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Dam Break Analysis and Development of Inundation Map: A Case Study of Asa Dam, Ilorin, Kwara State, Nigeria

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ABSTRACT

This paper presents the dam break analysis and development of inundation map for Asa dam in Ilorin, Kwara State. Empirical equations and hydrodynamic simulations with HEC-RAS software were employed to assess the potential flood impact resulting from a hypothetical dam break. The data collected on the dam's structural and the hydrological characteristics were used to perform a detailed dam break analysis to evaluate flood risks and identify flood-prone areas downstream. MacDonald and Langridge-Monopolis and Froehlich models were used to estimate breach parameters, while HEC-RAS was applied to simulate the flood wave propagation and inundation extent. The empirical analysis produced a peak discharge of 14,152 m³/s, a breach width of 130.86 m, and a failure time of 1.48 hours. Simulation results revealed that the maximum velocity ranges from 6 - 8 m/s with flood depths exceeding 10 meters in low-lying downstream areas. Flood hazard maps identified critical locations at risk, including Coca-kola Road, Amilegbe, and Isale Koko as critical risk locations, with varying degrees of inundation severity. These maps, along with the hydrographs generated, provide valuable information for flood emergency preparedness and early warning systems. A break at Asa Dam could lead to devastating consequences for downstream communities. To prevent the ugly incidence, immediate structural reinforcement, routine maintenance, sedimentation control, and the implementation of community-based flood awareness programs are recommended as decision-making tool for engineers, policymakers, and disaster risk managers.

INTRODUCTION

Dams are structures designed to regulate water flow, store water for multiple uses, and provide flood control and power generation (Vinod, 2022). However, dam failures pose severe threats to human life and property (Abdullahi, 2024; Adamo et al., 2020; Tunde 2024). Dam break analysis is a critical aspect of hydraulic engineering, especially in area where large volumes of water are stored by dams (Olorunfemi and Raheem, 2013; Balaji and Kumar, 2018; Aureli et al., 2023; Wang et al., 2022). This analysis models the possible failure or breach of a dam and examine the potential outcomes of such incidents. The abrupt failure of dams can cause devastating flooding, property destruction, fatalities and long-lasting environmental damage (Balogun and Ganiyu, 2017a; Beza et al., 2023).

Balogun and Ganiyu (2017b) analyzed a hypothetical failure of Asa Dam using the USACE HEC-RAS model revealed a significant flood risks for the downstream of Asa dam. Other authors that have done similar analysis include (Bharti et al., 2020; Duressa et al., 2018; Gee and Brunner, 2011; Jung and Kim 2017; Manamno et al., 2023; Mo et al., 2023).

Dottori et al. (2016) developed high-resolution flood hazard models using long-term river discharge data and two-dimensional hydrodynamic simulations, which effectively mapped flood risks.

Khattak et al. (2016) combined HEC-RAS hydraulic modeling with statistical methods and GIS to map Kabul River floodplains and revealing an increase in flood-prone areas during extreme events. Ansarifard et al. (2024) assessed flood risks in Iran's Khalkai watershed using HEC-HMS, HEC-RAS, and MIKE 21 models, their findings emphasize land-use influences and require accurate topography, acknowledging input-dependent limitations. Bharath et al. (2021) modeled dam breach scenarios for Hidkal Dam using HEC-RAS and HEC-GeoRAS, revealing that overtopping failure poses greater risk downstream than piping failure. Other authors that have done similar analysis include (Shahrak et al., 2012; Razack 2014; UNDRR 2015: Ezz, 2018; Sawai et al., 2019; Haltas & Akbulut 2024; Yakti et al., 2018; Ishak and Hashim 2018).

This study aims to simulate the effects of a potential dam break scenario at Asa Dam using both empirical formulas and the HEC-RAS software to predict flood extents, develop an inundation map and recommend flood mitigation strategies.

METHODOLOGY

Study Area Description

The Asa River originates in Oyo State, South-West Nigeria, and flows northward through Ilorin, the capital city of Kwara State. It serves as a natural boundary between the eastern and western parts of Ilorin. The river's main tributary is the Awon River, which eventually joins the Niger River about 12.2 km north of Ilorin. Other tributaries include the Oyun River to the east and the Imoru River to the west. Early tributaries of the Asa River include Afidikodi, Ekoro, and Obe, while in Ilorin, it is joined by the Agba, Aluko, Atikeke, Mitile, Odota, Okun, and Osere rivers. The river spans approximately 56 km in length, with a maximum width of about 100 m at the dam site. Its catchment area covers around 1037 km², extending across Kwara and Oyo States, with roughly one-third of the basin located in Oyo State. The Asa River is a crucial water source for economic, agricultural, and environmental purposes in Ilorin, supporting both residential and industrial uses. Farmlands, residential areas, and industrial buildings are located along the river's banks, both upstream and downstream of the dam (Balogun and Ganiyu, 2017a). The Asa Dam is situated between latitudes 8°36'N and 8°24'N and longitudes 4°36'E and 4°10'E in Ilorin as shown in Figure 1. Asa Dam was constructed in 1976 primarily for water supply purpose, and it has live storage capacity of about 39 x 10^6 m^3 and dead storage of 4 x10^6 m^3 making a gross storage capacity of 43 x 10^6 m^3. primarily for water supply and it is located on Asa river at a point which is 5 km south of Ilorin city. Development and expansion of the town have reduced this to less than one kilometre, the reservoir created by the dam is far away from the town. The dam is a composite earth embankment with a central spillway followed to the right by a mass concrete non overflow gravity section.

