

Evaluation of Downstream Flood Hazard with HEC-RAS for Potential Overtopping and Piping Failure of Oyan River Dam, Abeokuta, Nigeria



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ABSTRACT: This study presents a thorough dam break analysis of Oyan Dam, Nigeria, using the Hydrologic Engineering Center-River Analysis System (HEC-RAS) 6.6 software. The analysis simulated two hypothetical failure scenarios: overtopping and piping, to evaluate hydraulic and flood risks associated with potential failure of the dam. Breach characteristics were calculated using Froehlich's analytical formulas, and unsteady flow simulations were conducted for an 11 km downstream reach. Key hydraulic parameters, including peak discharge, stage elevation, flow velocity and flood wave travel time, were computed. Results revealed that the overtopping scenario produced a higher peak discharge of 22,556.47 m³/s at the dam and greater flood velocities of about 10.24 m/s, whereas the piping failure produced a lower peak discharge of 17,140.02m³/s. In both scenarios, flood wave propagation was characterized by deeper inundation near the dam and progressively reduced flood depths downstream. Floodplain mapping using HEC-RAS Mapper revealed extensive inundation of downstream areas, including critical infrastructure, settlements and natural reserves. Simulations indicated that overtopping poses an immediate and severe flood hazard, making it the critical failure mode. Evaluation of possible downstream flood hazards identified at-risk areas: Arakanga nature reserve, Awyan, Iwofin and potential flooding of Lagos State through the Ogun River tributary system. This study highlights the critical importance of implementing flood risk reduction measures, construction of levees, development of auxiliary retention dams, emergency evacuation planning and enhanced dam monitoring systems. This analysis should improve dam safety, disaster preparedness and regional flood management planning, especially for coastal communities like Oyan and communities downstream of the dam.

KEYWORDS: Oyan river dam, HEC-RAS, Dam breach characteristics, Peak discharge, Inundation depth

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I. INTRODUCTION

A dam is a structure or barrier built across a valley, river or stream to save, store or regulate water flow and create a reservoir for the purpose of water storage (El Gayer, 2020; De Wrachien, 2009). As integral infrastructure in water resources management, dams facilitate a range of services including potable water supply, hydropower production, irrigation, flood regulation, navigation, aquaculture and various socio-economic activities. The purpose of a dam can be a combination of any of the above, thereby making them multi-purpose dams, or single-purpose dams. They can either be small or large: large dams are structures constructed across valleys at elevations significantly higher than the maximum anticipated floodwater level (Loucks *et al.*, 2017). According to the International Commission on Large Dams ICOLD (2018), large dams are defined as those with a structural height exceeding 15 m above the foundation, or those between 10 and 15 m in height that impound a reservoir volume greater than 3 million cubic meters (3×10^6 m³ or 3 Mm³).

The common types of dams built are earth embankment/rock fill dams, arch and multi-arch dams, gravity dam, buttress dam (combination of gravity and arch dam), steel, timber and composite materials dams. Dams are unique engineering structures that differ significantly from other major civil works, primarily due to their stringent safety requirements throughout all phases from planning and design to construction, commissioning and operation (Bhattarai *et al.*, 2016). Each dam is considered a prototype because of its site-specific characteristics, including foundation conditions, geological and site materials, hydrology and reservoir operation models (Hager *et al.*, 2022).

Moreover, both the loading conditions and the structural resistance of a dam may vary over its functional lifespan as a result of environmental changes and material aging. Thus, the main causes of dam failures include the following (Hager *et al.*, 2022); floods exceeding the designed spillway capacity: 30% foundation ($\pm 5\%$); dams experiencing foundation problems (seepage, internal erosion, excessive pore pressures, faults movements, settlements): 37% ($\pm 8\%$); landslides happening to

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reservoirs (earth, rocks, glaciers, avalanches): 10% ($\pm 5\%$); improper dam design and construction; using inferior quality of material for construction; act of war; and inadequate or lack of regular maintenance operations: 23% ($\pm 12\%$). In addition, the failure of a dam can have disastrous consequences such as substantial human casualties, infrastructure destruction, as well as severe social and environmental impacts. Therefore, understanding the intricacies of dam breaches are critical for design, mitigation measures and development of emergency response plans (Hager *et al.*, 2022).

The Oyan river dam which is an essential infrastructure serves various functions including flood management and water provision. However, like many dams, it is vulnerable to potential failures caused by structural weaknesses, extreme hydrological events or operational errors (De Wrachien, 2009). The geographical and hydrological complexity of the Oyan river catchment area underscores the necessity of evaluating the risks linked with its dam failure, in order to minimize potential downstream impacts.

In recent years, dam-break analysis has received increasing attention across Africa, driven by rapid dam development and growing downstream vulnerability. Studies in South Africa, Ethiopia, Ghana, Morocco, and Sudan have applied hydraulic models such as HEC-RAS and MIKE-11 to simulate dam-break floods and assess downstream hazards, thereby emphasizing the importance of scenario-based analysis in data-scarce regions (Mulatu *et al.*, 2021; Ouammi *et al.*, 2020; Dalu *et al.*, 2018). These studies demonstrate that realistic breach modelling and unsteady flood routing are essential for effective flood risk management.

In Nigeria, dam-break research remains relatively limited. Existing studies on dams such as Kainji, Jebba, Shiroro, Eleyele, and Challawa Gorge have shown that dam failure could result in severe downstream flooding. However, many of these studies rely on simplified assumptions, or even completely lack comprehensive floodplain mapping and comparative failure-mode analysis (Lawal *et al.*, 2022; Oyeleke & Olatunji, 2019; Adewumi *et al.*, 2016). Therefore, the scarcity of detailed, scenario-based dam-break assessments for several strategic dams including the Oyan River Dam creates a significant gap in flood risk preparedness and dam safety planning in Nigeria.

