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Bathymetry Mapping and Simulation of Water Level in Cirata Reservoir Using Dual Beam Sonar

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Abstract: The Cirata Reservoir, an important water reservoir in West Java, plays a key role in hydropower generation, irrigation, and flood control. However, increasing sedimentation poses a significant threat to the reservoir's functionality. This study maps the bottom topography and evaluates flood risks from sedimentation through bathymetric mapping and water level rise simulations. Data was collected from 22 sampling points using Deeper Sonar Pro+, providing precise depth measurements. Depths ranged from 2.1 m to 45.9 m, with an average of 22.4 m and a standard deviation of 13.46 m. The deepest areas are located in the center and near the Citarum River, while shallower areas are found at the estuaries of the Cibalagung and Cisokan Rivers due to sediment deposition. Simulations of water level rise using bathymetric and NASADEM data showed that a rise of up to 15 m would inundate the western, southern, and southwestern regions of the reservoir. Although the total volume of the reservoir is not determined, these findings underscore the need for effective sediment management to sustain the reservoir's capacity and ecological functions. Further studies are required to estimate the reservoir's volume and model long-term sedimentation risks to support the Cirata Reservoir's sustainability.

Keywords: Bathymetry mapping; Cirata reservoir; Flood risk; Sedimentation; Water level simulation

Introduction

The Cirata Reservoir is located in West Java, with coordinates 6°44'23"S and 107°18'12"E. Built in 1984 and operational since 1988, this reservoir serves multiple purposes, including irrigation, power generation, agriculture, river flow control, and floating net cage cultivation (Ariyani et al., 2019). Human activities around the reservoir contribute to the deposition of various anthropogenic materials, which accelerate sedimentation (Fitriani et al., 2021; Supardiono et al., 2023). According to Putra et al. (2024), the Cirata Reservoir experiences a high level of sedimentation due to river basin degradation and waste from floating net cage activities. Consequently, sedimentation is strongly influenced by surrounding environmental conditions. (Sunardi et al., 2022). Furthermore, reservoirs are constructed along river courses, where all rivers naturally transport sediment caused by surface erosion and bank erosion. Over time, this sediment accumulates at the bottom of the reservoir basin.

According to Pratama et al. (2018), water flow from the Cibalagung Sub-watershed entering the Cirata Reservoir carries a significant suspended solid load, estimated at approximately 216.61 kg/day, due to high levels of human activity in the area. This situation is worsened by topographic conditions, characterized by a slope index of 0.27 and a watershed area of 118.09 km², which contribute to sedimentation. In contrast, the Cisokan River, with a drainage area of 896.20 km² and a relatively gentle slope of 0.08, experiences less erosion, resulting in shallower sediment accumulation compared

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to other areas. The impacts of sedimentation are further aggravated by factors such as climate change, which alters rainfall patterns and influences reservoir water storage and disposal strategies (Bharambe et al., 2023; Handayani et al., 2024; Liu et al., 2023; Elpiyani et al., 2023). Increased sedimentation negatively affects both the quality and quantity of water available to communities upstream and downstream. It also diminishes the reservoir's functionality, increasing the risk of flooding (Dwinanda et al., 2024; Hauer et al., 2018). According to Supiyati et al. (2024), physical parameters, such as topographic slope, significantly contribute to flood risk. Additionally, a decrease in water levels can disrupt reservoir discharge and affect the ability to meet electricity demands (Irwan et al., 2020; Akrom & Fauzi, 2023) and threaten the sustainability of socio-economic activities of the surrounding community.

To understand and manage the impact of sedimentation in the Cirata Reservoir, bathymetric mapping and water level rise simulations were conducted. Bathymetric mapping plays an important role in studying sedimentation volumes, analyzing reservoir bottom profiles, and identifying changes in depth caused by sedimentation (Arifin et al., 2021). Previous research on the use of bathymetry was conducted by Akgül et al. (2024), Septiawan et al. (2024), Oladosu et al. (2019), and Marupa et al. (2022). Additionally, Ndou et al. (2024) applied bathymetry in reservoir management decision-making. Bathymetric data supports simulations of rising water levels caused by sedimentation, which can result in flooding in the basin area. Spatial modeling of floods helps to assess their potential and impacts (Singh et al., 2017). Therefore, this method is an effective strategy for managing and mitigating flood risks (Virgota et al., 2024).

