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Prediction of Dam Breach Flood Hazard Using GIS

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Abstract

When dam breach occurs, the resulting flood can cause enormous damages to infrastructures and loss of life. The prediction of dam breach flood hard in this study was done for overtopping Dire dam breach. The flood hazard map was done in GIS after water surface elevation, maximum flood depth, and velocity were exported from HEC-RAS to GIS. The maximum flood depth and maximum flood velocity occurred due to dam overtopping failure were 16.41m and 22.74m/s respectively. The simulation outcomes presented that, in the event of Dire dam breach due to the overtopping dam break mode, some Dire dam downstream areas were observed as having high flood hazard due to the significant flood water depth and velocity values.

Key words: Dam breach, Flood hazard, GIS

1. Introduction

Floods are natural catastrophes that affect nearly all areas in the world today. The risk of flooding is a natural disaster that most commonly cause loss of property and lives. Assessments of the magnitude and frequency of floods is significant for infrastructure planning, design and in the management of water resources and riparian areas. Study on flood frequency has focused on the estimation of extreme flood events, rather than the more frequent small to moderate size flood events which dictate alluvial channel morphology. Flood inundation models play a central role in both real time flood estimating and in flood plain mapping(Kumar *et al.*, 2017). The development of flood inundation mapping is an important component of flood hazard management because flood inundation maps do not only provide accurate geospatial information about the amount of floods, but also, when coupled with a geographical information system, can help decision makers extract other useful information to measure the risk related to floods such as human loss, financial damages, and environmental degradation. For these reasons, flood maps have been broadly used in practice to evaluate the potential hazard of floods(Afsal *et al.*, 2016).

The major two consequences of a dam failure are Life loss, because of heavy flood resulting from dam break this loss may occurs if the villages and the residing families are washed away and also Economic loss, calculated in terms of revenue which is required to rebuild the washed away villages in terms of infrastructure, and other allied facilities. The dam break analysis will make possible to predict the flood and areas affected by flood at downstream due to breach. The study predicts the potential of precautionary measures which can be taken to completely avoid the dam break which avoid or minimize damage (Kulkarni and Jagtap, 2017). In the event of a dam failure, the possible loss of lives and destruction of infrastructures can be occurring at the downstream areas. Since the flood resulting from the breaching of a dam can cause massive destruction to the downstream civilian population and infrastructures, observing and analyzing embankment dams breaking condition is important to protect the dam from irreversible failure and to reduce catastrophic disasters on the downstream of the dam due to unusual flood (Duressa and Jubir, 2018).

Dire dam under this case study is a rock fill dam constructed of impervious clay core. The dam was located at the upper side of the downstream areas of small house housing wires from piezometers, Legadadi town of different infrastructures such as Residential areas, Religious areas, and High way road serving for transportation from Addis Ababa to Debre Birhan and to Dessie. The overall objective of this study is to predict the flood hazard on the downstream areas due to the Overtopping breach of Dire dam.

2. Methods

2.1. Study Area

Study area is located in Oromiya region, in the east of Addis Ababa city. Dire dam is an embankment dam of impermeable central clay core. The dam is constructed for water supply purpose of Addis Ababa city. The dam was bounded between 38°56′02″ E longitude and 9°08′53″ N latitude.

Figure 1. Photograph of the study are

2.2. Data acquisition

The data required for the study such as hydrological data, dam geometric data, unsteady flow data, reservoir volume relationship data, topographic data, and Legadadi geometry data were collected from the different sources.

Table 1: Required for the study

Important data	Data sources
Hydrological data (PMF)	Addis Ababa Water and Sewerage Authority
Dam geometric data	Addis Ababa Water and Sewerage Authority
Reservoir volume relationship data	Addis Ababa Water and Sewerage Authority
Topographic data (DEM)	http://vertex.daac.asf.alaska.edu/.
Legadadi River geometry data	Extracted from DEM of the study area via HEC-GeoRAS

2.3. Methodology

1. GIS software

GIS software was used to delineate study area, generate triangulated irregular network (TIN) from DEM of Dire watershed for creating of Legadadi river networks and developing dire dam downstream areas flood inundation map. In GIS the progress of creating Legadadi river networks were done through HEC-GeoRAS and the progress of developing flood plain map was performed after exporting the water surface elevation, the maximum flow depth and velocity from HEC-RAS into GIS.