Data Collection

Data were obtained from field surveys and Kwara State Water Works. The data include the salient features of the dam, dam dimensions, reservoir characteristics, crest elevation, and terrain data (DEM). The dam maintenance staff also provided some qualitative information insights to the operational practices and vulnerabilities.

Empirical Analysis of Dam Breach Parameters and Peak discharge

The breach parameters such as the peak discharge Q_p, the average breach width (B) and the time of failure (T_f) were estimated using the MacDonald and Langridge-Monopolis (equation, 1) and Froehlich equation (equation, 2 and 3). (Snorrason 1984; Pandya and Jitaji, 2013; Soleymani et al., 2015; Sammen et al., 2017; Dhiman and Patra 2020).

Peak discharge,

$$Q_p = 3.85(V_w h_w)^{0.411} \quad (1)$$

Where, Q_p is peak discharge; V_w is volume of

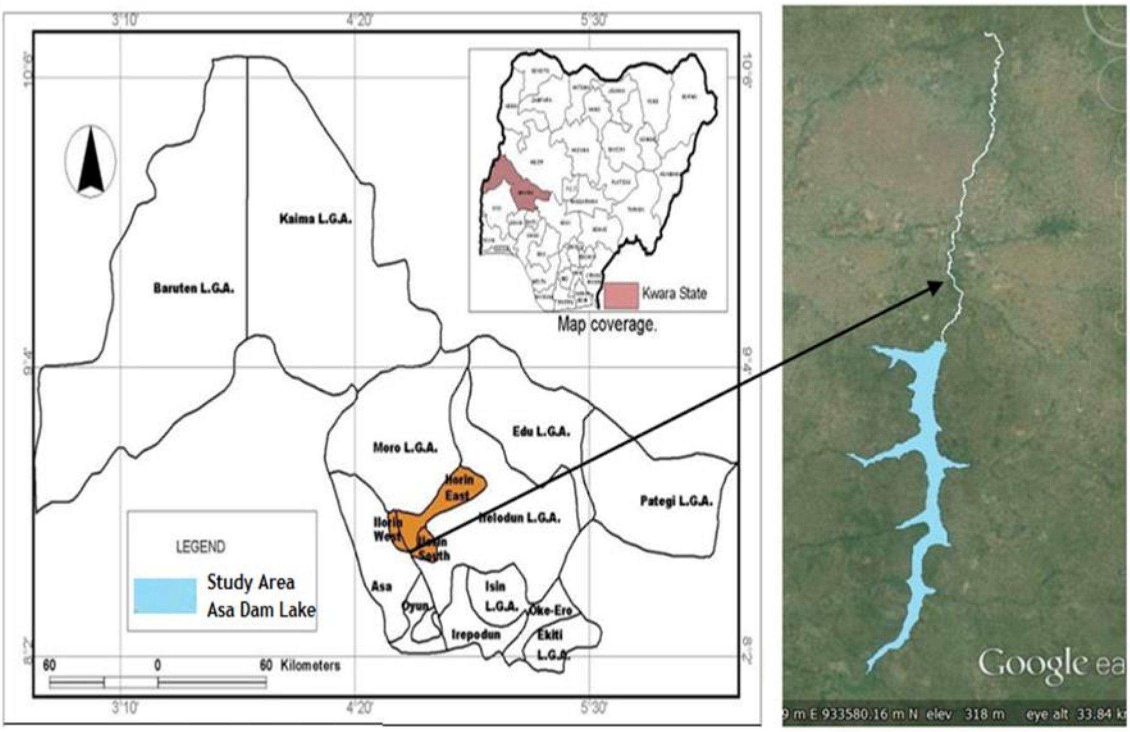

Figure 1: Maps showing the location of the lake dams (Ogunkunle et al., 2016).

water behind the dam at failure in (m^3), h_w is height of water above breach invert level at the time of failure.

The breach width (B) and time (**T_f**) to failure

$$B = 0.1803 V_w^{0.32} \quad (2)$$

$$T_f = 0.00254 (V_w)^{0.32} (h_b)^{-0.92} \quad (3)$$

Where, B is breach width; T_f is time to failure; V_w is volume of water behind the dam at failure in m^3; and h_b is height of water above breach invert level.

HEC-RAS Hydrodynamic Simulation and 2D Flow Area Definition

The Digital elevation map (DEM) of Asa river with 30 meter resolution was downloaded from USGS and then imported to RAS mapper. The DEM image of Asa dam is presented in Figure 2. , while the river geometry via digitized centerline and extracted cross-sections were generated automatically using the terrain model in HEC-RAS and presented in Figure 3. A two-dimensional (2D) flow area was defined to represent the downstream floodplain potentially affected by the dam break. The 2D mesh was created and presented in Figure 4 by drawing a polygon encompassing the flood-prone area, and a computational cell size of 50 meters was used to balance accuracy and computational efficiency. Dam breach setup using SA/2D connection, initiating breach when water exceeded crest elevation. Simulation duration was set for 24 hours with 5-minute time steps. Output included flow hydrographs, flood depths, velocities, and hazard map (HEC-RAS Hydraulic Reference Manual, 2024).

