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SIMULATING THE FAILURE OF DOMA DAM USING A MATHEMATICAL MODEL

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ABSTRACT

Doma dam plays vital role in the area of water supply, flood mitigation and irrigation purposes. There is a great deal of energy latently stored in the impounded reservoir. This will result in loss of lives, besides damage to properties and infrastructures in the event of failure. Short warning time prior to the break is often the bane of such colossal damage. Hence, the need for dam failure flood analysis to determine the travel times of flood, peak discharge hydrograph, peak to time stage, and the flood water velocities for a reach length of two kilometre downstream of the dam. These parameters provided a benchmark for adequate planning, management and prediction of downstream hazard potentials in the event of failure. This analysis is crucial bearing in mind that such has not been conducted in recent time. This was carried out using mathematical tool, BOSS DAMBRK hydrodynamic flood routing model. It adopted an inflow hydrograph peaked at 10,320 m^3/s for the simulation and a corresponding peak discharge hydrograph of 10,623 m^3/s was obtained. An optimum flow velocity of 2.05 m/s having a peak discharge of 10,320 m^3/s at 0.5 km downstream was obtained. The sudden drop in velocity from 2.05 m/s at station 2 (0.5 km) to 1.30 m/s at station 5 (2.0 km) with a peak discharge of 11,685 m^3/s proved that the peak velocity of flood reduced steadily and simultaneously with the flood wave downstream the dam owing to the river channel configuration and geometry.
Keywords: Downstream, Hydrograph, Inundation, Routing model, Reservoir, Simulation,

1. INTRODUCTION

Dams are barriers that impounds water or underground streams that generally serves the primary purpose of retaining water. Reservoirs created by dams constitute an important element for the provision of water to the increasing population of the world. Dams do store water at moment of high inflow from the upstream catchment and release it afterwards when river flows are considerably low. They are central to the social-economic well being of a country given the provision of basic necessities like irrigation, electricity, drinking water and hydropower, recreation. Dam construction can have negative impacts on upstream and downstream ecosystems, water chemistry, stream flow and wetlands (Tilt, et al, 2009). Its failure could be catastrophic downstream in the event that it happened. Hazards resulting from such incidences include destruction of infrastructures and utilities downstream of the dam, loss of human lives, and properties (Turalim and Mohamed, 2002; Alabi, et al, 2014).
The havoc that often emanates from dam break can be traced to the dearth of information on dam operations. Such avoidable tragic event can be minimized extensively if there were prior engineering studies conducted to ascertain the level of flooding that could result from a hypothetical dam break (Ryan, 2001). Therefore, important parameters for instance; the flood depth and the flood wave velocity are of tremendous significant in chatting a robust management roadmaps and disaster preparedness (Alabi, et al, 2014; Turalim and Mohamed, 2002). It is on this premise that this study is carried out to simulate the failure of Doma Dam, Lafia, using a professional engineering software package: BOSS DAMBRK Model.

This tool is one of the most advanced, one-dimensional hydrodynamic flood routing software available. It is the improved and updated version of DamBrK Model. The software accounts for dam and bridge failures, storage effects, floodplain overbank flow, and flood wave attenuation. It is used for dynamic flood routing, dam safety and reservoirs spillway analysis.

Plate I: Doma Dam Showing Morning Glory and Open Channel Spillway

Table 1.0: Doma Dam Details

S/No	Doma Dam Detail	
1	Name of Dam	Doma
2	Type of Dam	Earth fill
3	Year of construction	1988
4	Length of dam crest	520m
5	Dam's width at the crest	18m
6	Dam's width at its foundation	160m
7	Maximum Height of Dam	28.5m
8	Available head	15.7m
9	Reservoir capacity (at N.W.L)	37.5Mm2
10	Reservoir surface area (at N.W.L)	2.2km2
11	Live Storage Elevation	132m.a.s.l
12	Live Storage	30Mm3
13	Dead Storage Elevation	116.3m.a.s.l
14	Dead Storage	7.5Mm3
15	Design Flood	63m3 / s
16	Catchment area of the parent river at the Doma dam site	179.94 km2
17	Name of parent river	River Ohina (tributary of River Mada)
18	Purpose	Irrigation Other uses Water Supply
19	Net irrigable area	1,000 Hectares
20	Hydrological zone	IV
21	Spillway Type	Morning Glory and Open Channel Spillway

