Reducing Sedimentation in Catchment Areas as Part of the Revitalization Efforts at Batujai Reservoir in Central Lombok

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Abstract: This research discusses efforts to revitalize the Batujai Reservoir in Central Lombok with a focus on sedimentation problems. Batujai Reservoir has a strategic role in meeting water needs in the surrounding area, but faces serious challenges due to significant sedimentation. This research aims to analyze the impact of changes in land use in the Dodokan Sub-Watershed Catchment Area (DTA) on the characteristics and volume of sedimentation entering the reservoir, as well as evaluating this impact on the benefits of the reservoir such as irrigation, flood control and electricity generation. Apart from that, this research also aims to formulate recommendations for effective sedimentation management strategies to extend the service life of the Batujai Reservoir. Research methods include primary and secondary data collection, sedimentation modeling using the Water and Tillage/Sediment Delivery Model (WATEM/SEDEM), to evaluate the impact of sediment control structures such as check dams. Research variables include catchment area, population, annual rainfall, average daily evaporation, mainstay surface water availability, land surface erosion rate, sediment volume deposited in the reservoir, effective age of the Batujai Reservoir, and changes in land use in the Dodokan Sub-watershed. The results of this research will provide a better understanding of the main sources of sedimentation in the Batujai Reservoir and the impact of land use changes on the reservoir. It is hoped that the recommendations for sedimentation management strategies resulting from this research will help maintain reservoir storage capacity, which is important for meeting various water needs in the region.

Keywords: *Sedimentation problems; land use changes; sedimentation management strategies; Dodokan Sub-Watershed; Batujai Reservoir*

1. Introduction

Lombok Island is one of the regions in Indonesia which has an area of 4,860.78 km2 with a population of 3,758,637 people. This region is a national strategic River Basin (WS) which has 197 River Basins (DAS) spread across 4 districts and 1 city. Average annual rainfall ranges from 904 to 2,183 mm, with average evaporation of around 4 - 6 mm per day. This region also has 361 spring units with surface water availability of 2,352 Mm3 (NTB Province in Figures 2021).

One of the important infrastructure on Lombok Island is the Batujai Reservoir, which is located in the Dodokan River Basin (DAS). The Dodokan watershed is a watershed with high utility, utilizing two large dams, namely Batujai Reservoir and Pengga Reservoir, as well as dozens of reservoirs

that support the availability of food in West Nusa Tenggara. However, rivers in the Dodokan watershed experience rapid increases in flood water levels, while their decline is very slow. Therefore, the Dodokan watershed is included in the critical category.

Sulistiyo H. (2016) through his analysis concluded that the effective age of the Batujai Reservoir is only 35 years, namely from 1982 to 2017. Meanwhile, the Batujai Dam is estimated to have an effective remaining age of 2 years, or until 2017 from 2015, with the sedimentation volume reached 1,482,705 m3. This volume covers a dead storage volume of 1,400,000 m3. To extend the period of use of this dam, sediment dredging efforts are needed, while to reduce the rate of sedimentation, sabodams or checkdams can be built in rivers upstream of the Batujai Reservoir.

The development of the upstream area of the Batujai reservoir causes a high rate of soil erosion, which in turn triggers the problem of shallowing of the Batujai reservoir due to the high rate of sedimentation. Soil erosion is calculated using the USLE method, so secondary data is needed according to USLE parameters, such as rainfall data, land use data, soil type data and topographic data. The amount of sedimentation in the reservoir is calculated based on the bathymetric map of the reservoir floor measured using echo-sounding techniques. The sedimentation rate in this reservoir, based on the last measurements in 2017, shows that the contribution of soil erosion upstream of the Batujai reservoir is 109,974,078 tons per hectare per year. With a sediment Trap Efficiency value of 0.094%, the sediment entering the Batujai Reservoir over 35 years is 1,200,000 m3. From the analysis results, it is estimated that the useful life of the Batujai Dam is around 5 years and 10 months, namely in June 2021 (Danang et al., 2022).

Batujai Dam has technical characteristics which include inundation area, volume, spillway width, number of spillway gates, and certain capacity. Apart from that, this dam has a number of significant benefits for the surrounding area, such as water for irrigation, flood control, support for inland fisheries and raw water, micro hydro power plants (PLTMH), and a positive impact on the tourism sector. The Batujai Reservoir is able to utilize the water potential of several rivers such as the Leneng River, Tiwubare River, Sade River, Dodokan River and Kelebuh River for various purposes such as irrigation, power generation and flood control.

However, the main problem faced by the Batujai Reservoir is the sedimentation problem. Sedimentation is the process of deposition of solid materials such as sand, mud and rocks into reservoirs or reservoirs over time. Sedimentation can reduce the reservoir capacity and threaten various important functions of the reservoir. In this case, the Batujai Dam has experienced significant sedimentation problems for many years.

Therefore, this research aims to analyze the impact of changes in land use in the Dodokan Sub-Watershed Water Catchment Area (DTA) on the characteristics and volume of sedimentation entering the Batujai Reservoir, evaluate the impact of changes in sedimentation on the benefits of the Batujai Reservoir, and formulate recommendations for strategies for handling sedimentation which is effective in maintaining the storage capacity of the Batujai Reservoir and increasing its service life.