Results and Discussion

Empirical Results

The predicted breach width of 130.86 m was obtained for overtopping while 93.47 m for non-overtopping and Breach formation time was estimated as 1.48 hours using Froehlich's method. The MacDonald equation predicted catastrophic peak discharge of 14,152 m^3/s, significantly exceeding the spillway's capacity of 12,000 m^3/s.

HEC-RAS Simulation result

The following are the results obtained from the simulation of Asa dam break analysis using HEC-RAS software.

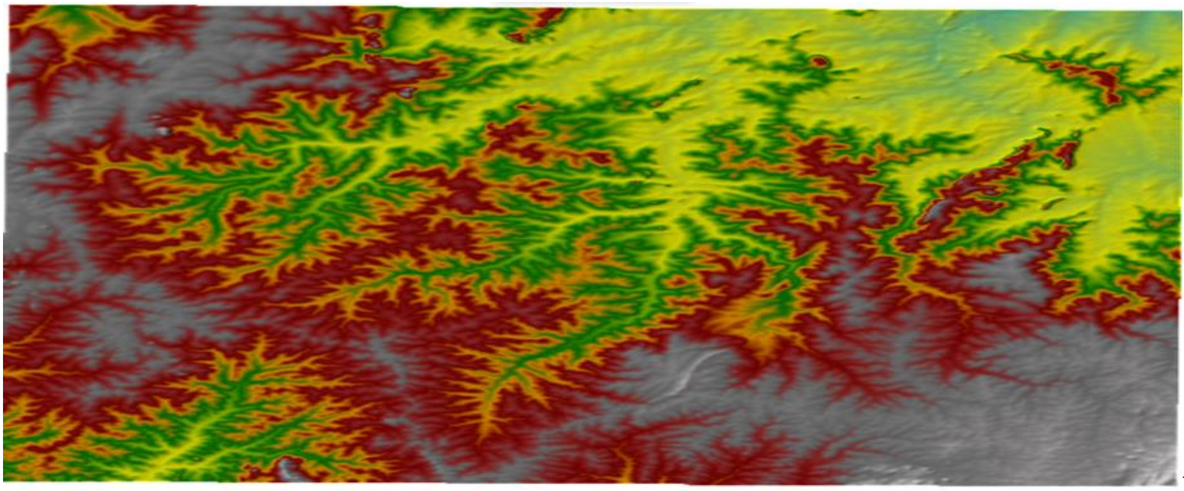

Figure 2: DEM image of Asa Dam

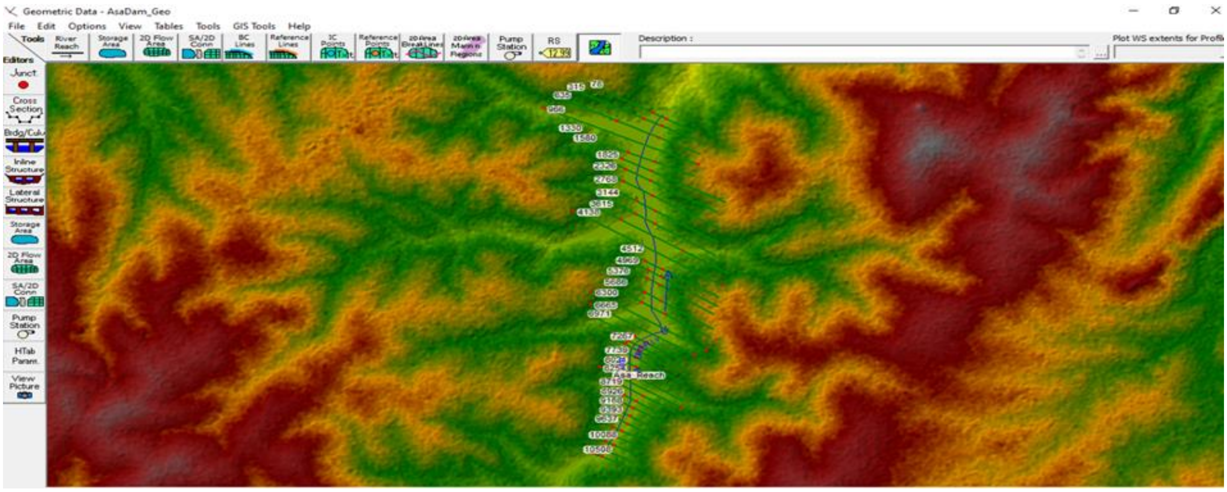

Figure 3: Asa River Centerline and Cross Sections

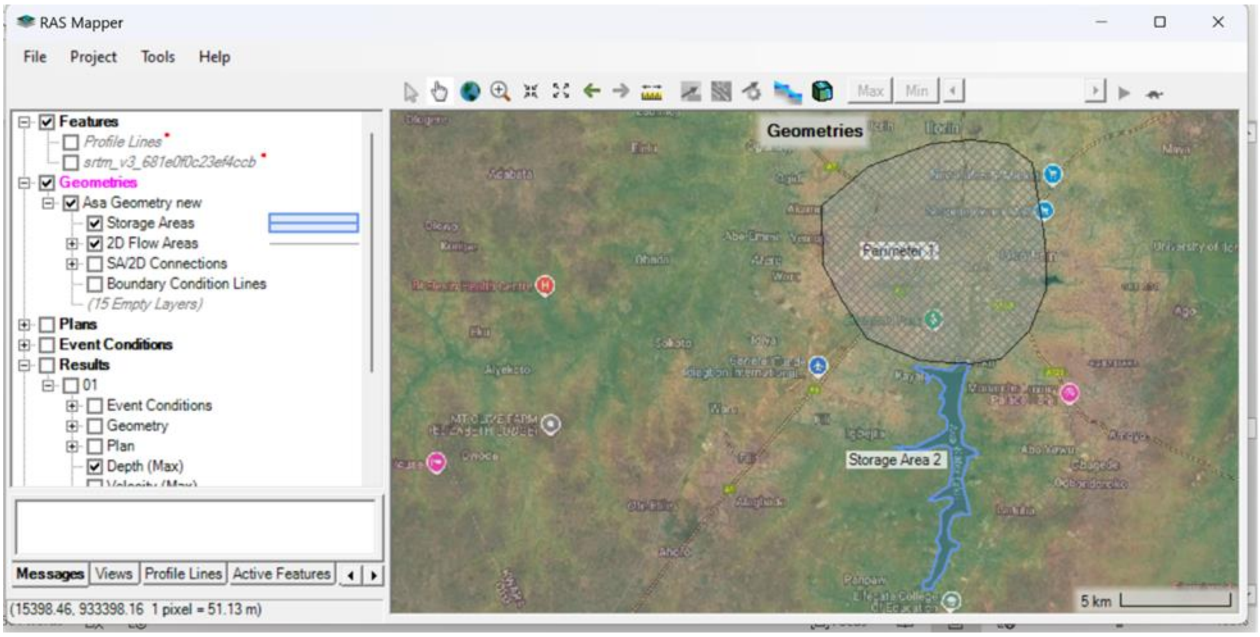

Figure 4: 2D Flow Area mesh for Asa River

Rating curve

The HEC-RAS-generated rating curve as presented in Figure 5 for Asa Dam reveals a nonlinear relationship between water surface elevation and discharge, with distinct phases of response. At discharges below 500 m³/s, water levels rise gradually (0.2–0.3 m per 100 m³/s), and reflecting in-channel flow conditions. Beyond 1,000 m³/s, the curve steepens markedly, with each 500 m³/s increase there is rise in water stages from 0.8–1.2 