, spatial data and geometric data.

The peak flow of 24-hr- Probable Maximum Flood (PMP) was the highest among other PMP's thus 24-hr PMP with peak flow of 5102m^3/s was taken as input in this study. The inflow from the Bheri river was taken into consideration as inflow hydrograph. The constant flow hydrograph of 150 m^3/s was provided at the boundary conditions of Bheri river. The Digital Elevation Model (DEM) from Alaska Satellite Facility (ASF) of 12.5 m high resolution terrain corrected from Advanced Land Observing Satellite Phased Array L-band Synthetic Aperture Radar (ALOS PALSAR) dataset were chosen. The topographic map of the project area was acquired from PAHAR mountains of central Asia digital dataset. Land cover data of Nepal 2019 of 30 m resolution was taken from International Centre for Integrated Mountain Development (ICIMOD). Storage area elevation vs storage data was obtained from the UFSR of NHP. The geometric data of dam is presented in

Tab. 1 below.

Tab. 1 - Geometric Data of Dam (Sorce:UFSR)

Type	Curved Gravity Roller Compacted Concrete (RCC) Dam
Maximum height above foundation	248 m
Crest Elevation	1588 masl
Length of crest	495 m
Width of crest	10 m

Watershed delineation and discretization

The high-resolution terrain corrected DEM data was processed in Geographic Information System (GIS) to merge the raster data. The combined data is clipped and made ready to use as DEM input in HEC-RAS. Using the hydrology capabilities in the ArcGIS geoprocessing toolkit, watershed delineation and discretization were carried out in ArcGIS to demonstrate the delineation of watershed and stream networks based on digital elevation models. Several datasets that together characterize the drainage patterns of the basin are derived using the hydrology tools. The digital elevation model underwent geoprocessing analysis to generate data on streams, stream segments, watersheds, flow direction, and flow accumulation. The information is then utilized to create a vector representation of drainage lines and catchments from chosen places. Later the outputs from the HEC-RAS were imported for inundation mapping.

HEC-RAS modelling

For two-dimensional (2D) analysis, at first the projection data was provided to River Analysis System (RAS) mapper. It is easier to use RAS Mapper tool to import necessary terrain data directly to the model. Storage area shape file from the ArcGIS was imported into the geometry and volume elevation relations could be obtained from the loaded terrain. Because of the availability of volume elevation relation, it was directly provided to the storage area. Also, 2D flow area was created with the grid size of 30m by 30m. 11,537 cells in total were used for the analysis. Additionally, the Manning's n value on related land cover grid was imported into the HEC-RAS geometry editor interface. The manning's n value for different land cover type was taken from HECRAS user manual. For a perfect characterization of unstable flow events over the simulation period, the roughness change caused by flood waves cannot be incorporated into the model.