Based on previous research, hydroacoustic technologies such as echosounders, fish finders, and sonar can be used to detect the bottom of water bodies (Lubis & Manik, 2017). According to Rahadi et al. (2020), sonar fish finders are effective for measuring points in a reservoir. However, the use of instruments like the Deeper Sonar Pro+ for bathymetric mapping, particularly in the Cirata Reservoir, remains limited. This device is highly capable of providing accurate depth data in deep and turbid waters, with the advantages of rapid data acquisition and ease of operation. Given the significant role of the Cirata Reservoir for the surrounding community, this study aims to map the bottom topography and evaluate flood risks through bathymetric mapping and water level simulations caused by reservoir sedimentation.

Method

Geology of Research Areas

Cirata Reservoir has an area of approximately 6.200 hectares, with a height of 225 meters above sea level. Its volume is around 2.165 million cubic meters, making it a power generating reservoir with an installed energy capacity of 1.008 megawatts (MW) (Awaliyah et al., 2019). The flow entering the Cirata Reservoir comes from the Citarum watershed system which includes five large rivers, namely the Citarum, Cisokan, Cimeta, Cikundul, and Cibalagung Rivers (Soekarno, 2024) which indirectly influence the quantity and quality of reservoir water, which is very important in fulfilling sustainability of its function.

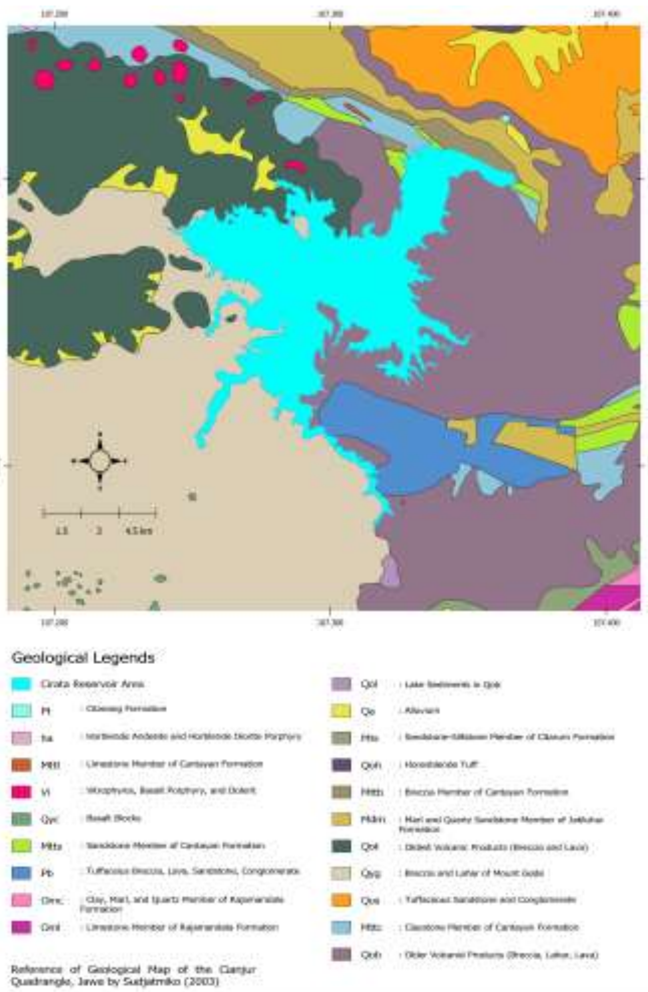

Figure 1. Geological background of Cirata Reservoir area

Geologically, the Cirata Reservoir area is characterized by formations originating from volcanic activity. According to Sudjatmiko's (2003) geological map, the reservoir contains three formations. First, the Qob Formation, which is the result of volcanic deposits consisting of breccia, lava, lava flows and andesite-basaltic plates, contributes to the robustness of the rock structure, making this formation relatively resistant to erosion and producing coarse sediment. On the other hand, formations consisting of breccia and propylized lava form hilly areas around the reservoir. This formation is more susceptible to erosion, with sediment accumulating in the center of the reservoir. Finally, the Qyg Formation consists of tuffaceous shale sandstone, tuffaceous breccia, and tuffaceous agglomerate, forming a plain around the reservoir that tends to be easily eroded and produces fine sediment.