m as floodplain activation increases hydraulic resistance. These characteristic emphasize the need for enhanced floodplain mapping and real-time monitoring to improve early warning accuracy, particularly for discharges exceeding 1,500 m³/s where the rating curve's nonlinearity becomes pronounced.

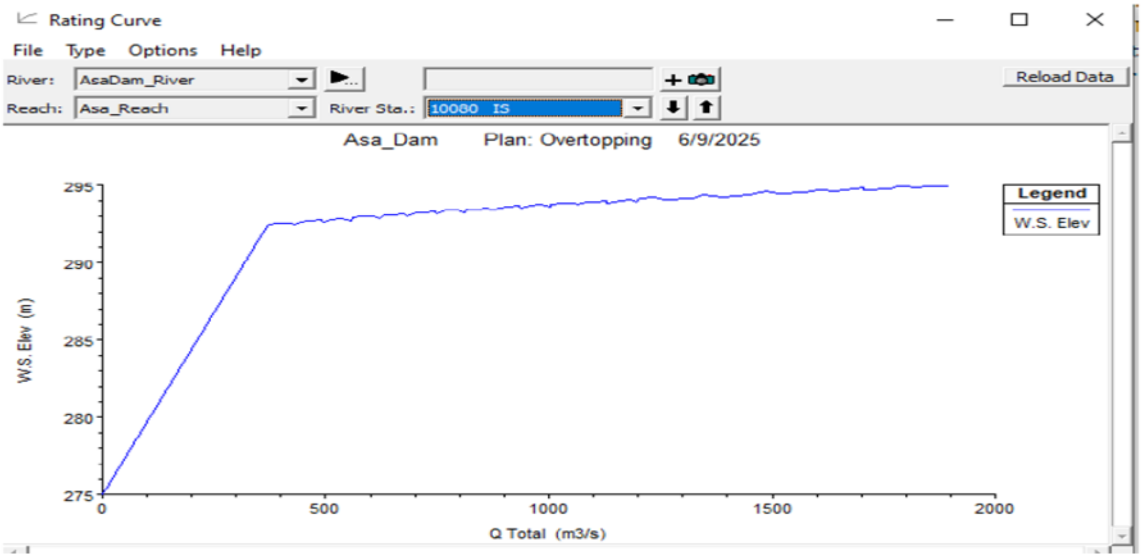

Figure 5: Rating curve of Asa dam

Stage and flow hydrograph

The stage-flow hydrograph presented in Figure 6 illustrates the dynamic response of the water system to a simulated dam break scenario. Analysis reveals that water surface elevation peaks at 295.10 m approximately 24 hours after breach initiation, followed by a gradual recession to 292.50 m. Concurrently, discharge rates exhibit a faster response, reaching maximum flow of 1,900 m³/s within 21 hours before diminishing to approximately 400 m³/s. The hydrograph's recession limb, showing system stabilization about 72 hours post-breach, provides valuable insights into reservoir depletion dynamics during catastrophic failure events. These results highlight the compound hydraulic effects of sudden water release, including the rapid initial surge followed by prolonged elevated water levels.