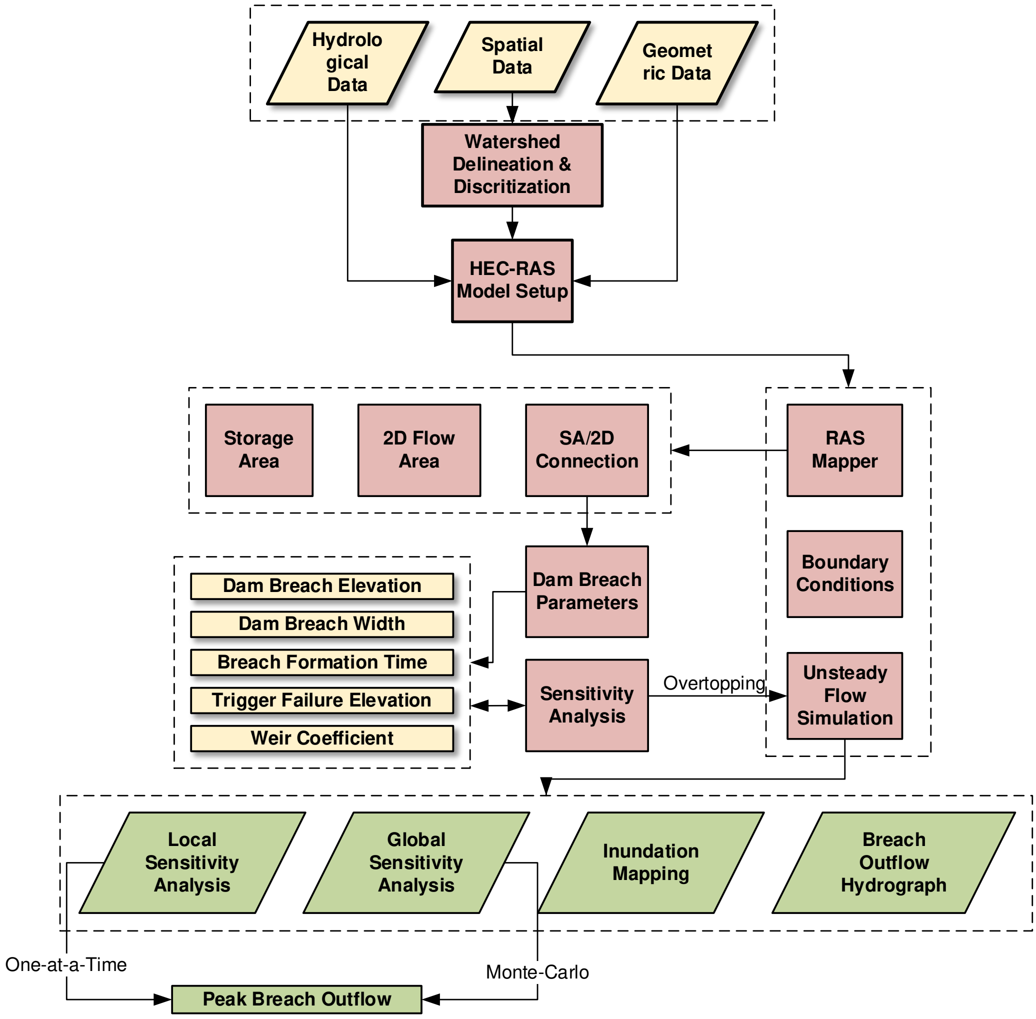


Fig. 2 - Methodological flowchart of the study

The dam was used to connect SA/2D flow area. The geometrical information will all be identical. SA and 2D flow area connections are capable of functioning as a particular kind of a dam structure. It is necessary to model the link as the dam structure using weir embankment data. Weir width, weir coefficient, weir crest shape, spillway height and design energy head are the required storage area connection weir data provided. Modeling the dam breakdown also requires the addition of the breaching plan data. The analysis of the 2D dam break model used different breaching conditions for different scenarios. Storage area connection breach data was provided. The mode of failure was considered as overtopping. Breach progression was set to sine wave. For breach data different breach parameters value were used based on scenarios created. Based on the data two scenarios, base-case scenario and worst-case scenario were created. The range of values of dam breach parameters were taken according to Federal Energy Regulatory Commission (FERC) as stated on HEC-RAS user manual.

Tab. 2 shows range of value for different dam breach parameters, the value of dam breach parameters for the base-case and worst-case scenario taken for the study. The value of the base-case was chosen in such a way that the value was the average of the range of dam breach parameters value. The worst case is defined as the breach with the largest geometry, shortest breach formation time, largest dam breach height, higher trigger failure elevation so that highest peak outflow magnitude occurs.

Tab. 2 - Different values of dam breach parameters based on scenarios

SN	Dam Breach Paramters	Range	Base-Case Scenario	Worst-Case Scenario
1	Dam Breach Width	0.1L to 0.5L	148.5 m	248.5 m
2	Dam Breach Elevation	1470 masl to 1510 masl	1490 masl	1470 masl
3	Breach Formation Time	0.1 hour to 0.5 hour	0.2 hour	0.1 hour
4	Weir Coefficient	1.1 to 1.8	1.44	1.8
5	Trigger Failure Elevation	1588.3 masl to 1588.7 masl	1588.5 masl	1588.7 masl
6	Left Side Slope	Vertical	Vertical	Vertical
7	Right Side Slope	Vertical	Vertical	Vertical
8	Failure Mode	-	Overtopping	Overtopping

Setting up the external boundary conditions was the initial stage in utilizing HEC-RAS to model the downstream channel of the Nalgad Hydropower Project Dam. The upstream limit was chosen so that it could exist independently of the conditions further downstream. The location of the downstream border was chosen to be independent of the flow characteristics below the boundary. All the scenarios on HECRAS model require the same flow and boundary conditions. A boundary line and a normal depth boundary condition have been established for the downstream 2D flow area connection. Upstream boundary condition was provided at dam connection where lateral inflow hydrograph (PMF) was provided. At downstream end of the study area normal depth boundary condition was considered. Also, boundary condition at the Bheri river was created. Storage area initial conditions was set at full supply level of reservoir as 1580 masl.

Unsteady Flow Simulation

The starting date and time of simulation time window was taken from 1st January, 2022 00:00:00AM to 1st January, 2022 1:00:00 PM. 0.2 seconds of fixed time step computation interval was taken. Mapping output interval was taken as 10 seconds whereas hydrograph output interval and detailed output interval was taken as 1 second.

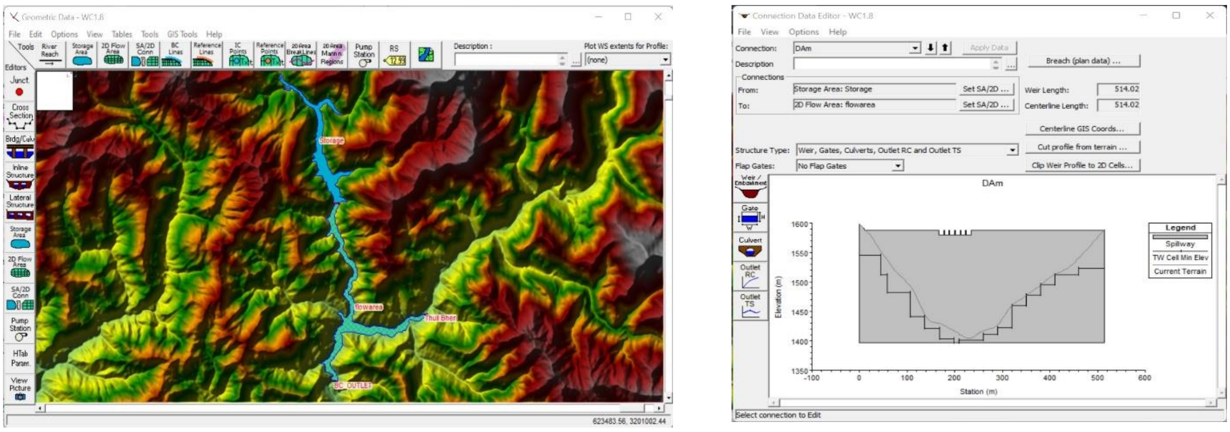


Fig. 3 - (a)Geometry of HEC-RAS model (b)Connection data editor

From the output of HECRAS, dam breach hydrograph can be obtained. Mapping of worst-case scenario downstream of dam was performed after exporting results from HEC-RAS to ArcGIS. Based on results sensitivity (SA) analysis was performed.