Meanwhile, the bedrock condition in the Cirata Reservoir shows a significant structural slope due to faulting and folding processes. According to Deng et al. (2025) and Dong et al. (2019), topographic conditions and geological formations are indirectly related to regional depositional processes and sedimentary facies. The geological characteristics of an area indirectly influence sedimentation patterns, water flow, and the bottom topography of its waters. Therefore, this is relevant to the current research on bathymetric mapping and simulating the rise in reservoir water levels (Zeng et al., 2024).

Bathymetry Measurement

Bathymetry measurement is an imaging process used to visualize the bottom of a body of water (Setiawan et al., 2020). In this study, bathymetry measurements were carried out in situ at 22 randomly selected sampling points. The determination of this point is considered very representative with the Cirata Reservoir area being around 62 km² when compared with research by Morlock et al. (2019) which involved 83 measurement points on a lake with an area of approximately 560 km². The instrument used to obtain data quickly and easily is the Deeper Smart Sonar Pro+ fish finder tool which requires Fish Deeper software to operate and can be connected to a smartphone via a Wi-Fi network. This device uses sonar technology to provide important information about water bodies (El-Khaq et al., 2024). Figure 2 shows the bathymetric measurement point with a distance of ±1.5 km between the points.

The basic concept of the instrument is that the sensor is placed on the surface and then sends a wave signal to the bottom of the water by recording the travel time of the tool when it reaches the bottom of the water and there is a reflection which is later displayed on the smartphone display to find out the topography of the bottom of the water (Vozza et al., 2023). The maximum depth range of this tool reaches approximately 80 meters. The average depth value in the Cirata Reservoir is 34.9 meters, so it is still affordable to measure using the tool (Hindayani et al., 2021). The results of the Deeper Smart Sonar Pro+ recording can be seen in Figure 3, which displays information such as depth values, temperature, fish presence, and topographic visualization of the bottom of the waters. There is information on the color layer where the orange part is categorized as the hardest part, the medium brown part, and the black part the smoothest part. In this research, the software used is Global Mapper (GIS), and QGIS which is environmental mapping software that can be accessed for free (Shareef & Abdulrazzaq, 2021; Nandi et al., 2016).