Flood Hazard Mapping

The flood hazard map presented in Figure 7, generated from HEC-RAS, depicts the simulated impact of a dam break scenario at Asa Dam, with particular focus on flood depth depicted in Figure 8 after 1 hour and the flow velocity depicted in Figure 9 after 1 hr simulated dam failure occurs. The map is color-coded, with darker shades of blue indicating greater water depths, reaching up to 15 meters in the most severely inundated areas. At this early stage of the flood event, the downstream areas closest to the reservoir are experiencing rapid and forceful inundation. The flood inundation analysis of Asa Dam reveals that the peak water surface elevation (WSE) presented in Figure 10 is approximately 309m.

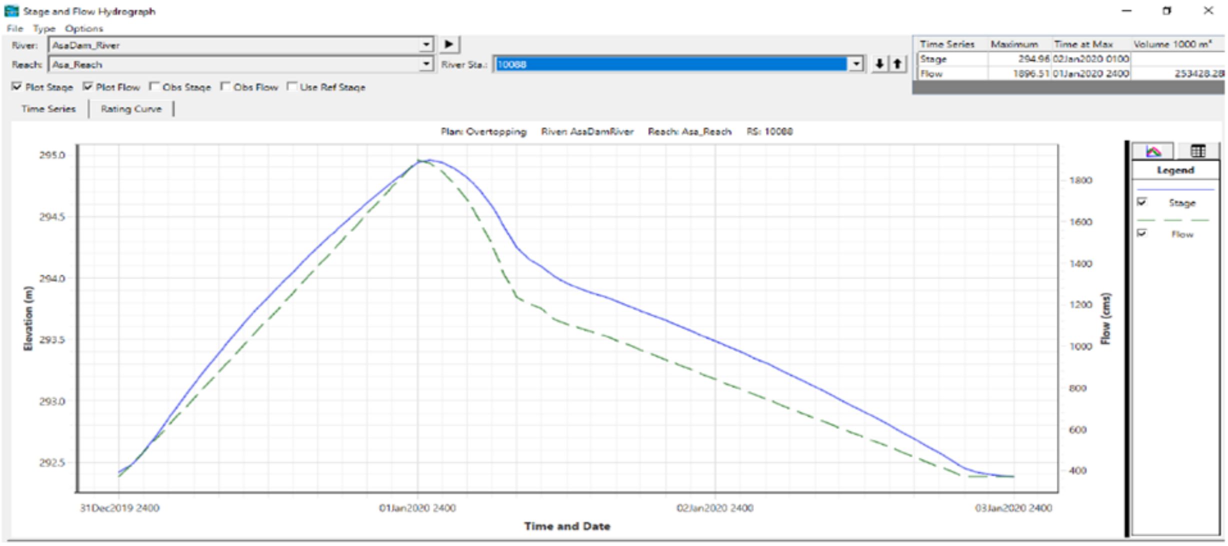

Figure 6: Stage and Flow Hydrograph of Asa Dam

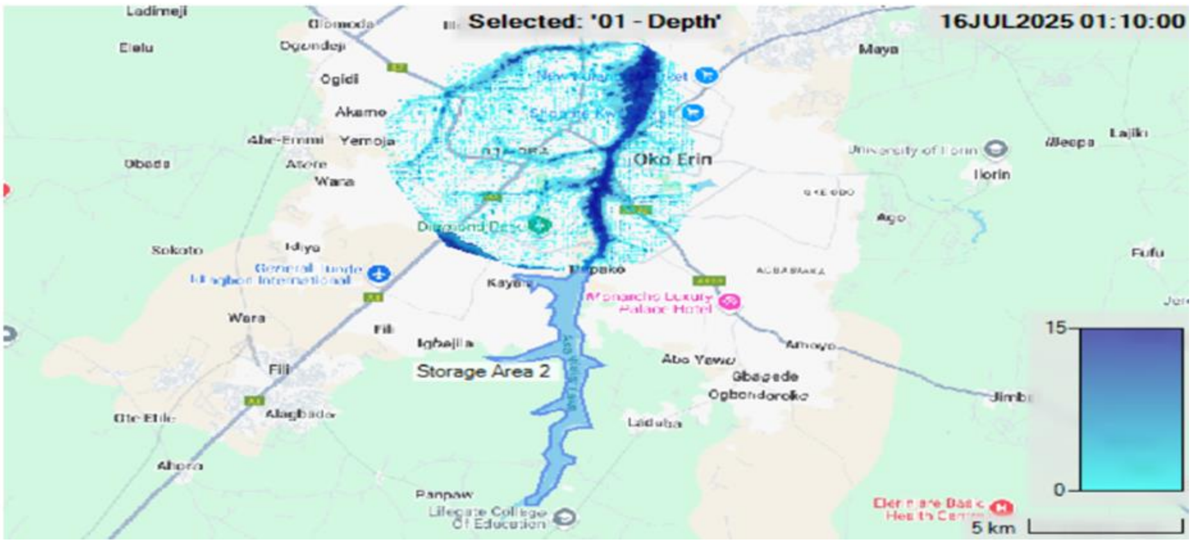

Figure 7: Flood Hazard Map of Asa Dam Downstream Areas

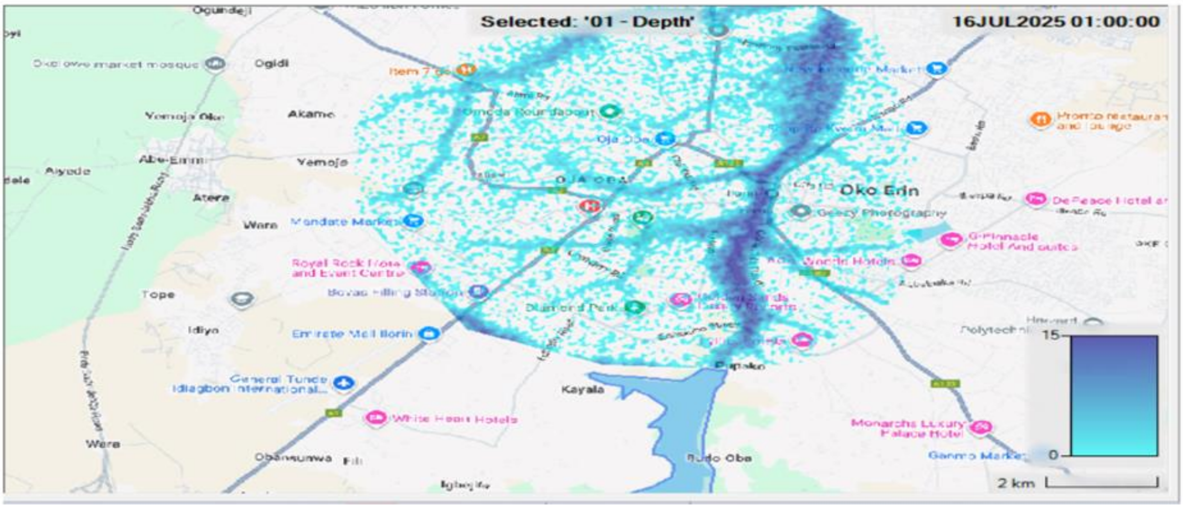

Figure 8: Flood Hazard Map of Asa Dam 1hour After Dam Break

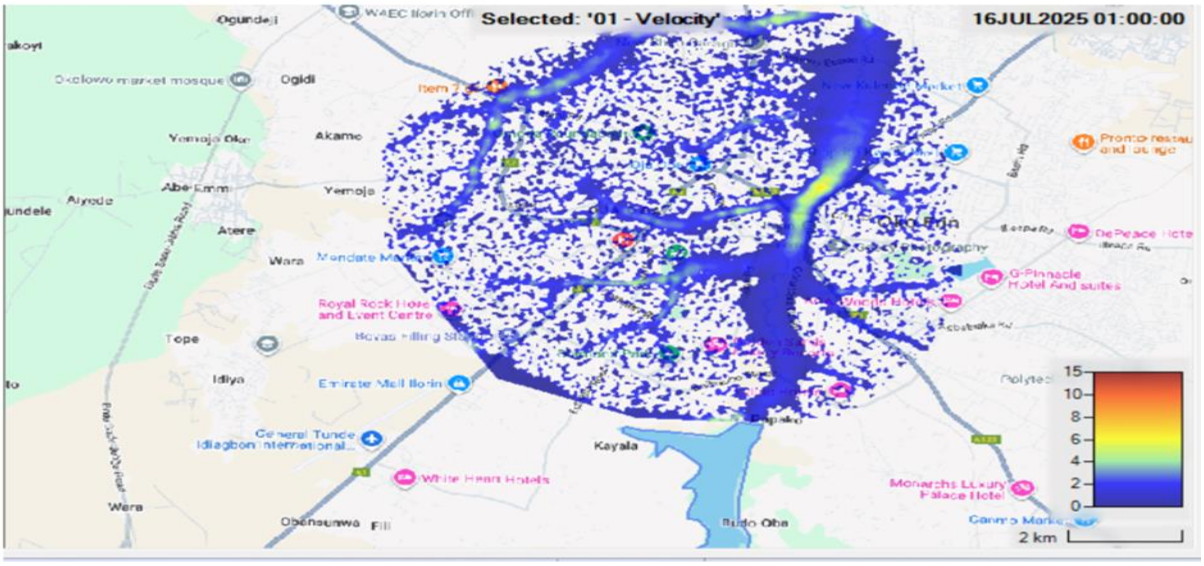

Figure 9: Flood Velocity after 1 Hour of Dam Break

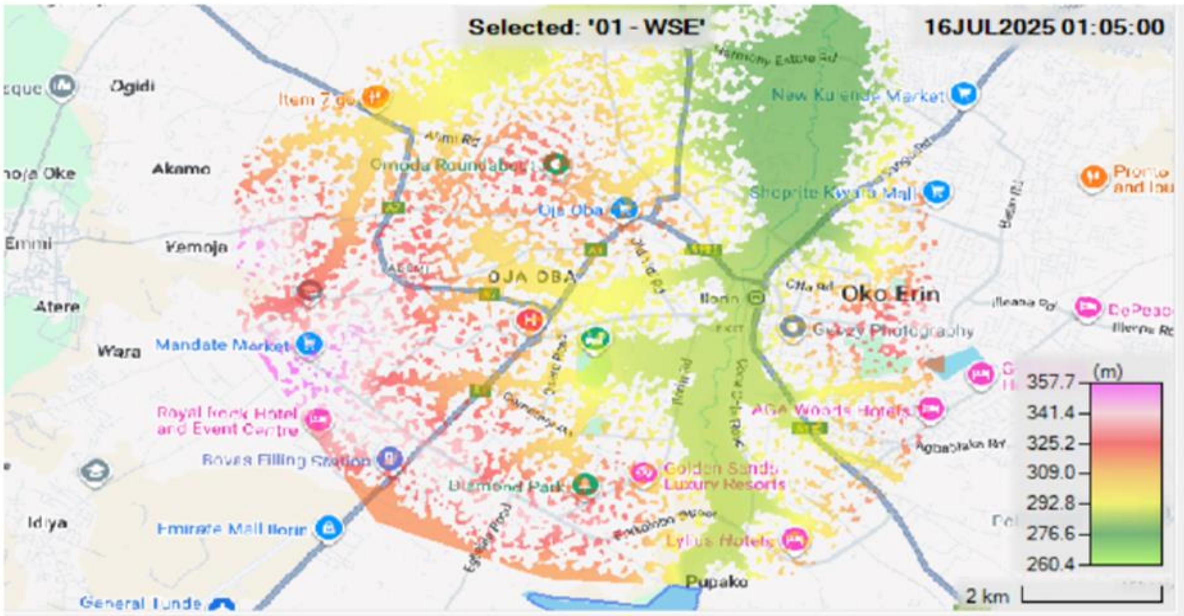

Figure 10: Water Surface Elevation One Hour after Dam Break

CONCLUSION AND RECOMMENDATION

Conclusion

The outcome of the study revealed an estimated peak discharge of 14,152 m³/s**,** breach widths of 130.86 m for overtopping scenarios and 93.47 m for non-overtopping breaches, occurred at about 1.48 hours. Hydrodynamic modeling using the HEC-RAS platform further explain the flood behavior following breach events, revealing nonlinear water surface responses and rapid flood wave progression. Simulations demonstrate that floodwaters would peak within 1 hours after breach initiation.