RESULTS

The condition, when the reservoir is at full supply level and then peak of the PMF impinges over reservoir is the most critical situation chosen in this study. For this case, it is assumed that the dam is just overtopped by PMF and then the dam is failed due to breaching. The important point in the breach analysis is to estimate accurate outflow hydrograph and downstream inundations area. Sensitivity analysis is used to assess sensitivity of hydrodynamic results to different breach parameters. The results obtained are classified based on following sub headings.

Breach Outflow Hydrograph

2D HEC-RAS analysis of dam break event based on breaching parameters (as mentioned in Tab. 2) gave hydrograph output at the dam structure between the storage area and river reach. Breach initiation had begun to occur on January 1st, 2022, at 9:54:47 AM for base case and at 10:19:11 AM for worst case. Total flow obtained at the full shaped dam break was 194036.2 m^3/s and 515976.8 m^3/s for base and worst case respectively. Fig. 4 (a) shows breach hydrograph for both scenarios.

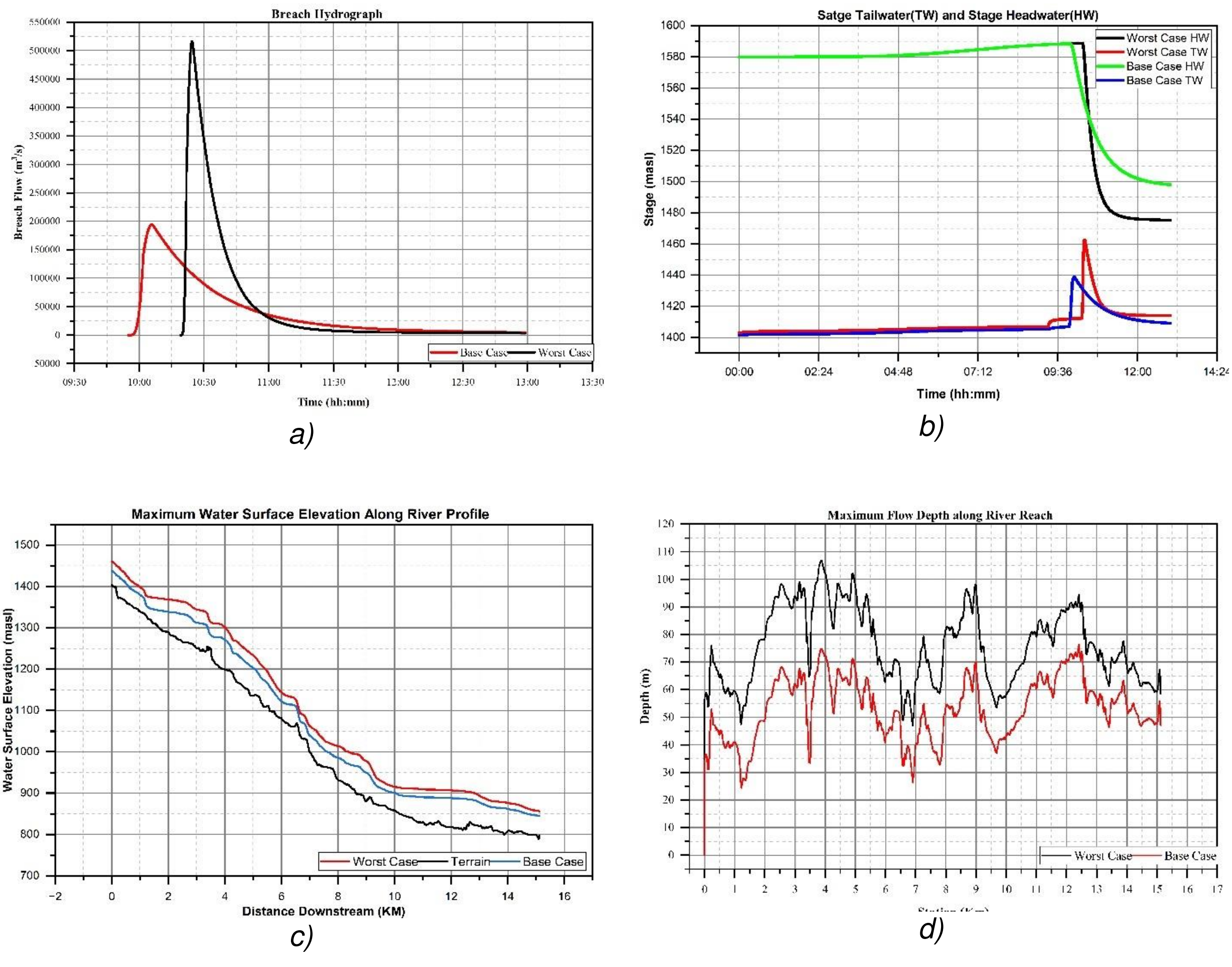


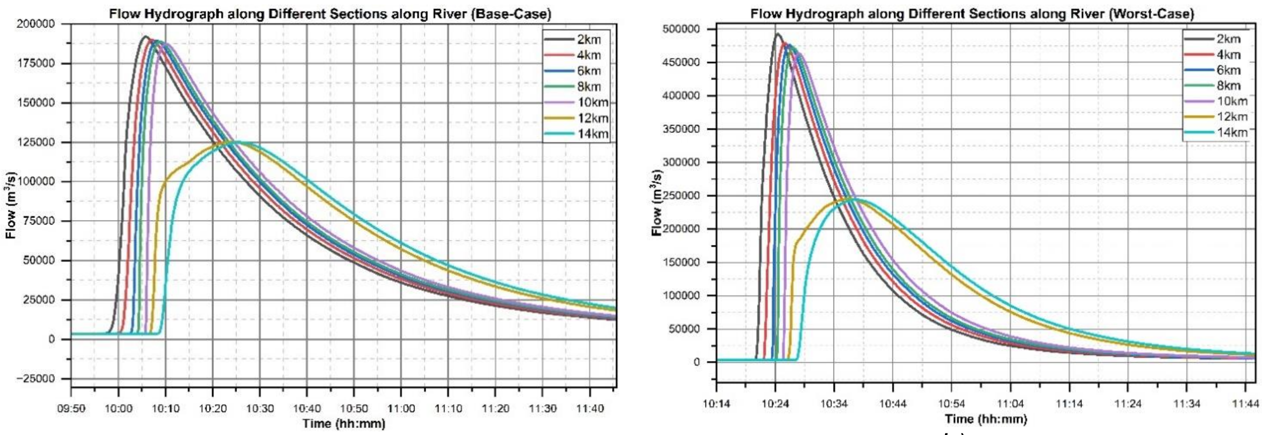
Fig. 4- (a)Breach Hydrograph (b)Stage HW and TW Curve (c)Maximum WSE along river (d)Maximum depth distribution along river

The Head Water (HW) stage, Tail Water (TW) stage, maximum velocity through breach, maximum depth and mimimum depth along river profile for base case and worst case was obtained as; 1588.52 masl and 1588.7 masl, 1438.77 masl and 1460.56 masl, 15.16 m/s and 20.85 m/s, 76.36 m and 24.45 m, 106.762 m and 47.061 m respectively. Maximum Water Surface Elevation (WSE) of the worst case seems to be greater as more breach flow passes through dam than base case. Fig. 4 (b), (c), (d) shows HW and TW curve, WSE and depth distribution along river profile respectively.

For overtopping failure flood hydrograph routing has been analyzed at seven chainage points, at 2 km downstream, at 4 km downstream, at 6 km downstream, at 8 km downstream, at 10 km downstream, at 12 km downstream and at 14 km downstream to show the effect of flood under overtopping at downstream of the dam.

Tab. 3 - Peak flow at different section from dam location