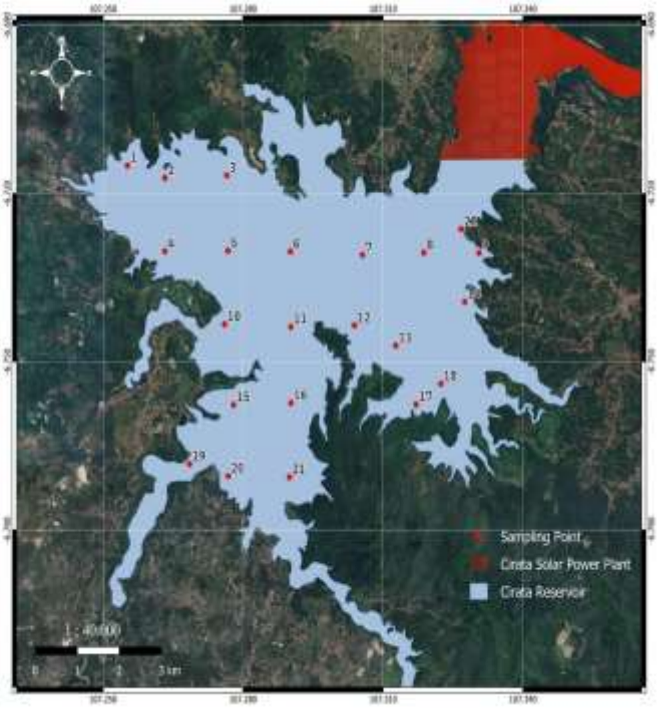

Figure 2. Bathymetry sampling points are shown by red dots

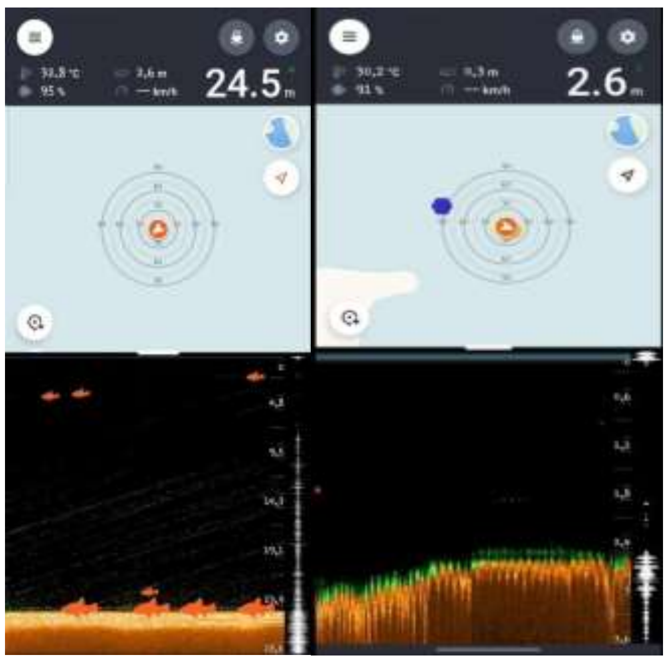

Figure 3. Deeper smart sonar pro+ recording

Global Mapper

Global Mapper is a Geographic Information System (GIS) analysis software used to visualize, analyze and process spatial data (Xu et al., 2023). This software can also be used to simulate rising water levels. The simulation begins by integrating NASADEM data with reservoir depth data obtained from interpolation results. The analysis feature used in the simulation is the "water level rise/flood" tool.

NASADEM is a modernization of the Digital Elevation Model (DEM) and related products resulting from reprocessing Shuttle Radar Topography Mission (SRTM) data. Its accuracy has been improved with additional data sourced from various data sets, such as the Ice, Cloud, and Land Elevation Satellite (ICESat), Geoscience Laser Altimeter System (GLAS) and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER). In this study, the NASADEM data used follows the WGS 84 coordinate system, with a spatial resolution of 1 arc second (approximately 30 meters) and a vertical accuracy of 5.3 meters (Tran et al., 2023). DEM data resolution plays an important role in influencing the extraction of hydrological systems, which directly impacts the accuracy of simulation results (Zhu & Chen, 2024). NASADEM's 30 meter resolution used in this study provides wide area coverage with fairly good representation, especially for simulating water level rise on a regional scale. The NASADEM data used in this research comes from the database available in the Global Mapper software. In this research, five water level rise simulations were carried out to observe the extent of the inundation, namely simulating water level increases of 1 meter, 3 meters, 5 meters, 10 meters and 15 meters. The results of this simulation provide valuable insight into the regional impacts of rising water levels around the Cirata Reservoir.

Quantum GIS (QGIS)

QGIS is free and open source software used to edit, visualize, analyze and map spatial data (Purwanto & Paiman, 2023). In this research, QGIS is used to visualize the two acquisition points, create the shape of the area under consideration (area of interest), and reference the resulting map (georeferencing). In addition, in a study conducted by Dumpis & Lagzdins (2020) on bathymetric mapping, open source software such as QGIS was proven to be effective in achieving optimal results, especially in generating basic data before carrying out simulations.

Data Processing and Simulation

The data obtained from the acquisition, consisting of depth and coordinate data, is then interpolated using the kriging interpolation method in the QGIS application. This is combined with NASADEM data, and the resulting bathymetry and DEM data are further processed in Global Mapper software to simulate water level rise/flooding.

Figure 4. Processing flowchart

Result and Discussion

Based on the bathymetric measurements at Cirata Reservoir, which were carried out at 22 sample points (Figure 2), the measurement results consist of coordinate and depth data, as presented in Table 1. The recorded depths ranged from 2.1 meters to 45.9 meters, with an average depth of 22.4 meters. The deepest measurement was at point 6, with a depth of 45.9 meters, while the shallowest was at point 1, with a depth of 2.1 meters.

