2D HYDRODYNAMIC MODELLING OF SAMPNA DAM

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Abstract
Sampna dam is classified as an intermediate dam as per IS11223- 1985, the potential risk factor in case of dam breach is also higher. 2D hydrodynamic model (HD) of Sampna dam is developed and Dam Break Analysis is carried out using HEC-RAS 5.0.7. The embankment dam was breached for assessment of flood inundation downstream of the dam. The dam failure was assessed for the scenarios such as overtopping failure and non-flood failure (piping failure). Inundation due to large controlled releases from the dam was also considered in the study. The inundation maps for the critical parameters such as water surface elevation, depth of water, the velocity of flow, and flood wave arrival time are prepared for all three-flood scenarios. The villages which are likely to be inundated in case of the Sampna dam breach were identified using Google Maps. The population affected due to inundation was obtained from the 2011 census data hosted on the data.gov.in website. Open-source Road and rail layers were also used in the map preparation. The peak discharge obtained for overtopping failure and non-flood failure (piping) is 8063 m^3/s and 5972 m^3/s respectively. However, for large controlled releases, the peak flood is the design discharge capacity of the spillways. The reasonableness of the peak discharge was as curtained by evaluating the velocity through the breach which has to be less than 3m/s for breach. The discharge at the end of the downstream boundary is 100 m^3/s and 80 m^3/s for overtopping failure and non-flood failure respectively.

Keywords: Hydrodynamic model, Dam break analysis, Overtopping failure, Piping failure.

1. Introduction

A dam can fail for a variety of reasons, depending on the type of dam and the conditions of the dam site. Flooding or dam overtopping are the most common causes of dam failure. The following most common cause is piping/seepage. Structural failure occurs as a result of a variety of factors, and it is the third most common category. Dams can also fail due to spillway gate failure, earthquakes, or poor design/construction. The failure of a dam varies depending on its nature or type. Concrete gravity dams may experience partial failure due to the failure of one or more monolith sections. Concrete arch dams can fail abruptly and completely in a matter of minutes. Embankment dams do not fail as completely or abruptly as concrete dams. Breaching action in an earthen dam continues until the reservoir is completely depleted or the breached materials resist erosion.

Froehlich (2008) developed mathematical expressions for the expected values of a trapezoidal breach's final width and side slope, as well as its formation time. Variances of the predicted quantities can also be calculated using the information provided. The statistical analysis findings were then used in a Monte Carlo simulation to estimate the degree of uncertainty in predicted peak flows and water levels downstream from breached embankment dams. Froehlich (2016) Based on the evaluation of measured outflows from 41 dam failures, two nonlinear mathematical models are presented to predict peak discharge from a breached embankment dam. Takaku et al. (2014) provide a brief overview of the most recent processing algorithms for global DSM datasets, as well as preliminary results from some test sites. The accuracies and error characteristics of datasets are analyzed and discussed in various fields. Froehlich (2017) Data from 111 embankment dam failures are analyzed in this paper to derive expressions for expected values of the final width, side slope, and formation time of the breach, as well as expressions for calculating variances and prediction intervals of the parameters.

The main purpose of the study is to find out the areas downstream of Sampna Dam which will be inundated due to dam breach scenarios such as overtopping and non-flood failure (piping) and to find out the inundation scenario in case of large controlled release. This study estimates the number of villages and people at risk due to dam failure and large controlled releases. It also assesses the submergence of infrastructure facilities such as roads and railways. In this study, the inundation maps for the breach scenarios such as overtopping and piping and for controlled large release were prepared.

2. Data and Methodology

2.1 Description of Sampna Dam

In 1956, the Sampna Dam is built on the Sampna River. It is a tributary of the Machana River. This project is located near Betul District and is approximately 12 km from Betul City. It has a catchment area of 44.75 km^2 and a submergence area of 254 ha. Cross-section details are given in Figure 1 and Figure 2.

Table 1 - Salient features of the Sampna dam (Source: National Register of Large Dams (NRLD), Central Water Commission (CWC)).