Distance from Dam (km)	Base-Case		Worst-Case	
	Peak Flow (m3/s)	Time in Peak (hh:mm:ss)	Peak Flow (m3/s)	Time in Peak (hh:mm:ss)
2	191806.17	10:06:40	492765.31	10:25:20
4	189632.05	10:08:00	478351.47	10:26:40
6	189153.06	10:09:10	476006.03	10:27:20
8	188719.44	10:09:50	471609.63	10:28:00
10	187132.53	10:11:00	463447.34	10:28:50
12	125311.30	10:24:40	245582.08	10:37:10
14	124852.57	10:26:30	244204.41	10:38:40



a) b)

Fig. 5 - (a)Flow hydrograph (Base-Case) at downstream sections (b) Flow hydrograph (Worst-Case) at downstream sections

Inundation mapping

Mapping of the worst-case scenario downstream of the dam was performed after exporting results from HEC-RAS to ArcGIS. Inundation mapping was done on RAS Mapper on HECRAS and later exported to GIS for further analysis and reporting purpose to identify the potential risk and safe settlement areas from the flow of the dam breach of the worst-case scenario was performed. Municipality based analysis on number of buildings, roads, landcover and area inundated are mapped. The data of buildings and roads was obtained from Geofabric de, open street map data of Nepal and land cover data 2019 was obtained from the ICIMOD.

The significant failure scenario which leads large flood plain according to the study is the worst-case scenario. So, mapping based on the worst-case scenario has been carried out. In general, high-water depth occurred along the main channel and spreads gradually to the floodplains. The total area inundated after the arrival of PMF into the storage area and the dam breach including reservoir storage was 14.478 square kilometers as seen in Fig. 6. Within the downstream study area two municipality (Nalgad and Athbiskot) and one rural municipality (Barekot) were inundated with inundation area of 6.514 km^2, 1.655 km^2 and 6.309 km^2 respectively. It was found that the depth is higher in storage area of the dam. The model result gave a flood depth 0.0012 m as the minimum to a critical height of 106.762m downstream from dam location. Velocity of flow increases as the dam breaks at downstream of the dam. The velocity was higher at the narrow region of the river and reduces at wider sections. The maximum velocity observed was 78.03 m/s and minimum was zero at storage.