2.4. Flood Inundation Mapping

Dam break flood inundation map shows area with the intention of floods as a result of a dam break. The maps are used by thick scope of end users for planning and as a reaction instrument to decide the effect of dam break in downstream areas. In addition, the incremental areas flooded as a consequence of dam break were considered for a dam classification exercise (Balaji and Kumar, 2018). The flood map embodies, areas where there is a risk of flooding and helps for warning the population and preparatory work of flood hazard map distribution among them proves to be effective to mitigating flood damage and reduce the numbers of casualties (Boussekine and Djemili, 2016).

2.5. Flood Hazard Prediction

The risk to public safety and to situate infrastructures damage triggered through floods based mostly upon the velocity and depth of flood occurred from breached dam. The larger these elements become, the larger the hazard to downstream civilian population and infrastructures. This hazard is categorized as high hazard, medium hazard and low hazard based on the risk related to magnitude of flood hazard detection factors.

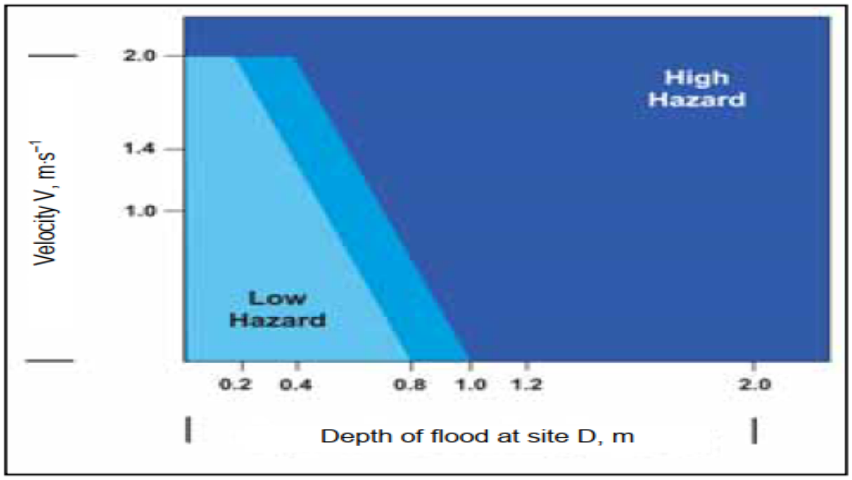

Figure 2. Flood Hazard zone classification as a function of velocity and water depth; source: (Derdous *et al.*, 2015).

3. Results and Discussions

3.1. Routing of flood hydrograph

In order to rout the flood hydrograph through the downstream of Dire dam, the upstream end river station of 12086.49 and the downstream end river station of 26.77806 and also intermediate river stations of 8924.878 and 26.77806 were used as important downstream flood wave indications.

Table 2. Routed breach outflow discharges by overtopping along the downstream of dire dam

S/N	River stations	Peak discharge (m^3/s) at different River stations
1	12086.49	9285.3
2	8924.878	9248.65
3	4701.743	9181.45
4	26.77806	9165.80

3.2. Longitudinal Profile of the Legadadi River

The Legadadi River longitudinal profile consist of the water surface elevation, the base elevation, the energy grade elevation, and the main channel distance from the upstream boundary condition to the downstream boundary condition. This profile was analyzed during dam breach by overtopping failure mode.

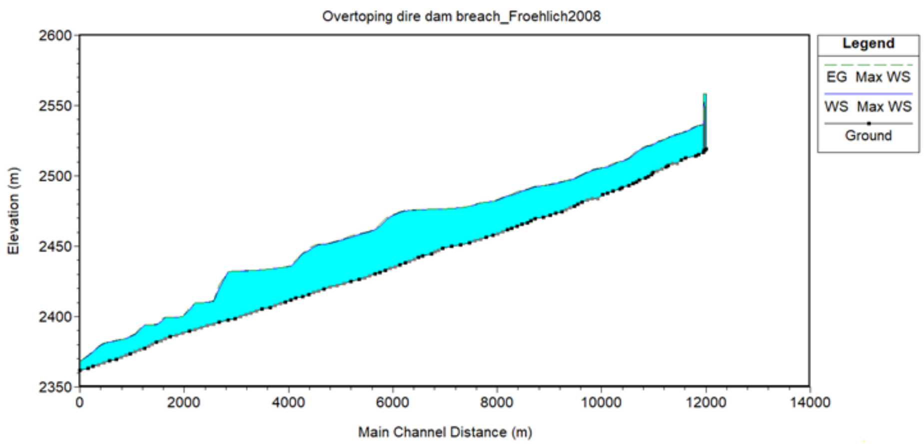

Figure 3. Longitudinal bed profile of Legadadi River

Table 3. The maximum flood profile of Legadadi River at the dam location (RS = 12086.49)