Name of the Project	Sampna
Type of Project	Irrigation
Name of the Dam	Sampna
Location of Dam	Betul, Madhya Pradesh
River Tributary	Sampna
Latitude	21°51'27.06" N
Longitude	77°59'36.47" E
Year of Start	1953
Year of Completion	1956
Catchment Area	44.75
Gross Storage Capacity	16.9 TMC
Live Storage	14.31 TMC
Dead Storage	686.1 TMC
Lowest River Bed Level (m)	RL 675.58
Crest Level (m)	RL 686.1
Full Reservoir Level (m)	RL 694.48
Maximum Water Level (m)	RL 695.7
Top of the Dam	RL 697.5
Type of Dam	Embankment
Length of the Dam (m)	1350
Height of the dam above the Lowest River bed level (m)	30.18
Top width of road way (m)	4.58
Designed flood intensity (Cumecs)	788
Spillway Discharge Capacity	492
Concrete Spillway Length	99.05 m

2.2 Elevation Data

The digital elevation model (DEM) used to create the two-dimensional computational mesh used to simulate flooding was derived from a global digital surface model (DSM) dataset provided by the Japan Aerospace Exploration Agency (JAXA) with a horizontal resolution of approximately 30m (1 arc-sec).

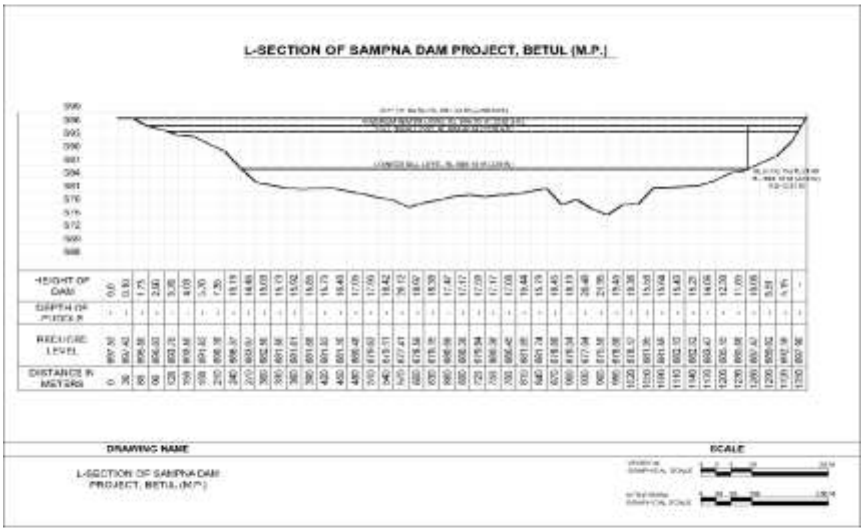

Figure 1 – L-section of Sampna Dam (Source: NRLD, CWC)

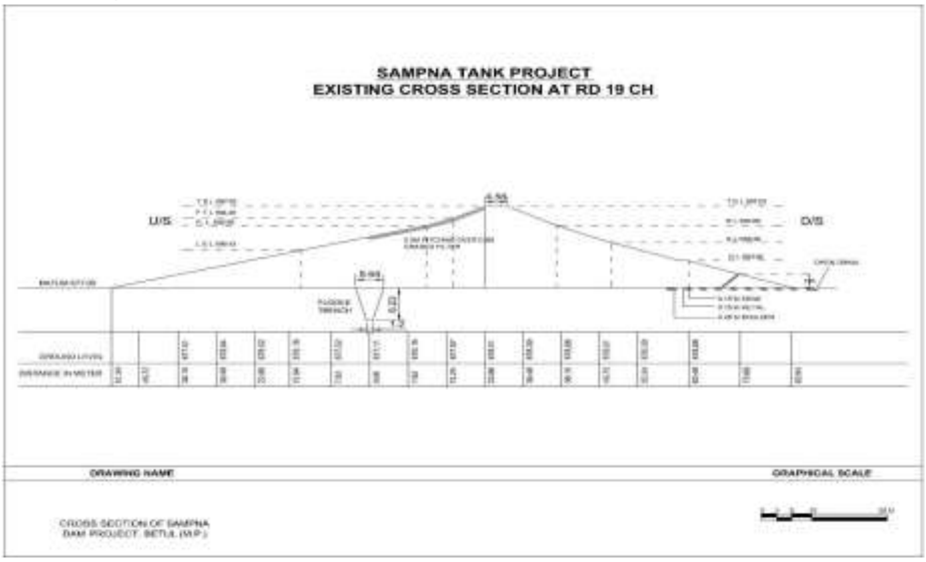

Figure 2 - Existing Cross Section at RD 19 CH (Source: NRLD, CWC)