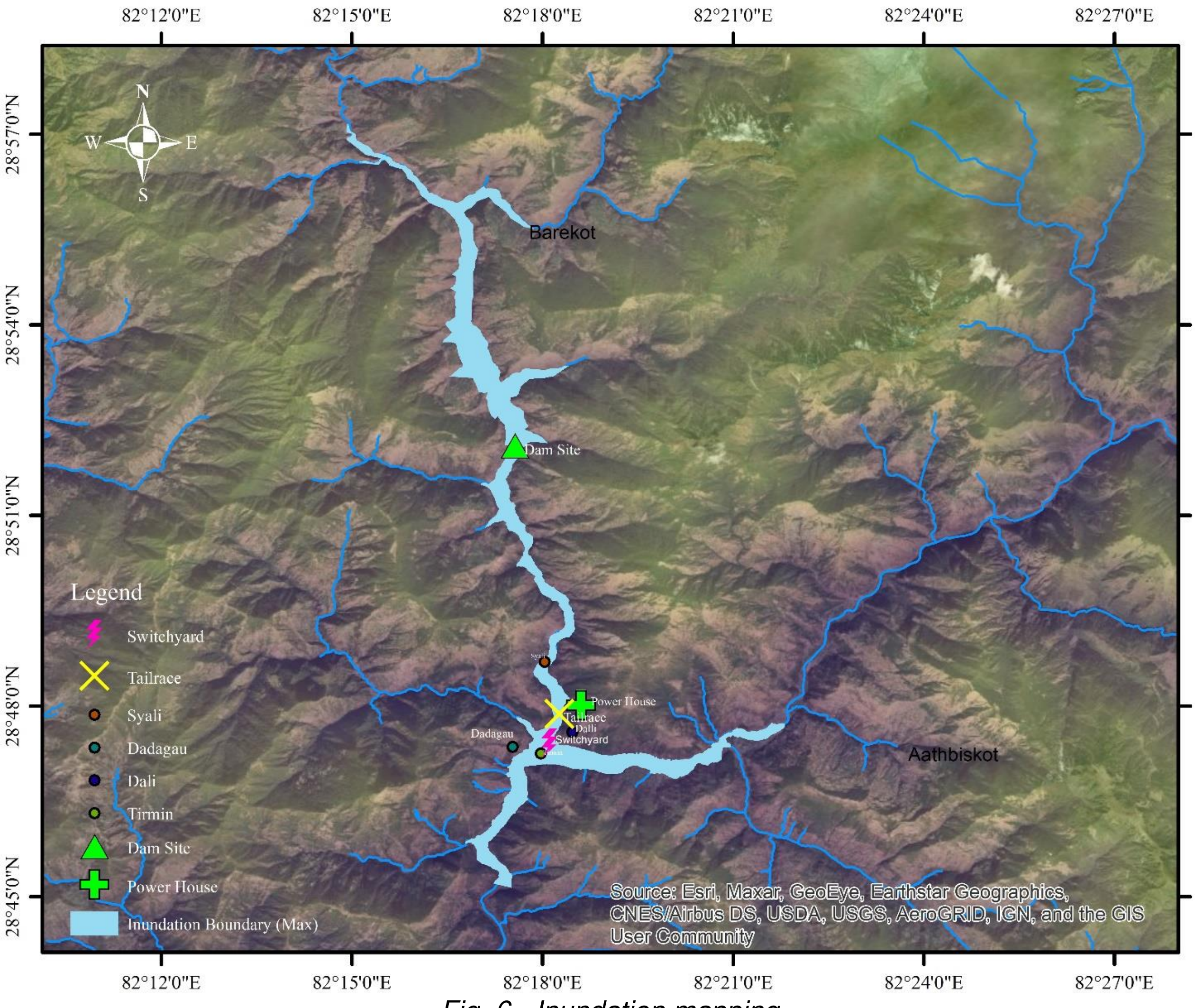
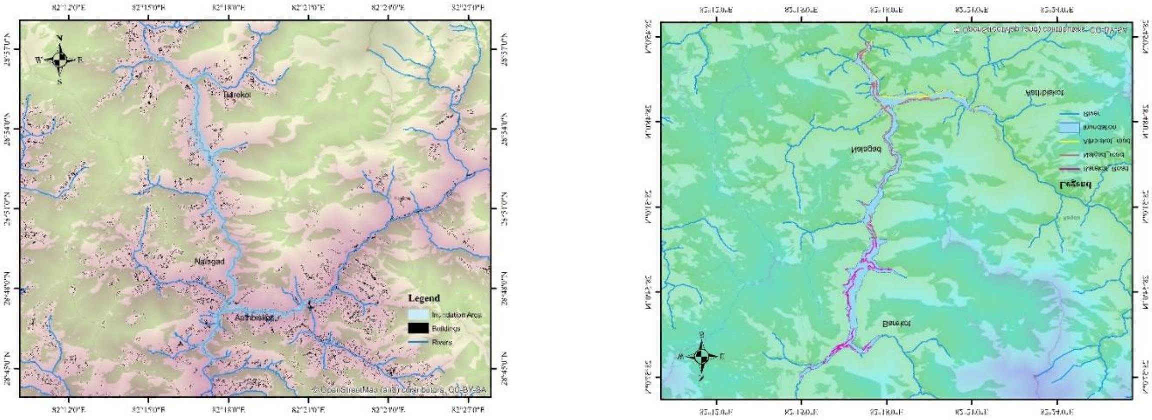


Fig. 6 - Inundation mapping

Fig. 7 (a) and (b) show inundation of buildings and roads across the study reach from the dam location respectively. Municipality based number of buildings and length of road inundated is presented in Tab. 4 and

Tab. 5 respectively. After the arrival of PMF at the dam on 1st January, 2022 at 12:00AM and the dam breached at 10:19:10AM. Arrival time of flood is maximum at upstream of the Bheri river due to backwater effect from flow in the river and at the end of downstream area taken under the study. Fig. 8 (a) and (b) show the depth and arrival time mapping along the study area.



a) b)

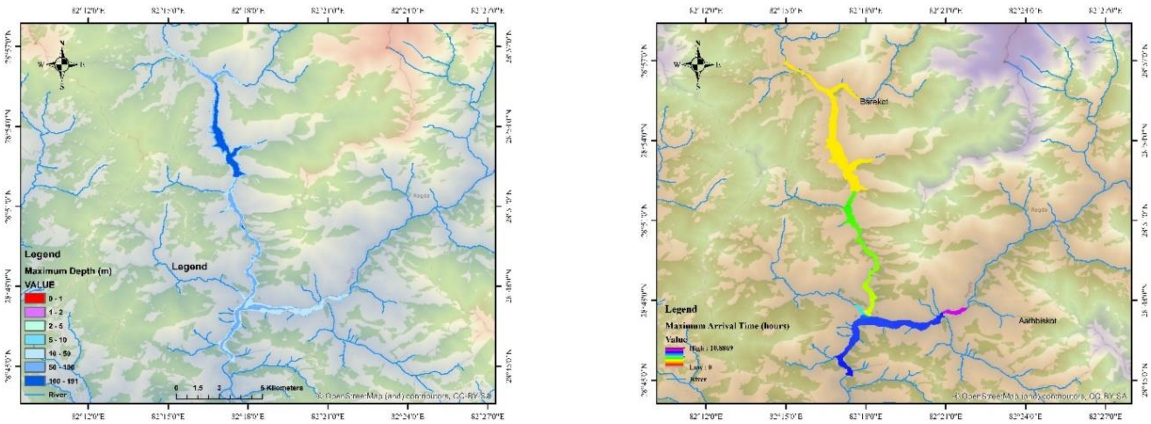
Fig. 7-(a) Inundation of Buildings (b) Inundation of roads