Source: Adebayo, W.S., et al, 2017, Okoye & Achakp, 2007

2. THE STUDY AREA

The dam is situated within the Lower-Benue Hydrological Area Four (HA-IV) of North central, Nigeria (NIWRMS, 1995; NIWRMS, 2012). It is a homogenous earth fill (Table 1.0) having a morning Glory and Open Channel Spillway (see Plate I). And situated some eight (8km) kilometers south of Doma town and about 30 kilometers away from Lafia the state capital. Doma local government is at Longitude: 8° 21' 19" E and Latitude: 8° 23' 35" N (Google Images, 2020). The dam is structured into three arms with each arm measuring more than 2km in length and 300m in width: they are the three (3) branches of the dam meant for farming and fishing activities in the downstream. Fringing the reservoir are hills which circle the reservoir. The catchment is substantially devoid of human settlements and management of the upstream watershed and reservoir area is quite good, with the soil essentially undisturbed and the catchment characterised by moderate to heavy vegetation cover through out the year which account for the excellent quality of water reaching the reservoir.

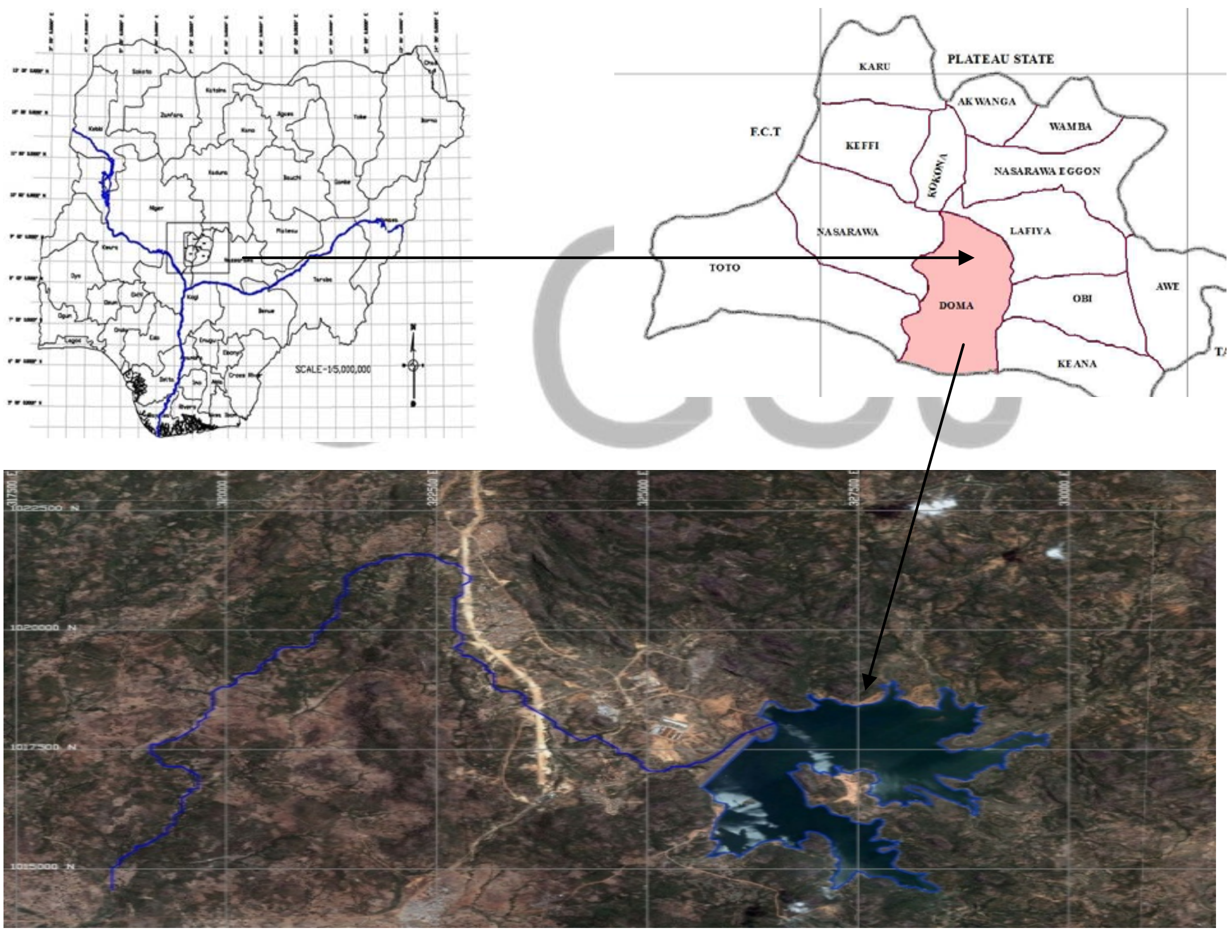

Figure 1a: The Study Area

3. MATERIAL AND METHODOLOGY

3.1 Dam Break (DAMBRK) Model:

The DAMBRK software was developed by the National Weather Services (NWS) (Fread, 1984) for simulating dam failure and the resulting flood wave via downstream valley. Warning time and the determination of the expected maximum crest height have been achieved through this model in several dam break simulations analysis. This model has the following to its advantages: The wave formed from the breached dam and its progression downstream can be estimated. It has the capability to define the failure mode geometrically, the outflow hydrograph from the breached section can be computed, and route the outflow through a downstream channel.

3.2 BOSS Dam Break Software (BOSS DAMBRK)

BOSS DAMBRK is a one-dimensional engineering software tool employed to develop the outflow hydrograph from a breached dam and hydraulically route the flood through the downstream channel. It is used for the detailed design, management and operation of both simple and Complex River and channel system (ASCE, 2000). The equations that govern this model are the complete one - dimensional St. Venant equations of unsteady flow (Chow, V.T. 1959). Boundary equations at the upstream and downstream limits of the routing distances are utilized. The systems of equations are solved by a non-linear weighted four-point implicit finite difference technique. The flow may be either subcritical or supercritical or combination of each varying in space and time from one to the other; fluid properties may obey either the