2.3 Land Use Land Cover Data

Glob Cover 2009 v2.3 dataset developed by the European Space Agency (ESA) was used to estimate the Roughness coefficients of the hydraulic model. The dataset consists of a GeoTIFF format file with 300 m spatial resolution of global composites and land cover maps with a total of 22 thematic classes. LULC map of study area is given in Figure 3.

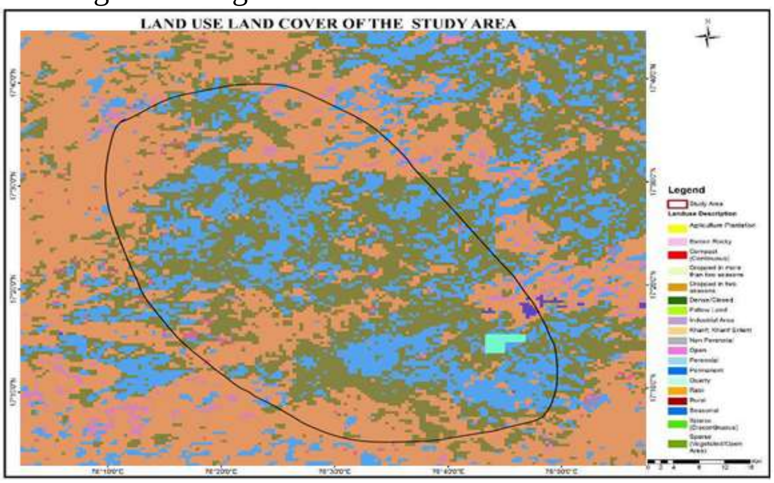

Figure 3 - LULC Map of Study Area (Source: ESA)

2.4 Population Data

The estimated population for each settlement as per the 2011 census was obtained from the data.gov.in portal. However, the present population in each of these settlements needs to be ascertained.

2.5 Hydraulic Data

The hydraulic data is obtained from National NRLD, CWC. The Sampna Dam has a 99.05m wide ogee fall. The length of the Embankment Dam is 1350m. The discharge coefficient for the weir is taken as 1.44 considering it as broad crested weir.

2.6 Hydrologic Data

The hydrologic data is obtained from the National Register of Large Dams (NRLD), Central Water Commission (CWC). The Sampna dam is classified as an Intermediate dam as per IS: 11223 (1985) "Guidelines for Fixing Spillway Capacity".

2.7 Inflow Design Flood

Inflow Design Flood was carried out by Hydrology Unit, Water Resources Development Organisation (WRDO). The spillway capacity is designed for 492 Cumecs (1, 00,000 cusecs).

3 Methodology

HEC-RAS software is used for the dam breach analysis of Sampna Dam. The 2D modeling approach was adopted. The following Dam breach scenarios are carried out overtopping failure, Large controlled release, and non-flood failure. The study area boundaries are limited to an extent of 45 km downstream of the Sampna dam where the flow gets restricted to the natural channel i.e., the total outflow in the downstream end of the model is within the channel carrying capacity of the mainstream.

3.1 Grid/mesh resolution

The two-dimensional depth averaged model was used in the study. The grid resolution of 75m x 75m was selected and the total cells were 75,558. Break lines are not used in the model. The roughness coefficient was selected based on the land use land cover of the study area, which was obtained from the Karnataka State Remote Sensing Application Center (KSRSAC) (Table 2).

3.2 Flow and Boundary Conditions

The initial condition and boundary conditions for the three scenarios are given in Table 3.

3.3 Dam Breach Parameters

Dam breach parameters were estimated using Froehlich's Equations for embankment dams (Froehlich, 2016), which is included in the Guidelines for Mapping Flood Risks Associated with Dams (CWC, 2018).