The outflow hydrograph with a sharp discharge peak near 1,900 m³/s indicates extremely intense downstream flooding, capable of overwhelming natural and built flood defenses.

Recommendation

The under listed precautions are recommended in order to prevent Asa dam from failure: (i) Regular inspections and maintenance of dam structures and spillways; (ii) Keeping spillway, outlet works, and channels clear of debris, sediment, and vegetation; (iii) Repair cracks, deformation, erosion damage, and structural deterioration in concrete and earthfill sections promptly to maintain dam integrity; (iv) Install early warning systems for downstream flood alert; (v) Develop and update Emergency Action Plans including community drills and education; and (vi) Conduct routine monitoring using sensors and update flood hazard maps regularly.

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REFERENCES

Abdullahi, M. A. (2024). History of dams' collapses in Nigeria. Blueprint. Retrieved from https://blueprint.ng/historyofdamscollapsesinnigeria/

Adamo, N., Al-Ansari, N., Sissakian, V., Laue, J., & Knutsson, S. (2020). Dam safety: Technical problems of aging embankment dams. Journal of Earth Sciences and Geotechnical Engineering, 10(6), 281–322.

Ansarifard, S., Eyvazi, M., Kalantari, M., Mohseni, B., Ghorbanifard, M., Moghaddam, H. J., & Nouri, M. (2024). Simulation of floods under the influence of effective factors in hydraulic and hydrological models using HEC-RAS and MIKE 21. Discover Water, 4(1), 92.