Hydraulic simulation tools such as the Hydrologic Engineering Centre-River Analysis System (HEC-RAS) offer robust tools for simulating dam break scenarios by integrating hydrological data, dam breach parameters and topographical information. Furthermore, HEC-RAS can predict flood routing and determine inundation extents due to dam breaks (HEC-RAS, 2021). This dam break analysis enables engineers and policymakers to identify high-risk areas along the downstream, develop effective response strategies and emergency plans (Wang, 2024).

Although dam-break analysis provides critical insight into flood hazards associated with potential dam failure, this study is particularly focused on the hydraulic simulation of breach-induced flooding at the Oyan River Dam. The investigation concentrates on unsteady flow modelling and downstream flood propagation resulting from overtopping and piping failure scenarios. As such, the analysis does not include

detailed geotechnical evaluation of dam materials or foundation failure mechanisms, nor does it extend to comprehensive social vulnerability or environmental impact assessments. This defined scope underscores the need for complementary studies that integrate hydraulic modelling with geotechnical and socio-environmental assessments to achieve a more comprehensive dam safety framework. Within this context, HEC-RAS was applied to simulate representative dam-break scenarios, analyse flood wave dynamics and evaluate potential downstream flood hazards.

II. METHODOLOGY

A. Scope of Study

This study covers investigation into the hydraulic and hydrological parameters of the Oyan river dam using HEC-RAS software to model dam failure under unsteady flow conditions through collection of the dam's catchment hydrology, topography, operational, construction and dam specific data. Also, this study simulates various breach scenarios using Froehlich empirical formulas to predict flood wave behaviour, inundation patterns and travel times, while also providing insights into the vulnerable downstream communities.

B. Study Area, Dam Hydrology and Geometry

Oyan river dam is situated along latitude $7^{\circ}15'$ to $7^{\circ}25'N$, and longitude $3^{\circ}08'$ to $3^{\circ}16'E$ at an elevation of 43.3 m above sea level. Located at the confluence of the Oyan and Ofiki rivers (tributaries of the Ogun River), the dam is approximately 20 kilometres northwest of Abeokuta. The dam's catchment area (Figure 1) covers around 9,000 km², with a reservoir spanning 4,000 hectares. Owned and operated by the Ogun-Osun River Basin Development Authority (O-ORBDA), the dam was commissioned on March 29, 1983. The Oyan river dam is characterized by a hummocky terrain with an undulating topography featuring forested hills and swampy lowlands with low fertility. At the downstream of the dam are settlement communities including, AbuleSikiru, AbuleTitum and Ibaro (Ayeni and Ojifo, 2018; Eruola, 2017). The structure comprises a 32.5 m high earth-fill embankment with a gated concrete service spillway and auxiliary spillway. Figure 2 showing the gated concrete spillway consists of a central portion with 4 radial spillway gates and three outlet valves, which maintain a normal water level at an elevation of 63 m. Its main functions are water supply and irrigation for the city of Abeokuta and parts of Lagos with the potential for hydropower generation (Ayeni and Ojifo, 2018).

The Oyan river catchment is characterized by a tropical climate featuring clearly defined wet and dry seasons. The wet season commences in April and reaches its peaks in June and September, with a short dry spell in August and ends in October alternately, while the dry season from November to March is characterized by minimal rainfall. The average yearly precipitation in the region is 1500 mm with temperature remaining relatively consistent throughout the year, but with slight variations between the wet and dry seasons (Eruola, 2017). The average annual temperature in the region is 27 °C with wet season temperature ranging from 24 to 28 °C, thereby providing a relatively cool and comfortable climate.

Furthermore, in the dry seasons, the temperature ranges between 26 and 31 °C (NIMET, 2025). Similarly, the Oyan river catchment area experiences a high humidity level throughout the year with average data hovering between 70 and 90 % humidity. Therefore, the climatic conditions experienced in Oyan consequently affect the rainfall volume that the dam receives yearly. However, the climate change currently affecting the earth could alter the rainfall volume and other associated parameters estimated at the time of design and construction of the dam, thereby predisposing the dam to imminent danger and the risk of failure.

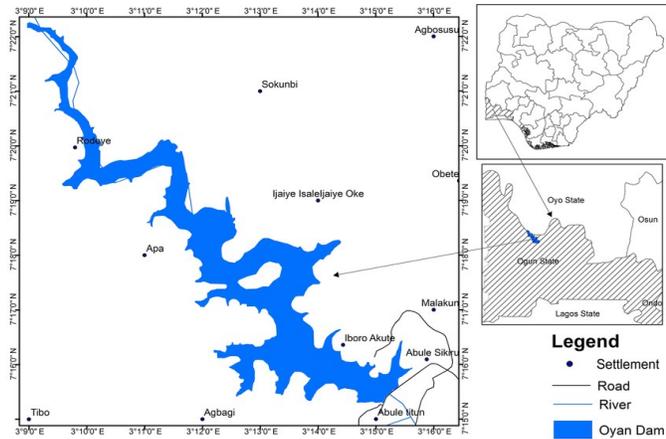


Figure 1 Oyan river dam catchment area



Figure 2 Oyan dam's concrete spillways and gates

The dam consists of a 32.5-meter-high earth-fill embankment, equipped with a gated concrete service spillway and an auxiliary spillway. It has a gross reservoir storage capacity of 270 million cubic meters and a dead storage capacity of 16 million cubic meters. The dam is designed with a freeboard of 2.10 meters to accommodate a flood event with a 10,000-year return period. It features four spillway gates, each measuring 15 meters in width and 7 meters in height, along with three outlet valves, each 1.8 meters in diameter. Also, the length of the dam crest is 1044 m. The reservoir normal water level is 63 m with minimum and maximum water level at 47.5 and 65.5 m respectively. These components regulate and maintain a normal water level at an elevation of 63.0 meters. The Oyan dam was designed to supply 700 million liters per day (mld) of raw water for the municipal and industrial requirements of Lagos and Abeokuta (Ayeni and Ojifo, 2018).