Table 2 - Land Use and Land Cover downstream of Sampna Dam and its Manning's 'n' value (Source: Karnataka State Remote Sensing Application Center (KSRSAC))

Sl.no.	Land Use and Land Cover type	Manning's 'n' Value
1	Agriculture land	0.034
2	Water body	0.04
3	Waste land	0.035
4	Buildup	0.4
5	Forest	0.05

Table 3 – Flow and Boundary conditions (NRLD, CWC)

Dam breach scenarios	Initial condition	Upstream boundary condition	Downstream boundary condition
Overtopping failure	MWL 697.7m	Inflow flood hydrograph	Normal depth 0.01

Dam breach scenarios	Initial condition	Upstream boundary condition	Downstream boundary condition
Non-flood failure	FRL 694.48m	Base flow 100 m^3/s	Normal depth 0.01
Large controlled release	FRL 694.48m	Spillway capacity 530.19m^3/s	Normal depth 0.01

Table 4 - Trapezoidal dam breach model parameters and obtained dam breach flood peak discharges

		Dam Failure Mode	
Breach parameter	**Units**	**Overtopping**	**Internal erosion (piping)**
Height	m	21.95	21.95
Bottom Width	m	100	90
Average side slope (horz: vert)	-	1:1	0.6:1
Formation time	h	1.35	1.25
Calculated peak discharge	m^3/s	8,063	5,972
[a] **Parameters of the trapezoidal dam breach model used in HEC-RAS (Brunner 2016)**			

Calibration and sensitivity analysis was not carried out. However, the breach parameters were finalized by conducting trials and verifying the breach velocity for embankment breach to be less than 3 m/s. The velocity threshold was monitored just after the breach formation time and was established based on the construction material of the dam. The dam breach parameters obtained after uncertainty analysis are given in Table 4.

3.4 Results

The simulation results show that for embankment breach, the breach velocity for overtopping failure is 2.09 m/s whereas for piping failure it is 2.02 m/s at the time of the breach. The peak discharge obtained for overtopping failure is 8063 m^3/s and for piping failure, it is 5972 m^3/s. The discharge at the end of the downstream boundary is 100 m^3/s. and 80 m^3/s for overtopping failure and non-flood failure respectively.

Flood hazard reference values consisting of maximum water depth, maximum depth - averaged velocity, and flood wave arrival time at various locations downstream of Sampna Dam, Population at risk as per the 2011 census data, and potential loss of life is presented in Table 5.

Inundation maps showing Maximum water depth in m, Maximum water velocity in m/s, and Maximum water surface elevation in m at MSL, vulnerability maps for all scenarios are developed using ArcGIS software. The map is scaled at 1:25,000. The total length of the inundation downstream of Sampna Dam is approximately 45 km, with eight tiles for overtopping and six tiles for non-flood failure and large controlled release scenarios. WGS-84 UTM zone 44 N is the projection type. The settlement layer is created by separating the settlement boundary from Google Earth. The inundation maps are shown in Figure 4, Figure 5, Figure 6.

3.5 Conclusion

The Sampna dam break analysis is carried out for the tier 2 approach using medium resolution terrain data. About 17 villages are found to be affected in the case of the Sampna dam breach.The people living in villages within 2 km downstream of the Sampna dam are most vulnerable as the flood wave arrival time is less. The peak breach flow obtained is 8,063 m^3/s and 5,972 m^3/s for overtopping and piping failure respectively. The breach velocity at the time of failure is 2.09 m/s and 2.02 m/s for overtopping failure and piping failure respectively which are well within the recommended limits. It is observed that the inundation on both sides of the river is significant in case of flood due to large controlled release. At a distance of approximately 45km from the dam site, it is observed that the flood water will be confined to the river course. Flood maximum depth, maximum velocity, Flood arrival time, Water surface elevation, and vulnerability maps are prepared at a scale of 1:25000. The developed inundation maps are useful for the preparation of EAP (Emergency Action Plan). The scope of the study is restricted to failure of the dam due to overtopping and piping only. However, inundation maps are prepared for both the cases of failure and large controlled releases. No other failure scenarios such as landslide, earthquake, malfunction of gates, and planned removal are considered in this study because the HEC-RAS Software cannot simulate these conditions. A tier-2 approach to dam breach and inundation mapping is followed which is an intermediate level of analysis using medium resolution terrain data. A tier 3 approach to dam breach analysis could be carried out using high-resolution LIDAR data.