Tab. 4 - Number of buildings inundated based on municipalities

Municipality/Rural Municipality	Total Number of Buildings	Total Number of Buildings Affected	Percentage Affected
Aathbiskot Municipality	9601	188	1.96
Barekot Rural Municipality	4738	298	6.81
Nalgad Municipality	8008	561	7

Tab. 5 - Inundation of roads along municipalities

Type of Roads/Municipality	Tertiary (m)	Path (m)	Footway (m)	Track (m)
Aathbiskot Municipality	6132.155	51.734	1260.5572	309.9702
Barekot Rural Municipality	-	14069.7715	-	4366.0556
Nalgad Municipality	3972.3097	16624.792	72.087	3974.8811



a) b)

Fig. 8-(a) Maximum depth (b) Maximum arrival time

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Local sensitivity analysis (LSA)

Local sensitivity analysis examines sensitivity only with regard to point estimates of parameter values, which results in the sensitivity measure being affected by the choice of breach parameters. In local sensitivity, first a base case (BC) was set with the breach parameters value as mentioned in the Tab. 2. Sensitivity analysis was performed by changing the breach parameter value one at a time (OAT) keeping all other parameters constant.

Tab. 6 - Values of dam breach parameters taken for LSA

SN	Dam Breach Width	Dam Breach Elevation	Breach Formation Time	Weir Coefficient	Trigger Failure Elevation
1	247.5	1510	0.1	1.1	1588.3
2	198	1500	0.15	1.27	1588.4
3	148.5	1490	0.2	1.44	1588.5
4	99	1480	0.25	1.6	1588.6
5	49.5	1470	0.3	1.8	1588.7

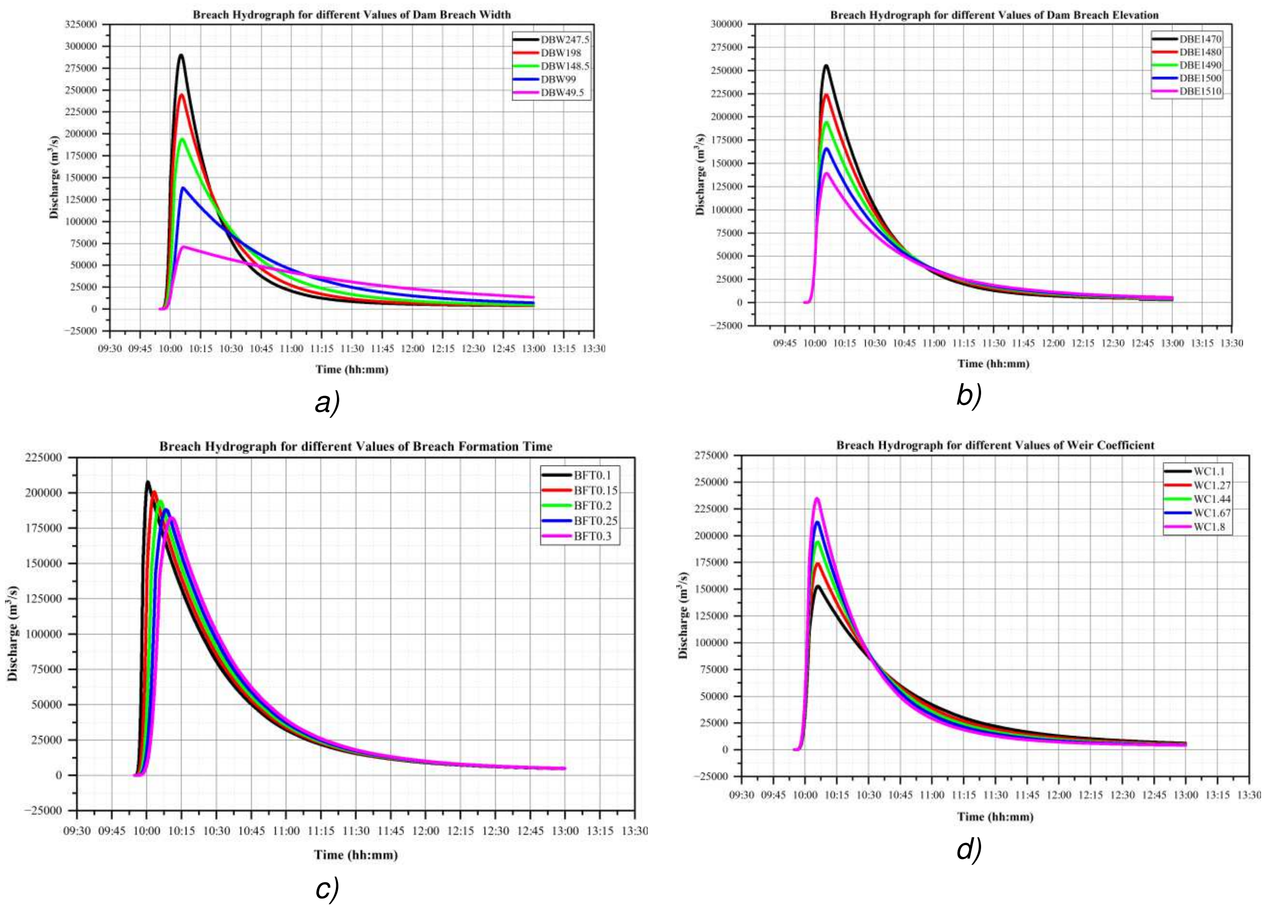

Fig. 9-Breach Hydrograph for different values of (a)dam breach Width (b)dam breach elevation (c)breach formation time (d)weir coefficient

Sensitivity was observed on peak breach flow at dam. Percentage change in output and percentage change in input was calculated and the ratio of percentage change in output to input which is sensitivity index, was determined. Different breaching parameters described the dam break peak flow, implying that the breaching parameters had a significant impact on peak flow estimation.