C. Estimation of Breach Parameters

Estimation of dam breach parameters is crucial for simulating potential dam failures. This was calculated using Froehlich's 2008 empirical equations to estimate breach width and breach development time for the different failure modes (Froehlich's 2008).

$$B_{avg} = 0.27 K_O V_w^{0.32} h_b^{0.04} \quad (1)$$

$$t_f = 0.0176 \sqrt{\frac{V_w}{gh_b^2}} \quad (2)$$

where; B_{avg} is average width of final breach in meters; hw is depth of water above breach at time of failure in meters; V_w is the volume of water that passes through the breach in cubic meters; h_b is height of breach in meters; t_f is breach formation time in hours; g is acceleration of gravity (m/s^2); and K_O is 1 for piping failure and 1.4 for overtopping. Typical breach side slope value of 1(H: V) for overtopping failure mode and 0.7 for other modes.

D. Dam Modelling and Calibration

The dam break analysis was carried out using HEC-RAS 6.6, with terrain and hydrological data sourced through Google Earth Pro and the Open Topography platform. The catchment area was first identified and delineated using Google Earth Pro by locating the dam and tracing its contributing watershed. To generate an accurate terrain model, the Shuttle Radar Topography Mission Global 1 (SRTM GL1) of Digital Elevation Model (DEM) was downloaded from Open Topography in GeoTIFF format. This DEM was imported into HEC-RAS after setting the appropriate spatial projection. To verify the accuracy of the elevation data, a comparison was made with the ArcGIS World Imagery base map within the HEC-RAS Mapper environment.

Once the terrain was prepared, the geometry of the study area was modelled in HEC-RAS. Cross-sections were digitized along the river course to define the channel profile (Figure 3) and the dam structure itself was modelled using the Inline Structure Editor represented in Figure 4, thereby incorporating the actual dimensions and characteristics of the Oyan River Dam (Xiong, 2011; Ackerman and Brunner, 2008). To simulate potential dam failure scenarios, breach parameters were estimated using empirical methods. Froehlich's (2008) equations were deployed due to their reliability in estimating breach width and breach formation time. These parameters included breach depth, width, side slope angles and formation time, with the comparative values of overtopping and piping failure shown in Table 1. The breach development was modelled under two primary failure modes: overtopping, which involves erosion due to excessive overflow caused by extreme rainfall or insufficient spillway capacity; and piping (internal erosion), where seepage through the dam embankment gradually creates a tunnel that eventually leads to structural failure.

Following the definition of breach characteristics and failure mode, an unsteady flow analysis was performed in HEC-RAS similar to the studies of (Zhao et al., 2024; Kiwanuka, 2023; Okeola and Adeleke, 2022; Sharma, 2016).

Upon completion of hydraulic modeling, the simulation results were exported to HEC-RAS Mapper to generate flood inundation maps. These maps detail water surface elevations, velocities, and inundation extents, which are essential for evaluating the potential impact of a dam failure and for developing effective emergency response strategies.

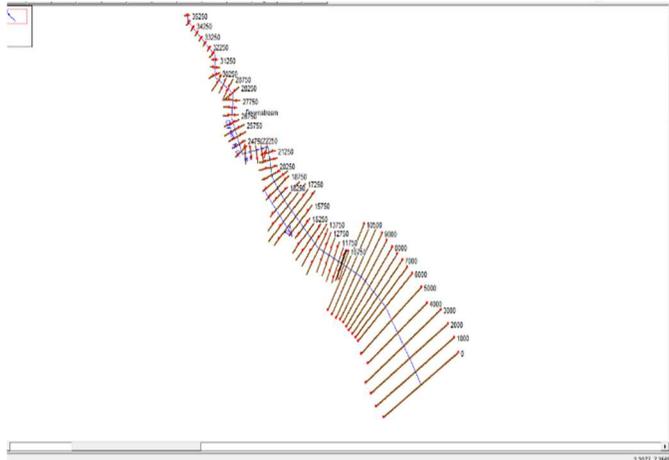


Figure 3 Cross-section of the upstream to downstream of Oyan river

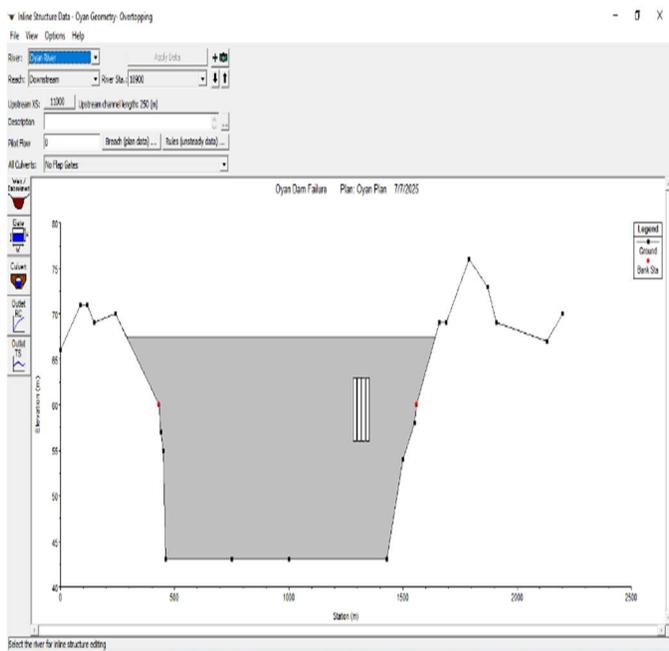


Figure 4 Inline structure editor used to model and calibrate the Oyan river dam geometry

Table 1 Comparison of breach parameters between overtopping and piping failure

	Overtopping	Piping
Breach Bottom Width	197.50 m	151.92 m
Breach Formation time	4.57 Hrs	4.57 Hrs
Breach Bottom Elevation	47.5 m	47.5 m
Side slope	1	0.7