These findings indicate significant depth variations across the reservoir. The average depth is approximately 22.4 meters, with a standard deviation of 13.46 meters, suggesting considerable depth fluctuations between measurement points. In this study, we highlight points 19 (Cisokan River) and 10 (Cibalagung River), which are clearly visible in Figure 5, as having relatively shallow depths, making them an interesting focus for understanding sedimentation conditions at the river mouths. The shallowest depths were recorded at the mouths of the Cisokan and Cibalagung Rivers, while the deepest depths were located in the middle of the reservoir and at point 16.

Table 1. Table of Bathymetric Measurement Results

Sampling point	Coordinate		Depth (meters)	Average	Standard deviation
	Longitude	Latitude			
Point 1	107.25525	-6.715027778	2.10	22.40	13.46
Point 2	107.2632778	-6.71722222	9.80		
Point 3	107.2765	-6.71677778	35.40		
Point 4	107.2632583	-6.73029722	22.60		
Point 5	-107.27675	-6.730222222	34.00		
Point 6	-107.29014	-6.730361111	45.90		
Point 7	-107.30558	-6.730972222	17.80		
Point 8	-107.31875	-6.730555556	28.10		
Point 9	-107.33056	-6.730611111	32.20		
Point 10	-107.27603	-6.743333333	3.00		
Point 11	-107.29025	-6.743777778	25.70		
Point 12	-107.30386	-6.743527778	24.60		
Point 13	-107.31272	-6.747111111	9.40		
Point 14	-107.3275	-6.739305556	20.00		
Point 15	-107.27797	-6.757722222	6.00		
Point 16	-107.29028	-6.757361111	45.50		
Point 17	-107.31708	-6.757638889	12.00		
Point 18	-107.32239	-6.753944444	25.30		
Point 19	-107.26853	-6.76825	2.40		
Point 20	-107.27681	-6.770416667	40.50		
Point 21	-107.28992	-6.770611111	25.50		
Point 22	-107.32672	-6.726361111	25.00		

To better illustrate these findings, Figure 5 displays the bathymetric map of the reservoir, with depth variations represented through a color gradient. The color gradient visually encodes depth, with darker colors indicating greater depths and lighter colors representing shallower areas, making it easier to interpret the spatial distribution of depth variations.

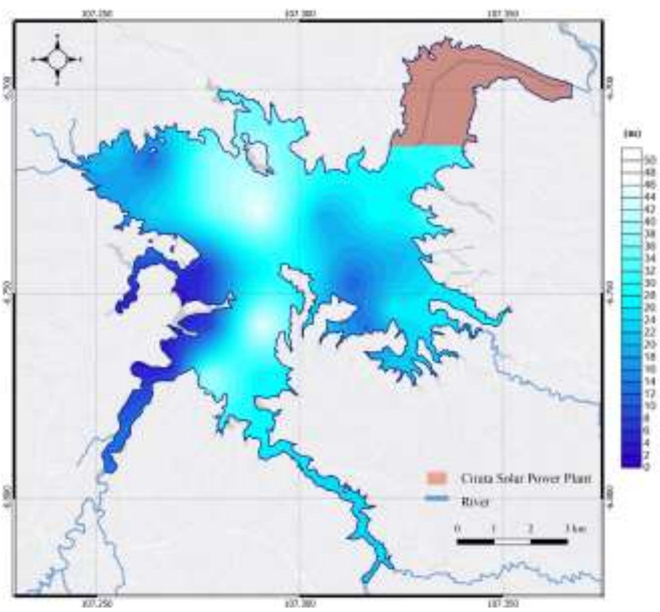

Figure 5. Bathymetry distribution map

The data obtained reveals a geographic pattern in depth variation. The southern part of the reservoir tends to have deeper depths, while the northern part is generally shallower, likely due to higher sedimentation rates. Measurement points with depths of less than 10 meters are identified as potential areas for sedimentation monitoring, whereas points with depths exceeding 40 meters serve as key water storage zones for the reservoir. Overall, the average depth is approximately 22.4 meters, with a varied depth distribution. Shallower measurement points suggest sediment accumulation, while deeper areas indicate potential for faster water flow and greater susceptibility to river erosion.

The results of the bathymetric analysis highlight the significance of depth variations for reservoir management. These variations influence storage capacity, the operational efficiency of hydropower plants, and sedimentation management in the Cirata Reservoir. Furthermore, depth is also a crucial factor for aquatic ecosystems, as it affects the distribution of water temperature, oxygen levels, and habitats for aquatic organisms.