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Table 5 – Flood hazard reference values

Location	Distance downstream from the dam (km)	Estimated population[b] (people)	Overtopping Failure			Non-flood Failure			Large Controlled Release	
			Maximum depth [c] (m)	Maximum velocity[c] (m/s)	Flood wave arrival time[d] (hh:mm)	Maximum depth [c] (m)	Maximum velocity[c] (m/s)	Flood wave arrival time [d] (hh:mm)	Maximum depth [c] (m)	Maximum velocity[c] (m/s)
Sohagpur	1.8	565	1.6	1.03	00:00	---e	---	---	---	---
Hathnora	4.6	284	4.74	3.51	00:45	4.3	3.16	00:50	0.9	0.41
Milanpur 1	4.6	154	1.29	0.92	00:56	0.86	0.41	00:56	---	---
Milampur 2	4.6	154	4.18	3.74	00:45	3.8	3.05	00:50	0.63	1.18
Milanpur 3	3.7	154	7.2	4.24	00:41	6.64	3.88	00:41	3.6	2.13
Betul Bazar 1	5.6	387	7.37	4.56	00:55	6.71	3.96	01:00	3.59	2.19
Betul Bazar 2	6.9	387	5.19	4.28	01:05	4.64	3.86	01:11	1.96	1.87
Betul Bazar 3	6.8	387	6.41	3.07	01:00	5.75	3.04	01:05	2.48	1.44
Ankawadi 4	0.9	71	0.67	0.26	00:41	---	---	---	---	---
Betul Bazar 3	6.8	387	6.41	3.07	01:00	5.75	3.04	01:05	2.48	1.44
Hanotiya	7.3	71	5.29	3.34	01:15	4.57	2.72	01:20	0.78	1.55
Balajipuram Betul Bazar	7.0	77	2.11	1.03	01:20	---	---	---	---	---
Hinotiya	7.5	71	3.6	4.3	01:15	2.99	3.64	01:20	---	--

Location	Distance downstream from the dam (km)	Estimated population[b] (people)	Overtopping Failure			Non-flood Failure			Large Controlled Release	
			Maximum depth [c] (m)	Maximum velocity[c] (m/s)	Flood wave arrival time[d] (hh:mm)	Maximum depth [c] (m)	Maximum velocity[c] (m/s)	Flood wave arrival time [d] (hh:mm)	Maximum depth [c] (m)	Maximum velocity[c] (m/s)
1										-
Balaji /Awasiya / Parisar /Hinotiya	7.8	75	3.22	2.41	01:20	2.65	2.03	01:30	---	---
Brainiacs International school	7.5	327	1.87	2.3	01:20	1.16	2.03	01:35	---	---
Batama 2	8.3	209	0.82	0.45	01:30	0.08	0.09	01:55	---	---
Batama 5	8.6	209	3.16	2.96	0	0.89	1.41	02:05	---	---
Bajpur	9.0	266	4.73	5	0	4.57	4.22	01:35	2.53	2.33
Badora Main	9.4	109	6.4	3.85	01:30	5.9	3.33	01:40	3.71	2.3
Badora 2	10.3	109	1.45	0.64	02:15	---	---	---	---	---
Betul 1	9.0	841	4.93	1.64	---	2.24	0.9	02:05	---	---
Danora 1	11.8	53	2.45	1.49	02:15	1.36	0.31	02:56	---	---
Danora 2	11.3	53	1.54	1.31	02:10	0.38	0.73	02:50	---	---
Danora 3	11.8	53	1.65	1.54	02:15	0.41	0.79	03:11	---	---
Danora 4	12.2	53	2.34	1.23	02:10	1.47	1.22	02:50	---	---
Parsoda	12.3	18	5.63	2.46	01:40	4.4	1.39	02:15	1.83	0.27
Bhadus 1	13.7	613	0.54	0.77	02:40	---	---	---	---	---
Bhayawadi 1	17.9	130	2.25	0.74	03:00	1.02	0.86	03:45	---	---
Hibarkhedi	24.7	327	1.97	1.03	04:26	0.55	0.69	05:41	---	---

[a]Approximate shortest distance downstream from dam.
[b]Estimated population within the assumed settlement boundaries.
[c]Maximum value near the specified location, which usually occurs near the center of thestream.
[d]Flood wave arrival time is the time since the initiation of the dam breach until thesettlement is inundated
[e]Location not inundated.