III. RESULTS AND DISCUSSION

A. Overview of Results

This study investigated the possible dam break of the Oyan river dam using HEC-RAS Software 6.6, for modelling the overtopping and piping failure scenarios with breach parameters estimated by (Froehlich, 2008) equations, which provided the most accurate estimation. The model was simulated for five days and results were obtained for about 11km downstream with values of their peak discharge, maximum water surface elevation, flow rate, flow velocity, flow area and flood inundation maps presented accordingly. The results obtained included water surface profiles, rating curves, and stage and flow hydrographs. Simulation outputs showed that the overtopping failure scenario resulted in a more sudden and higher flow discharge than the piping failure scenario, which produced faster flood wave arrival times and higher inundation water depths across downstream settlements. These results provide a clear picture of the possible outcomes of the failure of the Oyan river dam and form the basis for recommending appropriate prevention strategies and emergency response planning.

B. Overtopping Failure

An unsteady hydraulic flow analysis was carried out for overtopping failure for the Oyan dam reservoir considering a downstream stretch of 11km using estimated breach parameters with breach width of 197.50 m and breach time of 4.57 hours. Figure 5 presents the dam cross-section before and after the simulation respectively, illustrating the formation of the breach and the reduced water level observed at the conclusion of the simulation. Figures 6 to 8 present the result of the stage and flow hydrographs together with the corresponding rating curve, at some selected cross-sections along the river reach. These locations include the dam site, immediate cross section downstream and terminal cross-section of the river reach as representative findings. From the start of the simulation, the peak discharge flow rate of 22,556.47 m³/s was observed at 7.25 hours at the incline structure. The results showed the stage increase to 66.44m upstream of the dam at 4.25 hours and reduced to a maximum stage of 55.15 m downstream at 7.58 hours. Further downstream from the dam, the peak discharge reaches a maximum of 20,670.69 m³/s observed at 8.33 hours and a maximum stage elevation of 39.70 m at 8.33 hours which

reduces to 30.18 m at the end of the simulation. The rating curve at the dam structure illustrates a rapid increase, then a sudden drop in elevation against time and at the downstream where there is a reduction in stage and flow with time.

The simulation results in Figure 6 indicated a peak discharge of 22,556.47 m³/s and a flow velocity of 10.24 m/s at the dam structure. Figure 7 contains the corresponding rating curves of both the upstream and downstream sections generated for the overtopping failure at the inline structure, indicating its higher peak discharge relative to the piping failure. At the downstream end, approximately 11 km from the dam, the maximum discharge was 20,670.69 m³/s with a corresponding velocity of 3.88 m/s as shown in Figure 8. The reduction in peak discharge can be seen as it flows downstream of the channel. The flood wave attenuation gave a value difference of approximately 1885.78m³/s which accounts for the spread of water within the area considered. Comparisons with African dam-break studies also support these trends. The HEC-RAS modelling of the KesemKebena and Gidabo Dams in Ethiopia showed that peak breach outflows propagated downstream over long river reaches, with the highest flood stages and discharges occurring near the dams and progressively decreasing with distance downstream, a pattern consistent with the Oyan dam simulation (Kebede et al., 2020; Mekonnen et al., 2018).