In bathymetric mapping, the estuaries of the Cibalagung and Cisokan Rivers show relatively shallow depths. This aligns with the research conducted by Pratama et al. (2018), which explains that a comparative analysis of the Cisokan and Cibalagung Rivers reveals differences in the impacts on sedimentation. In the steep terrain of the Cibalagung River and its winding watershed, water flow accelerates, increasing erosion but reducing sedimentation near the mouth. In contrast, the wider and less steep Cisokan River watershed facilitates sediment deposition, resulting in shallower depths near its mouth.

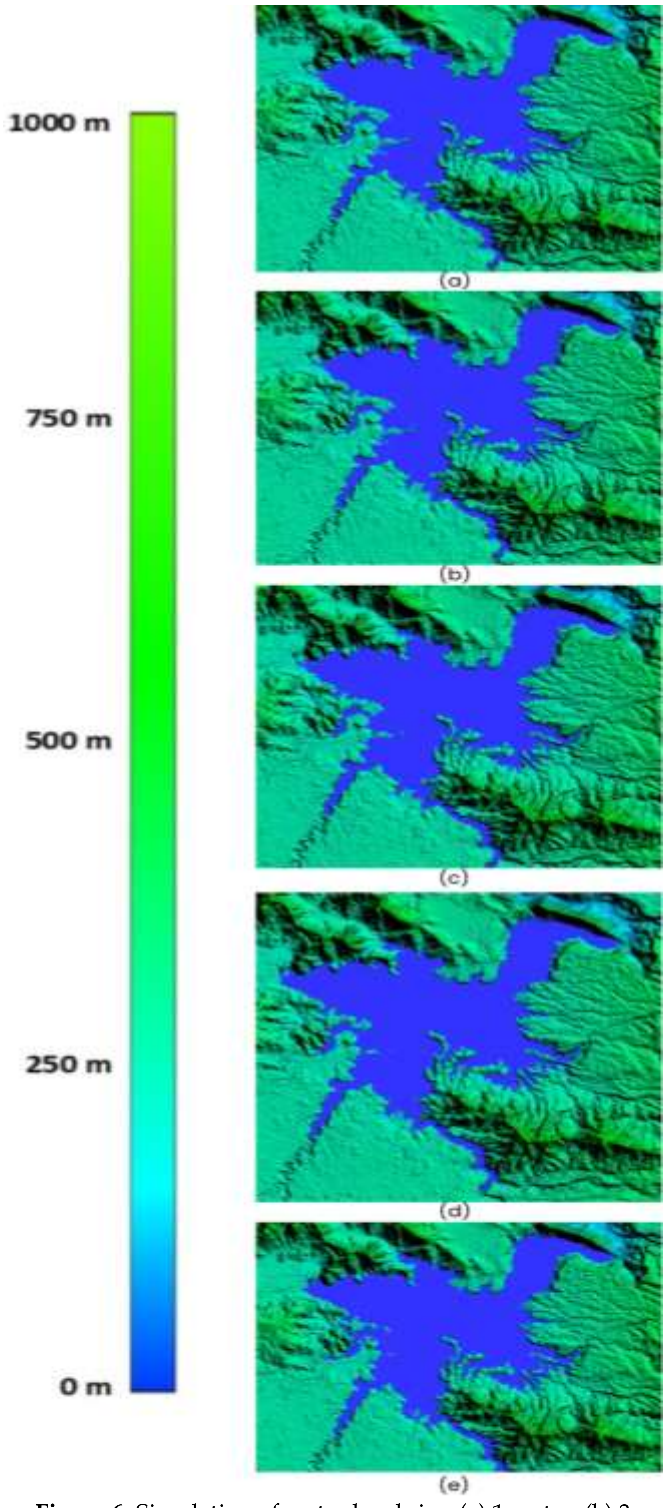

Figure 6. Simulation of water level rise: (a) 1 meter, (b) 3 meters, (c) 5 meters, (d) 10 meters, (e) 15 meters

Thus, the bathymetric mapping results for these two rivers show that, even though the water flow in the Cibalagung River is faster, the depth at the mouths of both rivers remains relatively shallow. This can be explained by geographical conditions and river flow dynamics that do not completely align with the sedimentation patterns observed in previous studies. While faster water flow would typically reduce sedimentation, other factors such as morphological changes or interactions with climatic conditions may influence the results, leading to sediment accumulation despite the relatively fast water flow.