S/N	Legadadi river characteristics	by dam Overtopping
1	Energy grade elevation (m)	2558.30
2	Maximum channel depth (m)	38.93
3	Maximum water surface elevation (m)	2558.24
4	Top width (m)	1107.12
5	Minimum channel elevation (m)	2519.31

3.3. Cross Sectional Profile of the Legadadi River

The cross sectional profile of Legadadi River was analyzed during dam breach due to overtopping failure mode. This cross sectional profile of the river contains maximum energy grade surface and maximum water surface.

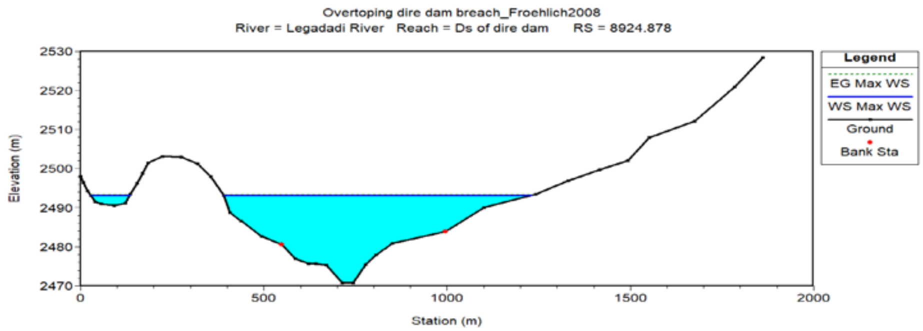

Figure 4. Cross sectional profile of Legadadi River by overtopping of RS (8924.878)

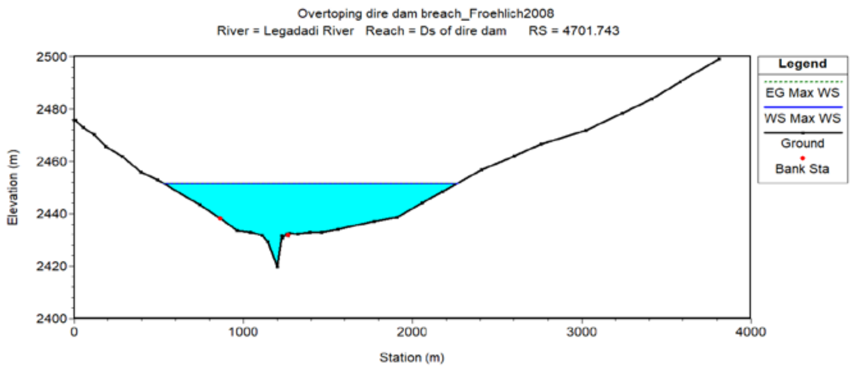

Figure 5. Cross sectional profile of Legadadi River by overtopping of RS (4701.743)

The maximum depth of flood and top width over the banks at different river stations of RS (8924.878), RS (4701.743), and RS (26.77806) were analyzed.

Table 4. The maximum depth of flood and top width over the banks at different river stations

S/N	River stations	flood depth (m) by overtopping	Top width (m) by overtopping
1	RS (8924.878)	10.97	946.18
2	RS (4701.743)	13.11	1740.92
3	RS (26.77806)	11.24	1629.27

Table 5. The flood arrival time at different river stations

S/N	River stations	flood arrival time (minutes) by overtopping
1	RS (8924.878)	20
2	RS (4701.743)	70
3	RS (26.77806)	100

3.4. Flood Inundation Map Development

The flood map for the Dire dam was done through the flood resulting by overtopping mode of failure. For this study, the area located downstream of the dam that would be inundated were small house collecting and housing wires from piezometers, Legadadi town with different infrastructures. The downstream areas that would be inundated by the flood resulting from the breached Dire dam were covered about 30.927 km^2. It was calculated in GIS from polygon created for the flood coverage of the downstream of the dam. The flood inundation map was developed based on the maximum flood depth and maximum flood velocity. The maximum flood depth and maximum flood velocity due to overtopping were 16.41 m and 22.74 m/s respectively. The flood map through downstream of Dire dam flooded area due to maximum flood depth and maximum flood velocity for overtopping was shown in figure 6 and 7.