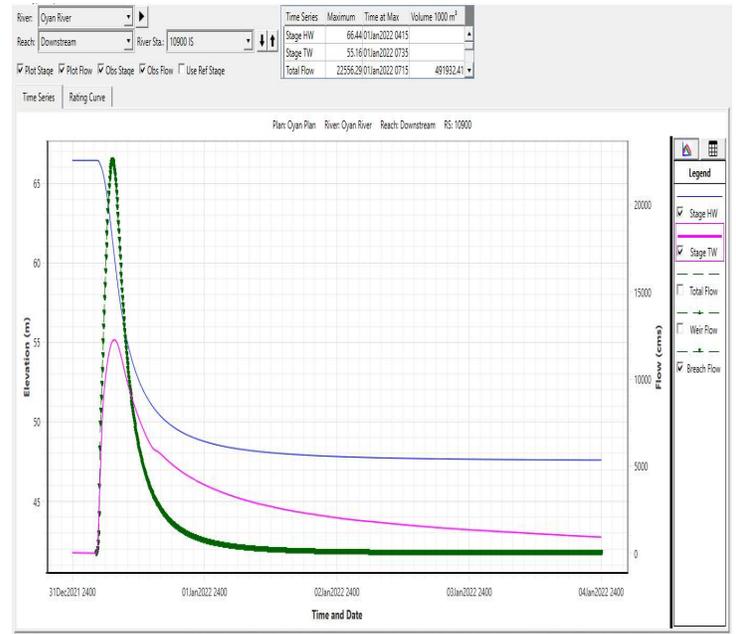


Figure 6 Stage and flow hydrograph for overtopping failure at inline structure

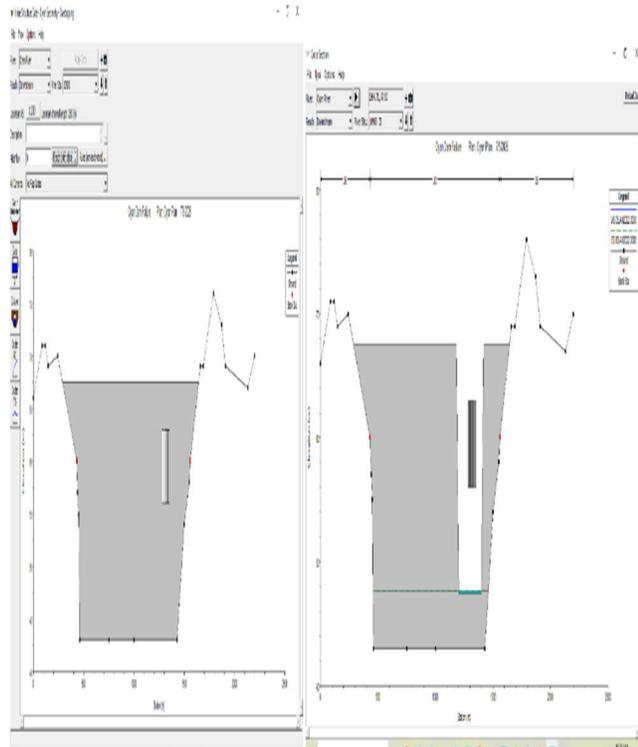


Figure 5 Before and after of simulation of overtopping failure

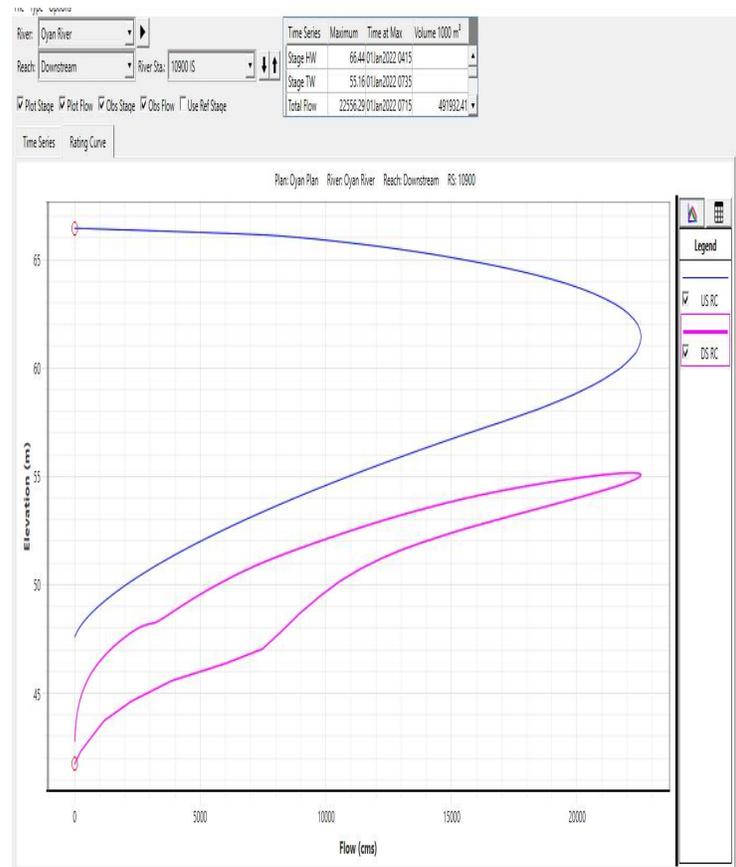


Figure 7 Rating curves of upstream and downstream for overtopping failure at inline structure

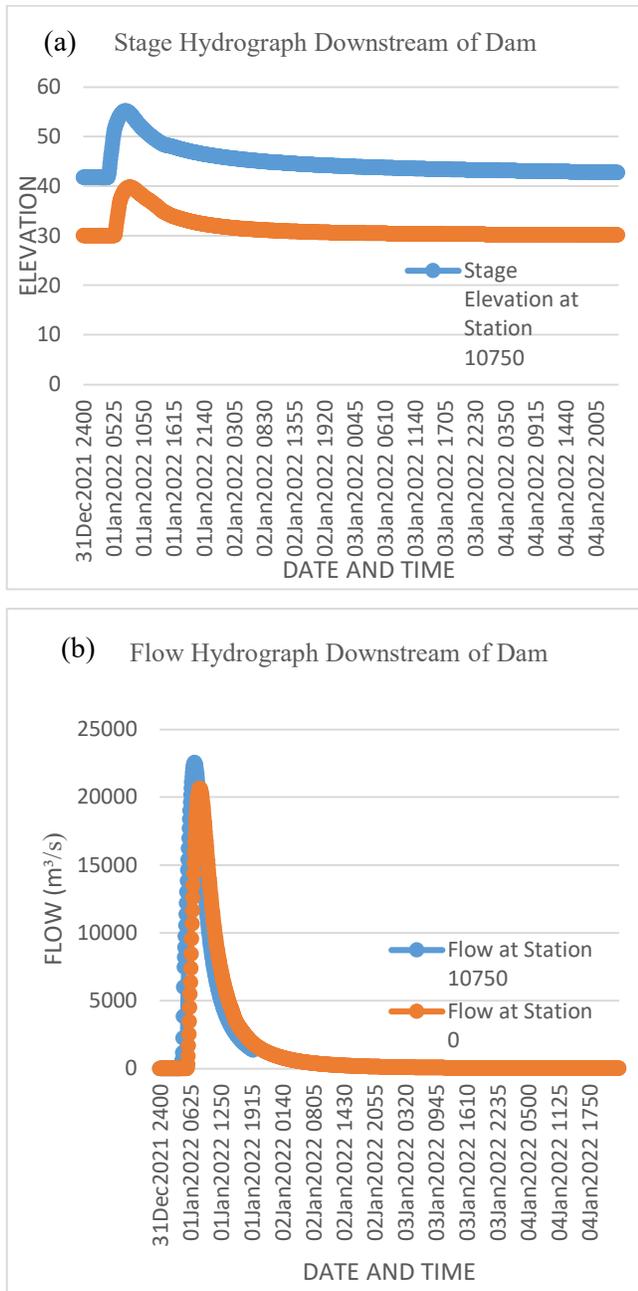


Figure 8 (a) Stage and (b) flow hydrograph for overtopping failure downstream.