principle of Newtonian (water) flow or non-Newtonian (mud/debris flows or the contents of a mine tailings dam) flow. In general, it is suitably use in the safety analysis of dam and reservoir spillway analysis. This software is preferred over the other models on the premise of it strength and merits: Its broad applicability, It is economically feasible to use in an operational environment, Its capacity to interface with different degree of data ranging from rough estimate to complete data specification in addition to its high level of accuracy. The computational scheme is robust. It is capable of distinctly modelling the most important features of the three component parts of dam-break flood analysis which entails: the description of the failure mode; the prediction of the outflow discharge hydrograph through the breached opening; reservoir storage characteristics, spillway outflows, and downstream tail water elevation; and outing the outflow hydrograph through the channel downstream in order to modify the hydrograph, estimate the resulting water stages and the travel-time of flood wave (BOSS International, 1999).

3.3 Model Data Requirement

The important data required to model failure of the dam and routing of the resulting flood wave downstream are: reservoir details, dam details and breach details. Both the reservoir and the dam details are displayed in Table 1 above. The breach details are highlighted below.

3.2 Breach Details:

The most frequent causes of failure of embankment dams are overtopping, internal erosion in the body of the dam and internal erosion of the foundations. The process and the time taken for failure to occur is invariably dependent on the height of the dam, the type of construction material, the degree of compaction, flood flow duration. The mode of failures in overtopping scenario could assume the shape of a rectangle or trapezoid (shown in figure 1b below). The duration of breach is usually few minutes to few hours. Once failure is initiated, a breach will progress through erosion and collapse mechanisms until the breach dimensions and hydraulic discharge reach equilibrium. The key model parameters used to describe the dam breach are the final breach size, and the time taken for it to develop. The usual approach when assessing the parameters is to use guidelines and equations based on past dam failures. It is essential to note that the regression relationships highlighted here are presented as helpful and practical approximations for predicting peak discharge that would constitute potential downstream damages when failure takes place.

Hence, the method employed to obtain the breach parameters and the maximum peak discharge from the breach was according to Froehlich (Froehlich, 1995)

.