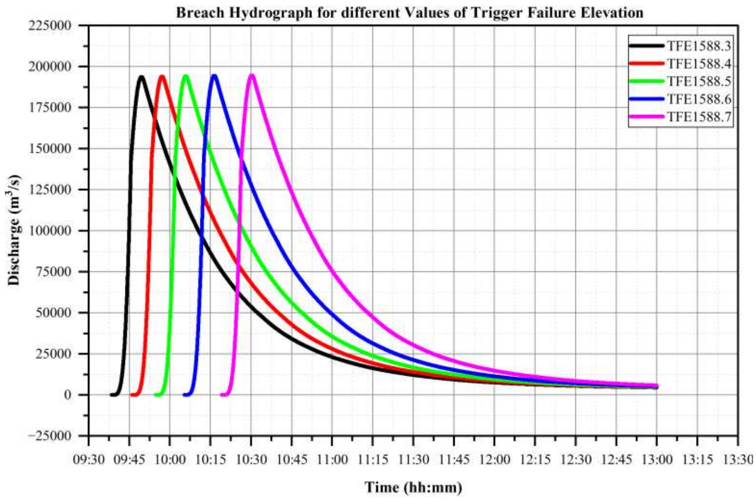

Fig. 10 - Breach hydrograph for different values of trigger failure elevation

Fig. 9 and Fig. 10 show the different peak flow hydrograph based on the different values of dam breach paramters. The mean of ratio of percentage change in output to percentage change in input for maximum peak outflow, for each parameter considered for local sensitivity analysis was calculated as shown in

Tab. 1. Dam breach elevation was found to be the most sensitive parameters followed by weir coefficient, dam breach width and breach formation time. Trigger failure elevation was found to be the least sensitive parameter.

Tab. 7 - Mean of ratio of percent change in output to input

Sensitivity On	Dam Breach Elevation	Weir Coefficient	Dam Breach Width	Breach Formation Time	Trigger Failure Elevation
Peak Outflow	1.17	0.87	0.667	0.129	0.025

Global sensitivity analysis (GSA)

The dam breach phenomenon is a complex one and parameters value for realistic breach of concrete gravity dam by overtopping failure is even more complicated. In global sensitivity analysis, first the input and output parameters were fixed. Dam breach parameters were fixed as input parameters and peak breach flow as output parameters. The input parameters that are considered for the sensitivity analysis are: dam breach elevation, dam breach width, breach formation time, weir coefficient and trigger failure elevation. Based on that, each parameter with maximum, minimum and mean value was taken and 3×3×3×3×3 plan was created based on these parameter values. The relation between considered parameter with breach outflow were obtained by non linear regression analysis where the outputs of the permutation plans from (243 cases) were used. Monte Carlo (MC) sensitivity analysis was performed in OriginPro 2022b. The input parameters distribution was considered to be normal distribution. Sensitivity graph based on plot between percentage change in variation of standard deviation of input parameters and standard deviation of peak putflow was given directly by the software. From the graph, parameters sensitivity was determined.

200000 samples of inputs were randomly generated between the ranges and simulated to get the output parameter values. Mean of the output from two lakh inputs was 188532.58 m^3/s and standard deviation of 44111.595. represents the standard deviation of peak outflow versus percent change in variation on standard deviation of breach parameters. The difference in standard deviation of DBE, BFT, DBW, WC and TFE on peak outflow were found to be 2931.12, 568.72, 3803.39, 1342.33 and 17.47 m^3/s respectively. The contribution of DBW to peak outflow was found to be maxmimum. So, DBW was the most sensitive and TFE was the least sensitive among other breach parameters.