C. Piping Failure

Figure 9 presents the dam cross-section before and after the simulation, respectively, illustrating the formation of the breach and reduced water level observed at the conclusion of the simulation. Figures 10 to 12 present the result of the stage and flow hydrographs together with the corresponding rating curve, at some selected cross-sections along the river reach. These locations include the dam site, immediate cross section downstream and terminal cross-section of the river reach as representative findings. From the start of the simulation, the peak discharge flow rate of 17,140.02 m³/s is observed at 7.92 hours at the inline structure. The result showed the stage

increase to 66.44m upstream of the dam at 4.08 hours and reduces to a maximum stage of 53.92 m downstream at 8.25 hours and reduces to a stage of 42.99m. Further downstream from the dam, the peak discharge reaches a maximum of 16,440.37 m³/s observed at 9 hours and a maximum stage elevation of 38.90 m at 9 hours, which reduces to 30.21 m at the end of the simulation.

Comparable attenuation of peak discharge and reduction in flood stage with downstream distance were observed in the HEC-RAS dam-break analysis of Asa dam, where channel slope and floodplain storage significantly influenced flood wave propagation (Balogun and Ganiyu, 2017). The rating curve at the dam structure illustrates a rapid increase then a sudden drop in elevation against time and at downstream there is a reduction in stage and flow with time. The simulation results in Figure 10 indicated a peak discharge of 17,140.02 m³/s and a flow velocity of 8.52 m/s at the dam structure. At the downstream end, approximately 11 km from the dam, the maximum discharge was 16,440.37 m³/s with a corresponding velocity of 3.58 m/s as shown in Figure 12. The observed reduction in peak discharge, resulting in a flood wave attenuation of approximately 699.65 m³/s, can be attributed to the gentle downstream channel slope and lateral spreading of floodwaters. This attenuation pattern is consistent with findings from African dam-break studies, which reported that low-gradient river channels and wide floodplains significantly reduce flood peak magnitude as the wave propagates downstream (Kebede et al, 2020)

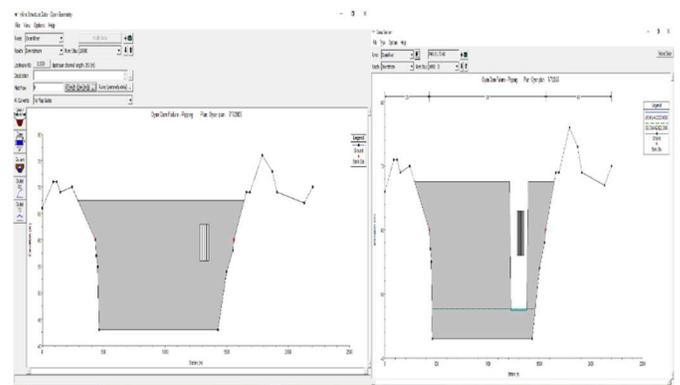


Figure 9 Before and after of simulation of piping failure

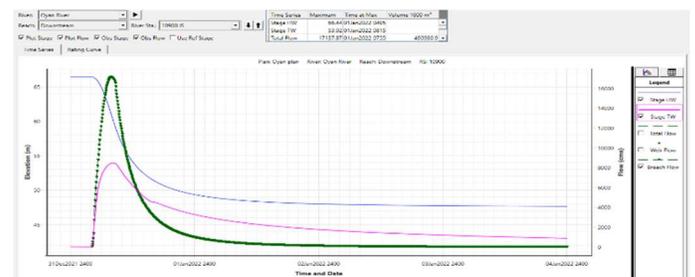


Figure 10 Stage and flow hydrograph for piping failure at inline structure

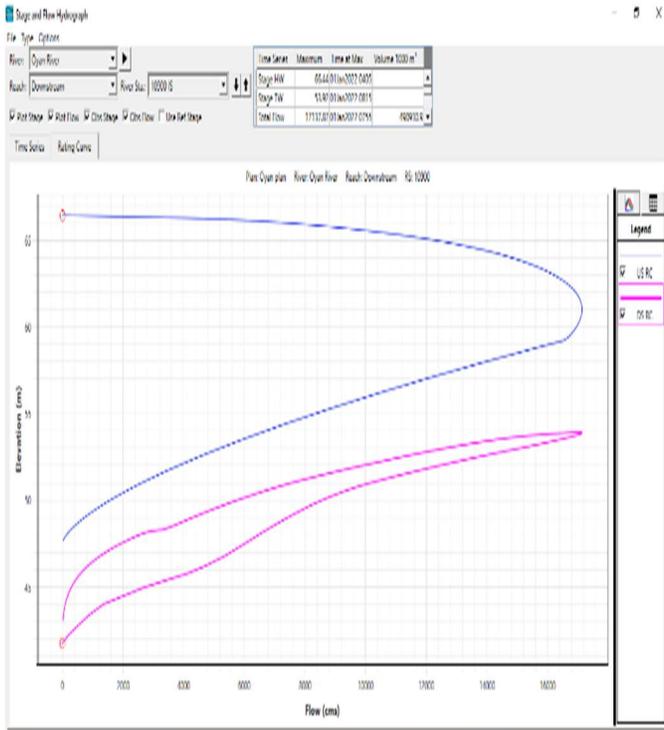


Figure 11 Rating curves of upstream and downstream for piping failure at inline structure