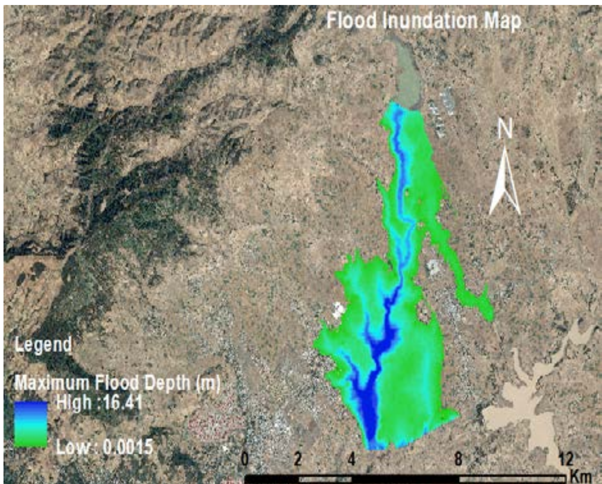

Figure 6. Flood map due to maximum depth

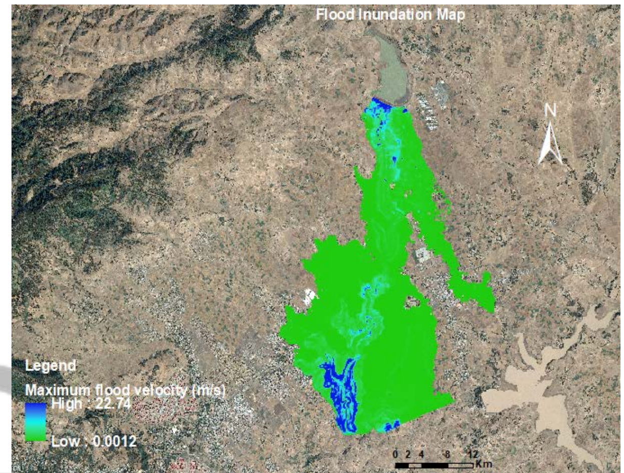

Figure 7. Flood map due to maximum velocity

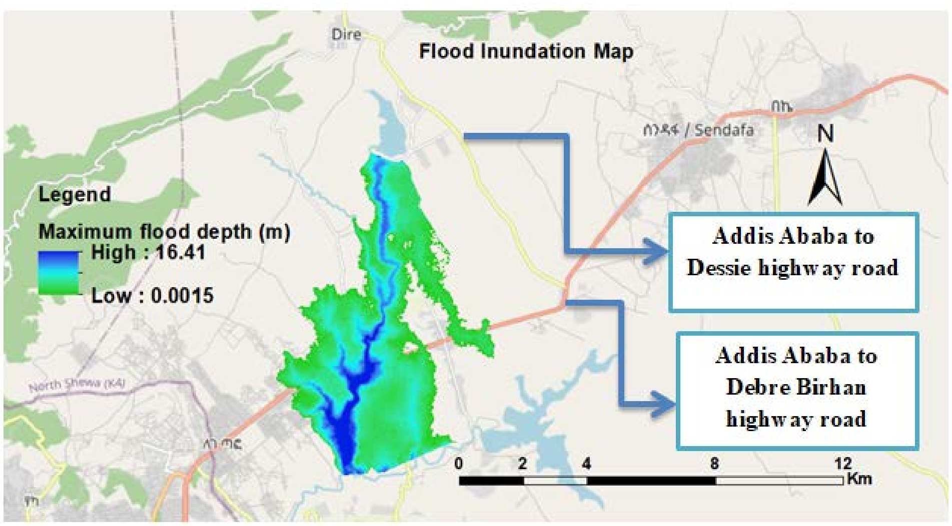

Figure 8. Addis Ababa to Dessie and to Debre Birhan Highway road that would be inundated from the breached dam due to Overtopping

3.5. Flood Hazard Mapping

The flood hazard map was developed in the GIS through combining depth and velocity maps. Figure 9 showed the downstream hazard flood map subsequent from the breach of Dire dam due to overtopping.