Aureli, F., Maranzoni, A., Petaccia, G., & Soares-Frazão, S. (2023). Review of experimental investigations of dam-break flows over fixed bottom. Water, 15(6), 1229.

Balaji, B., & Kumar, S. (2018, May). Dam break analysis of Kalyani Dam. International Journal of Civil Engineering and Technology (IJCIET), 9(5), 372–380.

Balogun, O. S., & Ganiyu, H. O. (2017a). Study and analysis of Asa River hypothetical dam break using HEC-RAS. Nigerian Journal of Technology, 36(1), 315–321.

Balogun, O. S., & Ganiyu, H. O. (2017b). Development of inundation map for hypothetical Asa Dam break using HEC-RAS and ArcGIS. Arid Zone Journal of Engineering, Technology and Environment, 13(6), 831.

Beza, M., Fikre, A., & Moshe, A. (2023). Dam breach modeling and downstream flood inundation mapping using HEC-RAS model on the proposed Gumara Dam, Ethiopia. Advances in Civil Engineering, 2023(1), 8864328.

Bharath, A., Shivapur, A. V., Hiremath, C., & Maddamsetty, R. (2021). Dam break analysis using HEC-RAS and HEC-GeoRAS: A case study of Hidkal Dam, Karnataka State, India. Environmental Challenges, 5, 100401.

Bharti, M. K., Sharma, M., & Islam, N. (2020). Study on the dam & reservoir, and analysis of dam failures: A database approach. International Research Journal of Engineering and Technology, 7(5).

Dhiman, A., & Patra, K. (2020). Empirical equations for predicting breach parameters of Indian dam failures. Journal of Hydrology, 584, 124686. https://doi.org/10.1016/j.jhydrol.2020.124686

Dottori, F., Salamon, P., Bianchi, A., Alfieri, L., Hirpa, F. A., & Feyen, L. (2016). Development and evaluation of a framework for global flood hazard mapping. Advances in Water Resources, 94, 87–102.