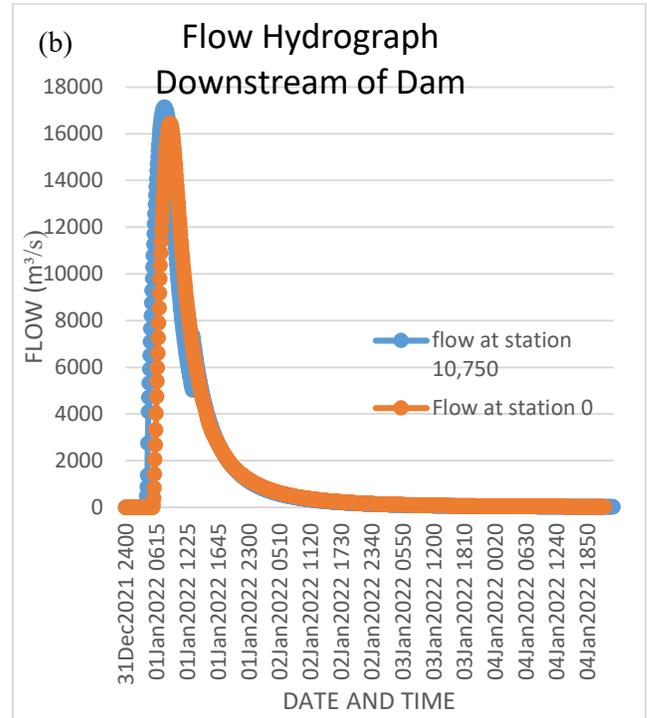
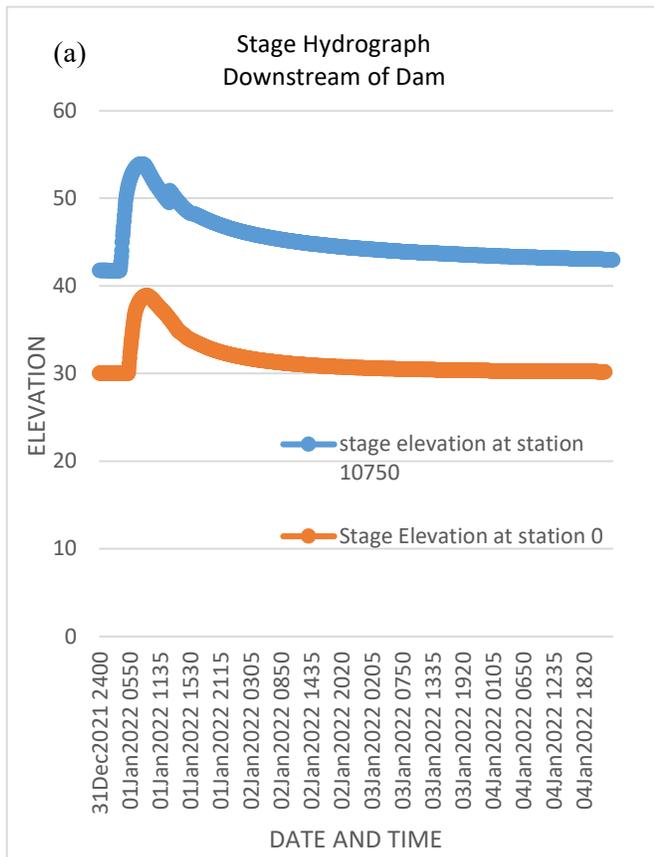


Figure 12 (a) Stage and (b) flow hydrograph respectively for overtopping failure downstream.



D. Indundation Exent and Downstream Evaluation

HEC-RAS outputs were viewed in HEC-RAS Mapper and floodplain maps were generated. Figure 13 show the areas inundated as a result of overtopping and piping scenarios respectively. For the overtopping failure, the maximum flow depth ranges from 18 meters immediately downstream of the dam and reduced to approximately 3.15 meters at the downstream end of the river reach. The overtopping scenario produces greater flow depths, indicating a more severe threat to the downstream region. This finding is consistent with dam-break studies conducted in Nigeria and other parts of Africa, where overtopping failures were observed to generate higher flood depths and wider inundation extents than piping failures. For instance, a hypothetical dam-break analysis of Asa Dam, Ilorin, using HEC-RAS reported significantly higher downstream water depths under overtopping conditions compared with internal erosion scenarios (Balogun and Ganiyu, 2017). Similar outcomes were also reported for earth-fill dams in East Africa, where overtopping produced more destructive flood waves than piping failures (Kebede et al., 2020). In contrast, piping failure scenario results in lower flow depths ranging between 2 and 16 m, indicating a less dangerous scenario relative to the overtopping failure. This trend agrees with results from other HEC-RAS-based dam-break analyses, which observed that piping failures generally lead to lower flood depths and reduced downstream impacts due to slower breach development (Mohamed et al., 2023).

In the event of failure of the Oyan dam, the affected areas will be inundated with water having depths of about 15 m that reduces over time, with most affected areas covered in water for an average of three days. The Oyan river is a tributary to

the Ogun River with a channel which has dried up over the years, because of the erection of the dam along the Oyan river to supply water to Lagos and Ogun States. Immediately the dam fails, flood waters will be released to the channels supplying the Lafenwa river, a tributary to the Ogun River, thereby leading to the potential flooding of some regions in Lagos State, while also flooding surrounding areas along its channel. Other areas that could be potentially affected are Arakanga nature reserve, Awyan, Oloko, Iwofin, IwofinOtegbade and even the Abeokuta-Igboora-Iseyin road.

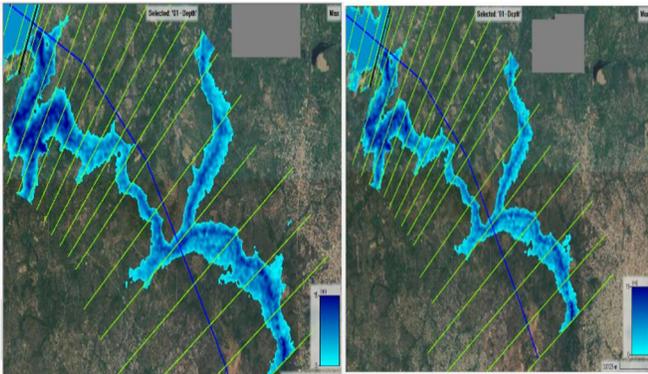


Figure 13 Inundation mapping for overtopping and piping failure respectively

E. Discussion

The overtopping failure scenario produced a significantly higher peak discharge of 22,556.47 m³/s at the dam structure when compared with the 17,140.02 m³/s in the piping failure scenario. Similarly, the downstream peak discharge at 11 km was higher in the overtopping scenario (20,670.69 m³/s) than in the piping case (16,440.37 m³/s). These differences are attributed to the larger breach width (197.50 m) and the sudden nature of overtopping, which causes a more catastrophic release of reservoir water compared to the relatively gradual internal erosion process in piping failure. Tables 2 to 4 contain the comparison between the failure modes; while overtopping resulted in greater peak discharges and flow velocities, piping failure showed slightly deeper water levels at some downstream locations due to its longer flood duration and slower wave attenuation. This indicates that although overtopping may pose a more immediate hazard, piping failure can still result in significant inundation and prolonged submergence of floodplains.