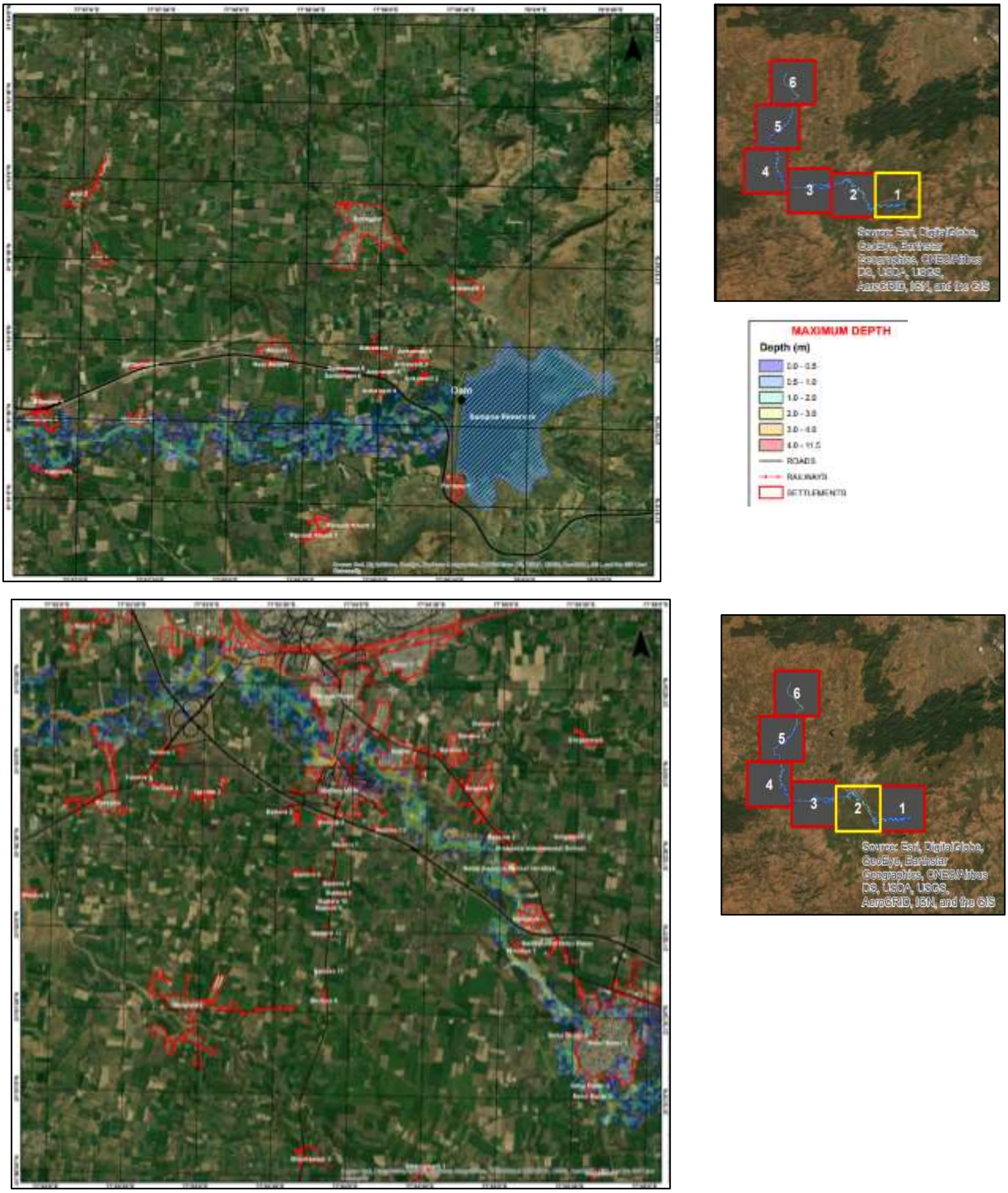

Figure 4 - Maximum water depth map of Large controlled release