This is given by: $Bav = 0.1803Ko(Vw)^{0.32}(Hb)^{0.19}$

$$Tf = 0.00254(Vw)^{0.53}(Hb)^{-0.9}$$

$$Qp = 0.607(Vw)^{0.295}(Hw)^{1.24}$$

Where:

Bav = Average Breach Width (m)

Tf = Time of Failure (hrs)

$Ko =$ failure Mode Factor (1.0 for Piping, and 1.4 for overtopping)

Vw = Volume of Reservoir (m^3)

Hb = Height of Breach (m)

Q_P = Peak Discharge from the breach (m^3/s)

Hw = Height of water behind the dam (m)

For Doma Dam;

$Vw = 37 * 10^6$ m^3, Hb = 29m, $Ko = 1.0$

$$Bav = 0.1803 * 1.0 \left(37 * 10^6\right)^{0.32} (28.5)^{0.19}$$

$$= 0.1803 * 1.0 * 264.13 * 1.89$$

= 90.00 m

$$Tf = 0.00254(Vw)^{0.53}(Hb)^{-0.9}$$

$$= 0.00254 \left(37 * 10^6\right)^{0.53} (28.5)^{-0.9}$$

$$= 0.00254 * 10259.99 * 0.05$$

$$= 1.3Hr$$

$$Qp = 0.607(Vw)^{0.295}(Hw)^{1.24}$$

$$Qp = 0.607\left(37*10^{6}\right)^{0.295}(28.5)^{1.24}$$

= 0.607 * 170.85*65.85

= 6,829.036 m^3/s

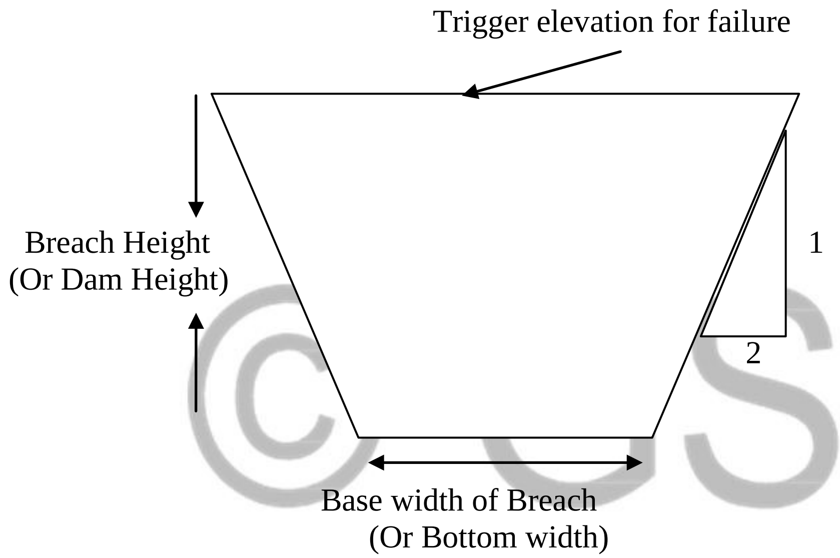

Figure 1b: Breach Parameter of Doma Dam

4. RESULT AND DISCUSSION

4.1 Combined Stage and Depth Hydrograph

The combined flow depth hydrographs, and combined stage are shown in Figures 2a and 2b respectively. The water flooding the reach length is greater than 1.0 m in depth and the velocity higher than 3.0 m/s. this portends a high danger and threat to the lives of adults, children, houses and vehicles (Enzel et al, 1994, Singh and Snorrason, 1984; USDI, 1988). The results indicated that in the event of Doma dam failure, spots within the reach length of 2 Km would be inundated beginning at 0.0Km (dam site) to 2.0 Km (lower end of dam) and thus unsafe for human lives and development.

4.2 Flood Arrival Plot

From the wave arrival time and time of wave to peak stage plot (Figures 3a – 3b), the values obtained at downstream distances of 0.0 Km, 0.1 Km, 0.5 Km, 0.8 Km and 2.0 Km showed that the flood wave travelled downstream to attain its peak stage approximately 0.72 Hr at 1.0 Km downstream. The peak stage varied from 0.84 Hr to 1.32 Hrs over downstream distance of 2.0 Km.

This scenario further demonstrated the occurrence of dam failure at 1.3 Hrs upon the breach formation with consequent flood discharge of 10,623m^3/s at 0.0Km. Peak stage was attained with a discharge of approximately 11,100 m^3/s at 0.8 Km within 0.72 Hr.