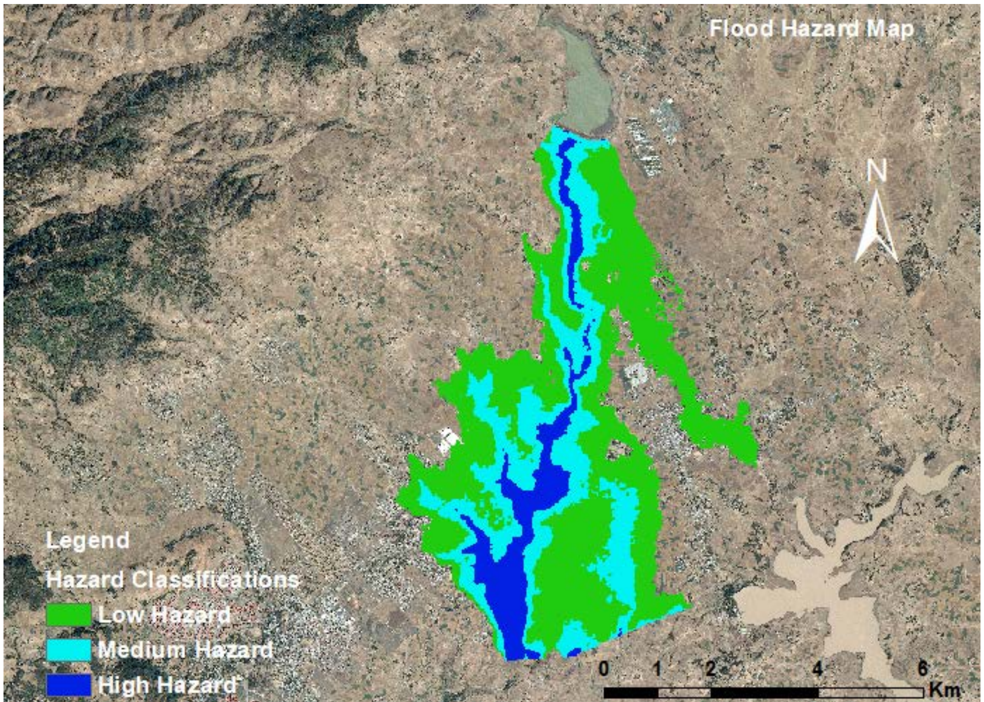

Figure 9. Flood hazard map resulting from the failure of Dire dam

Based on (FEMA, 2013) dam hazard classification as observed from the flood hazard map, at the point of low hazard symbolized by green color, the inundated flood on the downstream areas of Dire dam would results no probable loss of community life and low economic and environmental losses. For Medium hazard class represented by aqua color, the flood occur would probably cause economic loss and environmental damage, and also for high hazard class symbolized by blue color, the flood would probably cause loss of community life.

4. Conclusion

Floods are natural catastrophes that affect nearly all areas in the world today. The risk of flooding is a natural disaster that most commonly cause loss of property and lives. When dam breach occurs, the resulting flood can cause enormous damages to infrastructures and loss of life. The prediction of dam breach flood hard in this study was done for overtopping Dire dam breach. The flood hazard map was done in GIS after water surface elevation, maximum flood depth, and velocity were exported from HEC-RAS to GIS. The maximum flood depth and maximum flood velocity occurred due to dam overtopping failure were 16.41m and 22.74m/s respectively. The simulation outcomes presented that, in the event of Dire dam breach due to the overtopping dam break mode, some Dire dam downstream areas were observed as having high flood hazard due to the significant flood water depth and velocity values

5. Recommendation

The study results presented that, some areas located downstream of dire dam would be flooded from resulting flood in the event of dire dam break. These areas located near the Legadadi River flood plains would be damaged by the flood as observed from flood hazard map and better if the residential houses and infrastructures are built at the minimum distance of 350m from the left bank and 200m from the right bank. The maximum flood depth found due to the overtopping breach scenarios was 16.41 m, therefore people living very close to Legadadi river banks in downstream area needs to build their houses above this level. For more improvement of the results found, the dam owner should also have conducted further study by collecting downstream elevation data for lessening the deviation from the actual one.

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