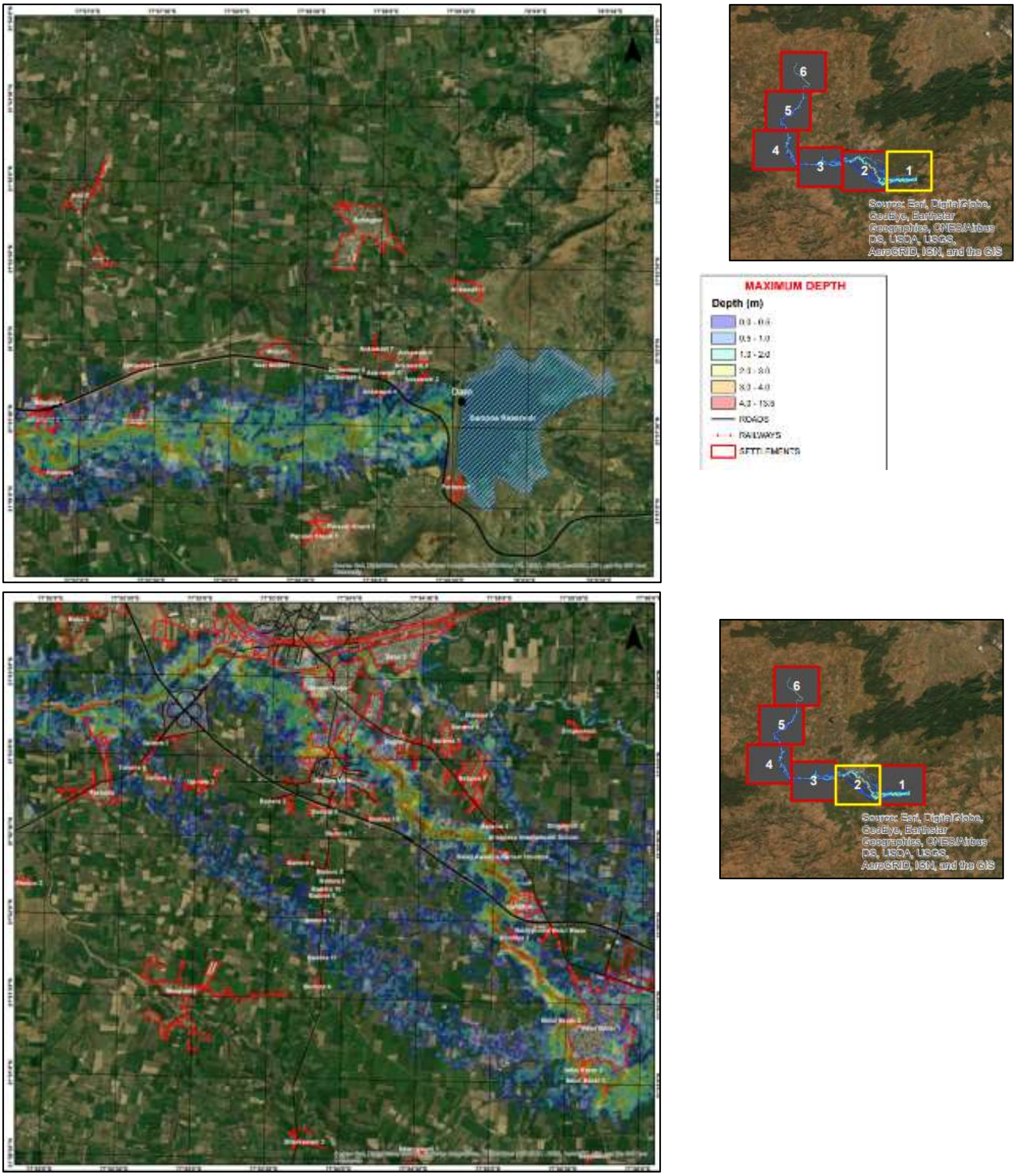

Figure 5 – Maximum water depth map of non- flood failure

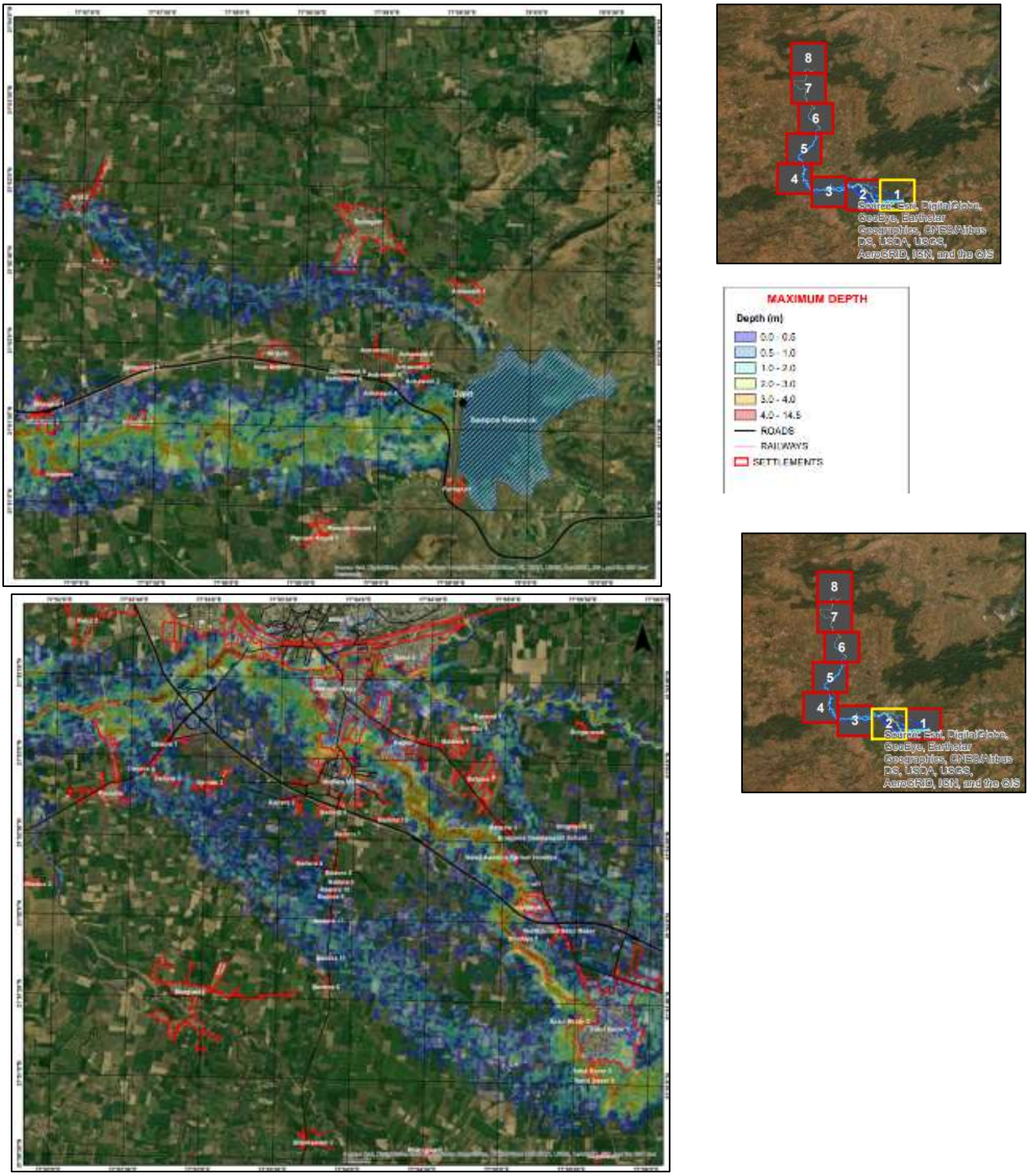

Figure 6 – Maximum water depth map of overtopping failure

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