This study does not include direct information about the reservoir's volume. However, according to Soekarno (2020), the estimated annual sedimentation rate is generally 5.7 x 10^6 m^3/year. The results of this study, however, indicate that the volume of sedimentation has been increasing annually. For instance, in 2017, sedimentation increased by approximately 8.4 x 10^6 m^3, showing an annual difference of 2.7 x 10^6 m^3 compared to the initial prediction. This suggests that sedimentation volumes are likely to continue increasing both now and in the future, potentially causing significant rises in water levels.

Water level rise simulations were conducted using Global Mapper software with bathymetric and NASADEM data to predict the reservoir's response under various scenarios. These scenarios were designed to assess potential flood risks due to rising water levels, provide insights into the impacts on vulnerable areas, and support long-term planning for reservoir management and flood mitigation. The simulation results, illustrated in Figure 6, include water level increases of 1 meter, 3 meters, 5 meters, 10 meters, and 15 meters. The findings indicate that the western, southwestern, and southern regions characterized by shallower depths are more vulnerable to inundation.

This study also identified potential limitations. Future research can address these limitations by providing direct measurements of reservoir volume to estimate its capacity more accurately. Additionally, expanding the measurement area to include more zones, such as solar PV areas, will yield a more comprehensive data set and enhance the analytical power. Suggestions for future research include measuring reservoir volume and utilizing 3D modeling to improve the accuracy of predicting the impact of sedimentation, which has the potential to raise water levels.

The results of this study show that bathymetric mapping successfully identified depth variations in the Cirata Reservoir, ranging from 2.1 to 45.9 meters, which are critical for understanding storage capacity and sediment distribution. Water level simulations of up to 15 meters revealed that the western, southwestern, and southern regions are the most vulnerable to flooding due to sedimentation. These findings directly align with the objectives of mapping the bottom topography and evaluating flood risks caused by sedimentation, highlighting the need for intensive sediment management and further studies on reservoir capacity.

Table 2. Simulation Results for Rising Water Levels

Simulation of water level rise	Potential impact areas
1 meter	Minimal impact on humans but significant effects on aquatic ecosystems.
3 meters	Significant impact on flood risk in low-lying and residential areas.
5 meters	The impact disrupts community activities due to inundation in the western and southwestern regions of the map.
10 meters	Serious impact on settlements, infrastructure, and ecosystems.
15 meters	Extremely large impact with an extreme flood risk in the western, southwestern, and southern regions of the map.

Conclusion

This research presents the results of bathymetric mapping of the Cirata Reservoir with depth variations ranging from 2.1 meters to 45.9 meters, and an average depth of 22.4 meters. These results are very important for calculating the volume of a reservoir, which is directly related to its storage capacity and the risk of flooding due to sedimentation. Volumes affected by varying depths, especially in shallower areas such as the west, southwest and south, increase the potential for flooding. However, this study does not provide direct information regarding reservoir volume. However, overall, there is an increase in the volume of sedimentation every year, which may have an impact on rising water levels. Water level rise simulations, showing increases between 1 meter to 15 meters, identify these regions as the most vulnerable to flooding. These findings directly support the research objectives of mapping the bottom topography of the reservoir and evaluating flood risks due to sedimentation. The shallower depths near the mouths of the Cisokan and Cibalagung Rivers lead to sediment accumulation, which exacerbates the flooding issue. Conversely, the deeper areas, particularly in the central and eastern parts of the reservoir, provide safer conditions for infrastructure development and other activities. The implications of these findings highlight the importance of effective sediment management and continuous monitoring of water level changes to mitigate flood risks and preserve the reservoir's capacity. Recommendations for future research include more precise sediment volume measurements, as well as the use of high-resolution mapping and 3D modeling to more accurately predict the impacts of sedimentation and changes in reservoir capacity. These steps will strengthen disaster mitigation strategies, long-term planning, and ensure the operational sustainability of Cirata Reservoir.

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Conflicts of Interest
The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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