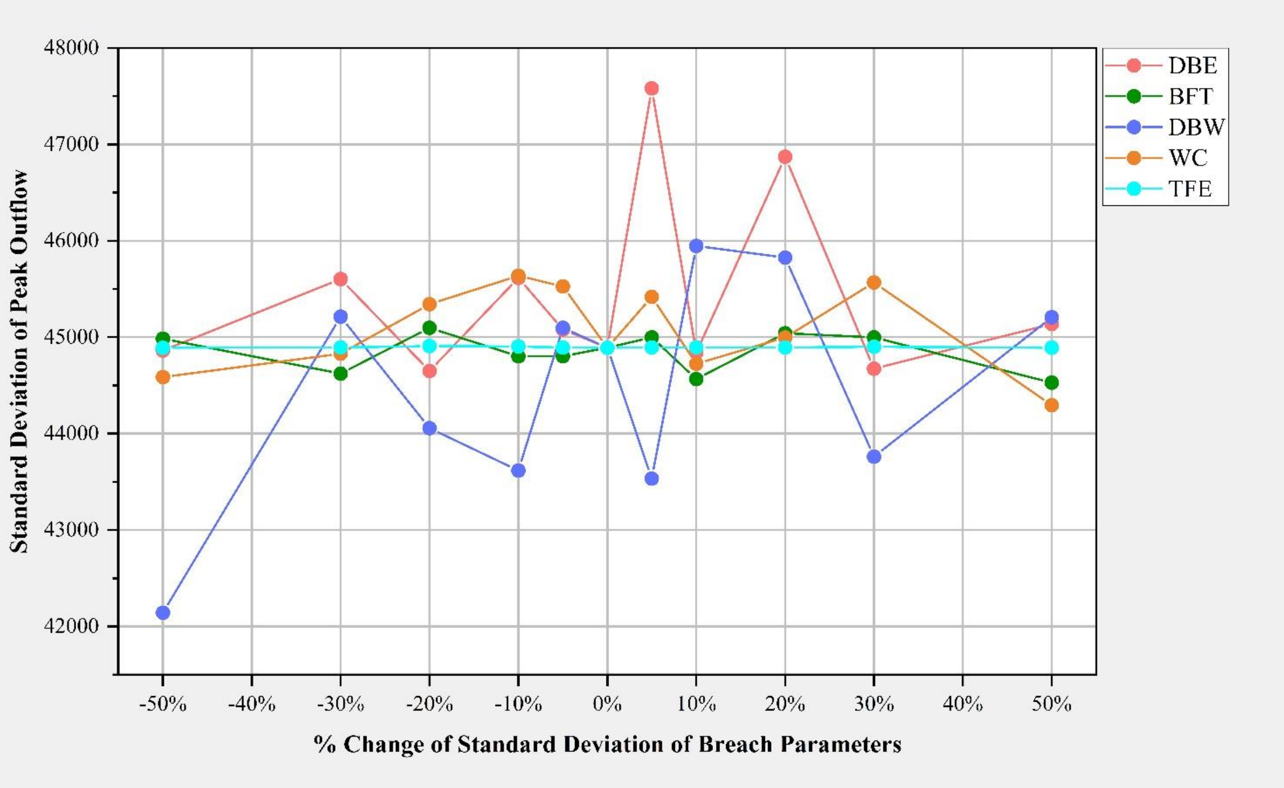

Fig. 11 - Standard deviation of peak outflow Vs Percent change in standard deviation of breach parameters

CONCLUSION

HEC RAS was used to simulate the dam breach and parameter sensitivity analysis for the proposed Nalgad Hydropower Project. The result of this study shows that, a slight change in dam breach parameters resulted in significant changes in peak flows at the dam site and WSE, velocity and arrival time at the specified reach stations in downstream channel at different kilometers.

Based on the results obatined from dam breach analyses and parameter sensitivity analyses the following conclusions were drawn.

- A maximum breach flow of 194036.2 m^3/s was noted for the base-case scenario with 12.036 km^2 area of inundation. Due to worst-case scenario maximum breach flow from dam was noted as 515976.8 m^3/s and a total of 14.478 km^2 was inundated. The output such as water depth, peak discharge, velocity, arrival time, duration was used for generation of inundation maps. Avereage flood depth along entire study area of base case including storage area was 59.62 m for base case and 59.72 m for worst case. High water depth occurred along the main channel and spreads gradually to the floodplains.

- A total of 1047 buildings from three municipalities: Aathbiskot municipality (188), Nalgad municipality (561) and Barekot rural municipality (299) were estimated to be inundated by worst-case scenario. Around 50.83 Km of road (including tertiary road, path, footway and track) were also estimated to be inundated across these municipalities.
- Human settlement area such as Tirmin and Syali, switchyard, tailrace was flooded due to overtopping failure of NHP dam. Power house was found to be one of the safe places from the flood. People from Tirmin and near switchyard area can be safer at Monika hotel whereas people from the Syali will have to move around 118 m to be safer from flood with warning time of 8.41 minutes.
- An increase in the values of dam breach width and weir coefficient increase the peak outflow. BFT and DBE were inversely proportional to peak breach flow. TFE has very less effect on peak outflow.
- The sensitivity analysis of dam breach parameters on peak outflow was undertaken by local and global sensitivity analysis. According to LSA, dam breach elevation was the most sensitive among others. TFE and BFT have least impact than DBE on breach outflow. GSA on peak outflow, the overall effect on outflow while changing all breach parameters, dam breach width was found to be the most sensitive parameters and triggering failure elevation being least sensitive.

Future study may focus on following aspects;

- Determining population at risk, economic valuation of potential damages of downstream infrastructures, land and vegetation and sediment transported by flood should be carried out for determining the actual adverse effect of the flood in wider extent.
- Consideration should also be given to different hydrologic scenarios such as different year return year floods, 30% to 50% reduction in PMF’s and sunny day dam break event which helps in determining remedial measure accordingly and preparing emergency action plan.
- Instead of using overly generalized "rules of thumb" or guidelines, potential failure modes assessment should be utilized to establish the most acceptable breach size. To enable sensitivity analysis in the dam break modeling, a range of probable breach geometries should be indicated.
- In cases where there is insufficient or no geological and geotechnical information of dam site, the possibility of the complete failure of dam should be considered.
- In this study, the sensitivity analysis in the downstream river was conducted solely using a two-dimensional unsteady flow routing technique. Similar to this, the reservoir routing was carried out using an only one modeling software and single method. The modeling program has a variety of restrictions and presumptions. So, considering different modelling tools and different methods, results can be compared.
- LSA and GSA on other hydrodynamic outputs like water surface elevation, velocity and arrival time of flood should be carried out.

ACKNOWLEDGEMENTS

We would like to thank all the esteemed faculty members of Department of Civil Engineering, Pulchowk Campus for guiding and encouraging throughout the study. We are thankful to Dr. Divas B. Basnyat for providing detailed feasibility report of Nalgad Hydropower Project that required for the study.

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