Duressa, J. N., & Jubir, A. K. (2018). Dam break analysis and inundation mapping: Case study of Fincha'a Dam in Horro Guduru Wollega Zone, Oromia Region, Ethiopia. Science Research, 6(2), 29–38.

Ezz, H. (2018). Integrating GIS and HEC-RAS to model Assiut plateau runoff. The Egyptian Journal of Remote Sensing and Space Science, 21(3), 219–227.

Gee, L., & Brunner, G. (2011). Comparison of HEC-RAS with FLDWAV and DAMBRK models for dam break analysis. Journal of Hydrologic Engineering, 16(6), 487–497.

Haltaş, İ., Yılmaz, A., & Akbulut, S. (2024). Non-linear effects of breach parameters on peak discharge in dam break analysis. Water Resources Management, 38(3), 1234–1250. https://doi.org/10.1007/s11269-023-03140-9

HEC-RAS Hydraulic Reference Manual. (2024). Causes of dam failure. USACE Hydrologic Engineering Centre. Retrieved from https://www.hec.usace.army.mil/confluence/rasdocs/ras1

dtechref/6.5/performing-a-dam-break-study-with-hec-ras/estimating-dam-breach-parameters/causes-and-types-of-dam-failures

Ishak, N. H., & Hashim, A. M. (2018). Dam pre-release as an important operation strategy in reducing flood impact in Malaysia. E3S Web of Conferences.

Jung, C. G., & Kim, S. J. (2017). Comparison of the damaged area caused by an agricultural dam-break flood wave using HEC-RAS and UAV surveying. Agricultural Sciences, 8(10), 1089.

Kawy, W. A. (2022). Two-dimensional electrical resistivity (ER) technique for dam safety assessment. Journal of Geology & Geophysics, 11(7), 1044.

Khattak, M. S., Anwar, F., Saeed, T. U., Sharif, M., Sheraz, K., & Ahmed, A. (2016). Floodplain mapping using HEC-RAS and ArcGIS: A case study of Kabul River. Arabian Journal for Science and Engineering, 41, 1375–1390.

Manamno, B., Amdeselassie, F., & Alene, M. (2023). Dam breach modeling and downstream flood inundation mapping using HEC-RAS model on the proposed Gumara Dam, Ethiopia. Advances in Civil Engineering, 2023.

Mo, C., Shen, Y., Lei, X., Ban, H., Ruan, Y., Lai, S., & Xing, Z. (2023). Simulation of one-dimensional dam-break flood routing based on HEC-RAS. Frontiers in Earth Science, 10, 1027788.

Olorunfemi, F. B., & Raheem, U. A. (2013). Floods and rainstorms impacts, responses and coping among households in Ilorin, Kwara State. Journal of Educational and Social Research, 3(4), 135–148.

Pandya, P. H., & Jitaji, T. D. (2013). A brief review of method available for dam break analysis. Indian Journal of Research, 2(4), 117–118.

Razack, R. (2014). Dam break analysis using GIS applications. International Journal of Engineering Research, 3(5).

Sammen, S. S., Mohamed, T., Ghazali, A., Sidek, L., & El-Shafie, A. (2017). An evaluation of existent methods for estimation of embankment dam breach parameters. Natural Hazards, 87, 545–566.

Sawai, A., Shyamal, D. S., & Kumar, L. (2019). Dam break analysis – Review of literature. International Journal of Research in

Engineering Application and Management, 4(12), 538–542.

Shahraki, A., Zadbar, A., Motevalli, M., & Aghajani, F. (2012). Modeling of earth dam break with SMPDBK: Case study, Bidekan earth dam. World Applied Sciences Journal, 19(3), 376–386.

Snorrason, A. (1984). Comparison of modeling approaches for dam break analysis: DAMBRK vs HEC-1. Journal of Hydraulic Engineering, 110(5), 763–775. https://doi.org/10.1061/(ASCE)0733-9429(1984)110:5(763).

Soleymani, S., Golkar, H., Yazd, H., & Tavousa, M. (2015). Numerical modeling of dam failure phenomenon using software and finite difference method. Journal of Materials and Environmental Science, 6(11), 3143–3158.

Tunde, O. (2024). Flood: Relocate to higher ground – Kwara urges riverine residents. Punch. Retrieved from https://www.google.com/amp/s/punchng.com/flood-relocate-to-higher-ground-kwara-urges-riverine-residents/%3famp

UNDRR. (2015). Disaster risk reduction: A global framework for action. Retrieved from https://www.undrr.org

Vinod, G. (2022). Components of dam – 12 dam components explained. Vin Civilworld. Retrieved from https://vincivilworld.com/2024/10/28/typesof damsclassificationcriteria/

Wang, J., Liu, J., & Zhang, X. (2022). Safety risk assessment of reservoir dam structure: An empirical study based on cloud and Dempster-Shafer evidence theories. Scientific Reports, 12, 71156.

Xiong, Y. (2011). A dam break analysis using HEC-RAS. Journal of Water Resource and Protection, 3(6), 370–379.

Yakti, B. P., Adityawan, M. B., Farid, M., Suryadi, Y., Nugroho, J., & Hadihardaja, I. K. (2018). 2D modeling of flood propagation due to the failure of Way Ela natural dam. In MATEC Web of Conferences, 147, 03009. EDP Sciences.

Zolghadr, M., Hashemi, M. R., & Zomorodian, M. (2011). Assessment of MIKE21 model in dam and dike-break simulation.