In both scenarios, a gradual reduction in peak discharge and flow velocity was observed along the 11 km downstream stretch. This attenuation of 1,885.78 m³/s in overtopping and 699.65 m³/s in piping demonstrates the effects of the gentle slope and natural channel resistance in dissipating flood energy. However, the overtopping case showed a more intense and rapid flood wave, which poses a greater risk for flash flooding in communities closest to the dam. The maximum flow velocities recorded at the dam were 10.24m/s for the overtopping scenario and 8.52m/s for the piping scenario, indicating highly erosive flows capable of damaging physical infrastructures.

Floodplain mapping revealed that both breach modes resulted in nearly identical extents of inundation (97,994m²), although flood depths varied significantly. The spatial distribution of water depths and extent of flooding confirms that settlements within 1- 6 km of the dam are at the highest risk. The overtopping scenario shows deeper and faster-arriving flood waves, thereby underscoring the urgency for mitigation strategies.

The dam-break simulations results are subject to uncertainty arising from the use of empirical breach parameter equations, assumptions in channel roughness, terrain representation, and boundary conditions. In addition, the lack of historical dam-failure data limits direct model calibration. Consequently, the simulations represent plausible flood hazard scenarios rather than exact predictions of future events. Still, the outcomes of this study contribute to improved understanding of dam-failure-induced flooding and provide decision-relevant information to support safety planning and resilience enhancement within the Ogun–Osun River Basin.

Table 2 Stage and Flow data at the inline structure

Particulars	Overtopping Failure		Piping Failure	
	Maximum elevation (m)	Time formed in hours	Maximum elevation (m)	Time formed in hours
Headwater stage (m)	66.4	4:15	66.44	4:05
Tailwater Stage(m)	55.15	7:35	53.92	8:15
Peak Discharge (m ³ /s)	22,556.47	7:15	17,130.18	7:15

Table 3 Peak flow and its time along Downstream for Failure modes

Station points(m)	Overtopping Failure		Piping Failure	
	Peak flow (m ³ /s)	Arrival time (hrs)	Peak flow (m ³ /s)	Arrival time (hrs)
10,750	22,556.29	7:15	17,137.87	7:55
0	20,670.69	8:20	16,440.37	9:00

Table 4 Maximum flood stage and time it reaches downstream locations under different failure scenarios

Station points(m)	Overtopping Failure		Piping Failure	
	Maximum Stage (m)	Arrival Time (hrs)	Maximum Stage (m)	Arrival Time (hrs)
10,750	55.16	7:35	53.92	7:55
0	39.77	8:20	16,440.37	9:00

IV. CONCLUSION AND RECOMMENDATIONS

A. Conclusions

Dam break events are highly complex and potentially catastrophic, requiring robust hydraulic analysis to understand their downstream consequences. In this study, a comprehensive dam-break simulation of the Oyan River Dam was conducted using the Hydrologic Engineering Center's River Analysis System (HEC-RAS) under unsteady flow conditions. Hydrological and geological data were applied to simulate both overtopping and piping failure scenarios, enabling analysis of breach development, flood wave routing, and key hydraulic parameters along the downstream river reach. HEC-RAS Mapper was further used to delineate inundation extents and identify downstream communities potentially affected under each failure mode.

The results indicate that the overtopping scenario generates higher peak discharges immediately downstream of the dam than the piping scenario, thereby representing the more critical failure mode. Simulations further reveal that areas located within the immediate downstream reach are particularly vulnerable to deep inundation due to pronounced differences between ground elevation and floodwater levels. These findings underscore the severe threat that dam failure poses to human life, infrastructure, and the surrounding environment, emphasizing the need for proactive flood risk management and emergency preparedness planning.

It is important to note that the outcomes of this study are subject to certain modelling limitations. Breach characteristics were represented using empirical relationships, and the hydraulic routing was based on one-dimensional flow assumptions, which may not fully capture complex flow behaviour across wide floodplains. In addition, uncertainties associated with terrain representation, roughness parameters, and the absence of calibration data for extreme failure events may influence predicted flood depths and velocities. Consequently, the results should be interpreted as plausible hazard scenarios rather than exact predictions. Nevertheless, the study provides valuable decision-support information for dam safety planning and forms a foundation for future research integrating geotechnical, hydrodynamic, and socio-environmental assessments to enhance flood resilience in the Oyan River basin.

B. Recommendations and Future Works

Based on the analysis and observed outcomes from the HEC-RAS simulations, the following recommendations are proposed:

- I. The design and construction of engineered levees along critical flood-prone downstream communities to act as controlled barriers diverting floodwaters during a dam failure event.
- II. Constructing a strategically placed auxiliary dam downstream along the Ogun river that would function as a retention structure to absorb excess floodwaters, most especially to protect Lagos communities vulnerable to downstream flooding in the event of dam collapse.
- III. Upgrading existing instrumentation, dam monitoring and operation systems
- IV. Installing a semi-permanent engineered crest raising to increase effective freeboard, thereby delaying or preventing overtopping.

AUTHOR CONTRIBUTIONS

A. A. Olanipekun and O. O. Olofintoye: Conceptualization, Supervision. **O. J. Badmus:** Methodology, Software, Validation, Writing – original draft. **D. U. Idusuyi, F. Alao and O. Bayode:** Methodology, Writing – review & editing. **J. I. Braimah, O. O. Aiyelokun and A. A. Opebiyi:** Software, Validation, Writing – review & editing.

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