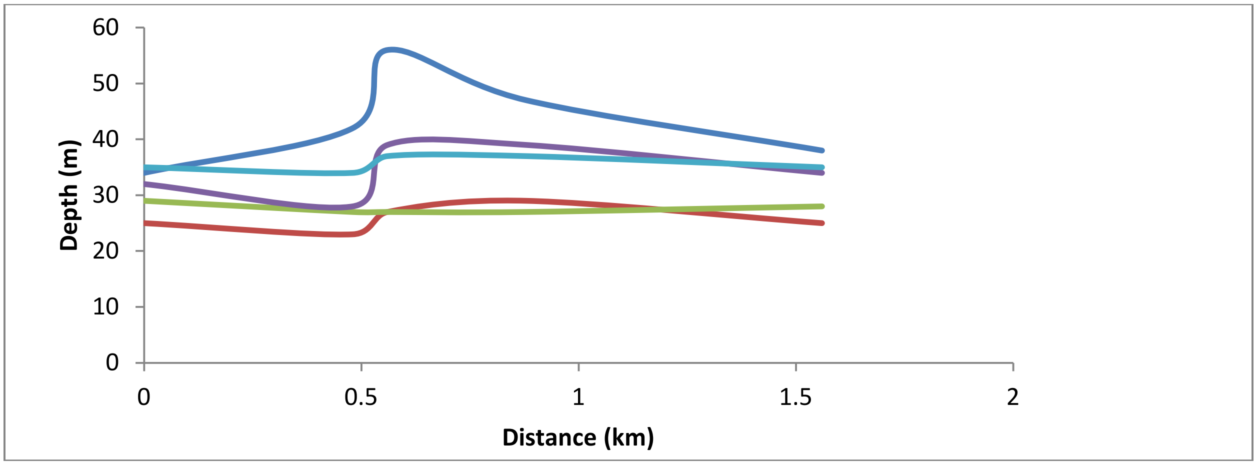

Figure 2a: Combined Flow Depth Hydrographs for River Valley

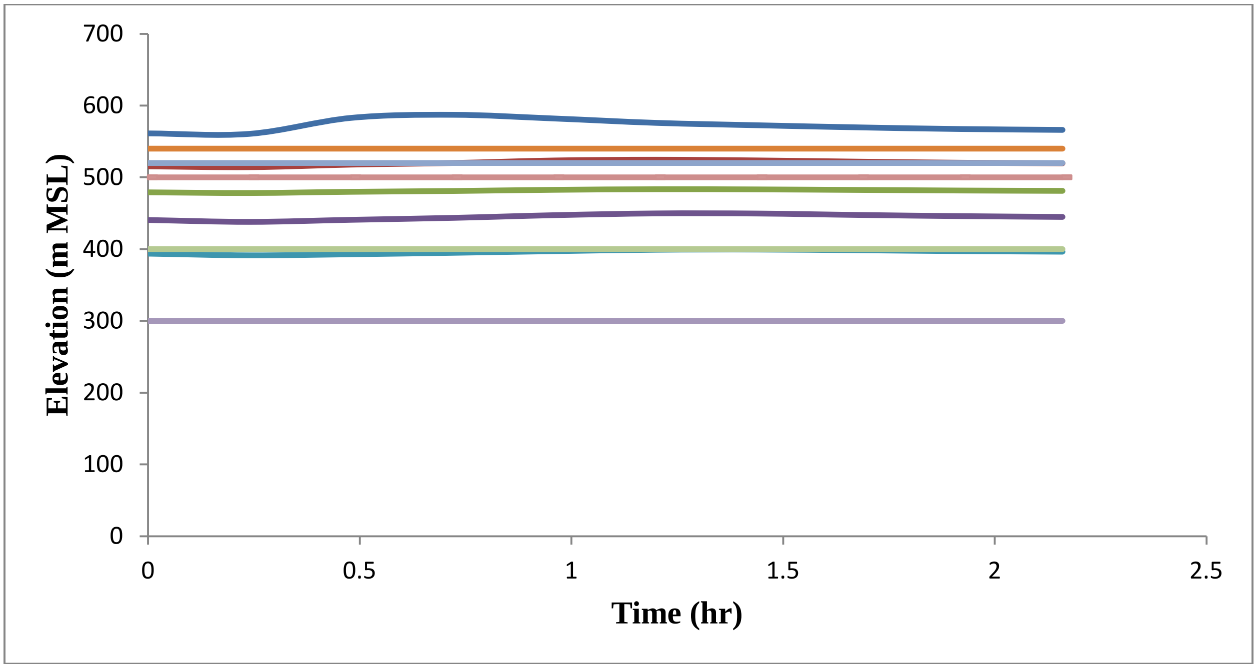

Figure 2b: Combined Stage Hydrographs for River Valley

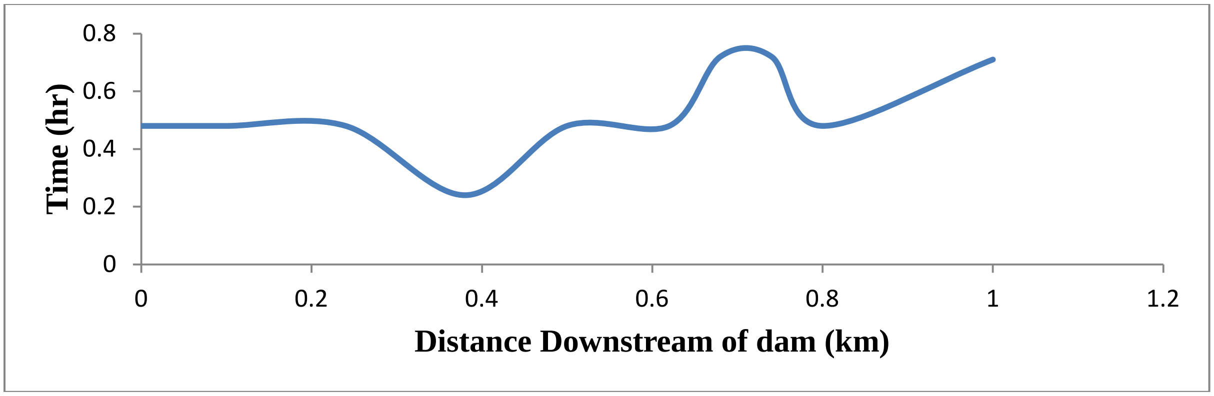

Figure 3a: Flood Wave Arrival Time

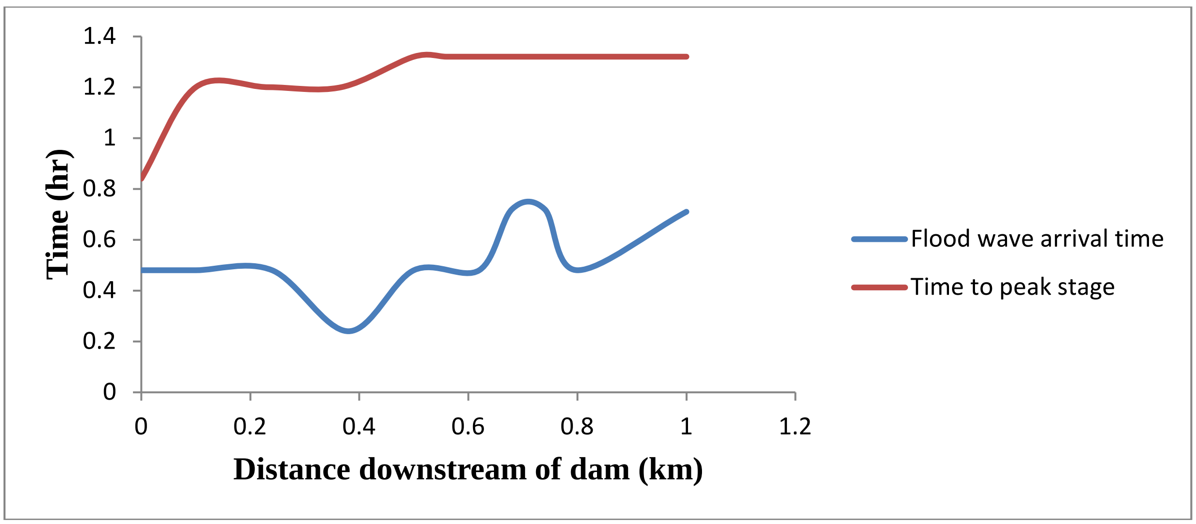

Figure 3b: Time of wave to peak stage

5. CONCLUSION

the speed of propagation of the flood wave arrival time is one of the crucial defining indices of dam break modelling. This allows emergency planners to identify when and at what level inundation of a given area expected. The wave arrival time constitutes an indicator in this respect as shown in Figures 2 and 3 above. In conclusion, activity within the given span should be moderated and controlled to prevent untold havoc and catastrophic flash flooding in the event that Doma dam failed.

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