This research uses various methods, including field surveys, sampling, modeling using the Water and Tillage/Sediment Delivery Model (WATEM/SEDEM) program, as well as hydraulic modeling using the CIVILGEOHECRAS program. Primary and secondary data are used for analysis of land erosion, sedimentation, and hydraulic modeling. It is hoped that the results of this research can provide appropriate recommendations to overcome the sedimentation problem in the Batujai Reservoir and analyze the useful life of the reservoir.

2. Research Problems

Understanding the various challenges faced by the Batujai Reservoir due to sedimentation requires addressing several critical questions. This research aims to dissect these challenges by exploring the following key problems:

1. How do changes in land use in the Dodokan Sub-watershed catchment area affect sedimentation characteristics, such as sediment type, sediment concentration, and sedimentation rate entering the Batujai Reservoir?
2. What is the impact of changes in the characteristics and volume of sedimentation in the Batujai Reservoir on the benefits of the reservoir, such as irrigation, flood control and electricity generation?
3. How can an effective sedimentation management strategy be implemented to extend the service life of the Batujai Reservoir and maximize its benefits?

3. Rescarch Objectives and Benefits

To comprehensively address the sedimentation challenges faced by the Batujai Reservoir, this research is guided by the following objectives:

1. To analyze the impact of changes in land use in the Dodokan Sub-Watershed on the characteristics and volume of sedimentation entering the Batujai Reservoir.
2. To evaluate the impact of changes in sedimentation on the benefits of the Batujai Reservoir, including irrigation, flood control and electricity generation.
3. To formulate recommendations for effective sedimentation management strategies to maintain the storage capacity of the Batujai Reservoir and increase its service life.

4. Research Methods

The research flow chart, which outlines the sequential steps and methodology of the study, is presented in Fig. 1.
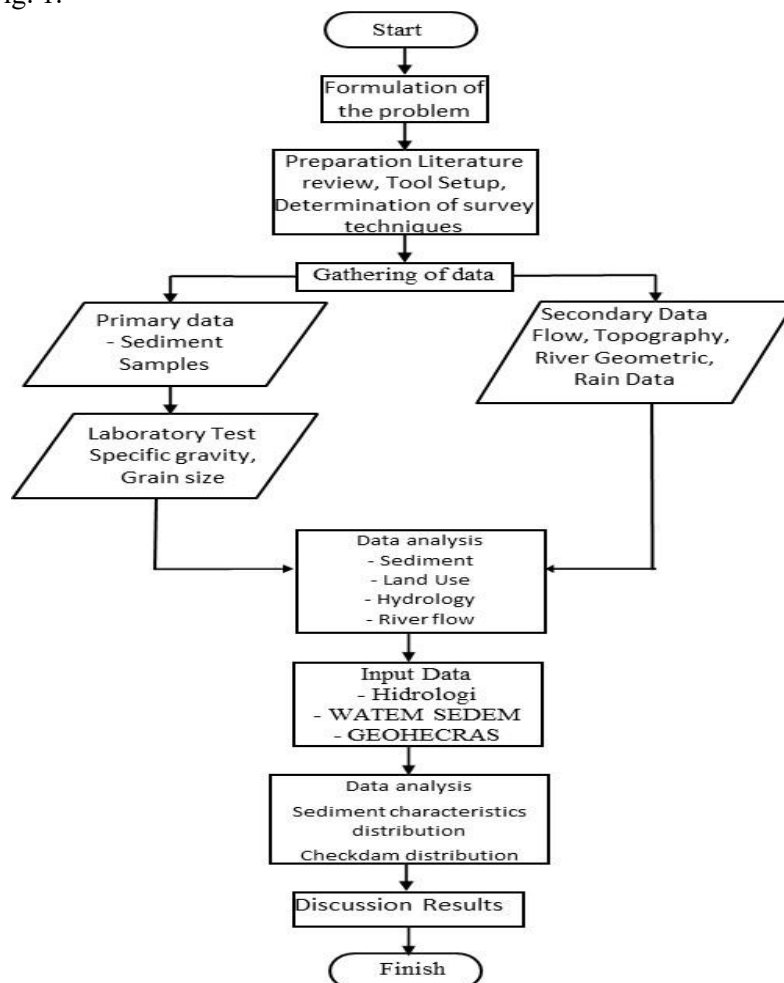
Fig. 1. Research flow diagram.

4.1. Research Sites

The location of this research was carried out in the Batujai Reservoir Water Catchment Area (DTA) in the Dodokan Watershed system. The boundaries used in this research are boundaries that have a direct impact on the carrying capacity of the Batujai reservoir, namely the Dodokan watershed area. The research area at Batujai Reservoir is located in Batujai Village, West Praya District, Central Lombok Regency, West Nusa Tenggara Province, with coordinates 8044'08.54" S and 116015'28.26" E. Batujai Reservoir consists of 5 sub-watersheds of the Leneng River, Tiwubare River, Sade River, Dodokan River, and Kelebuh River.

4.2. Research Data

a. Data types and sources

To carry out an analysis of land erosion that occurs in the Dodokan Sub-watershed, primary data and secondary data are used. Primary data includes specific gravity and sediment grain size, as well as the physical condition of the watershed. Meanwhile, secondary data obtained includes topographic data obtained from the Badan Pertanahan Nasional, hydrological data from the Balai Wilayah Sungai Region 1 (BWS NT-1), as well as regional spatial and land use data from BPN. The location of Batujai Reservoir can be seen on Fig. 2.
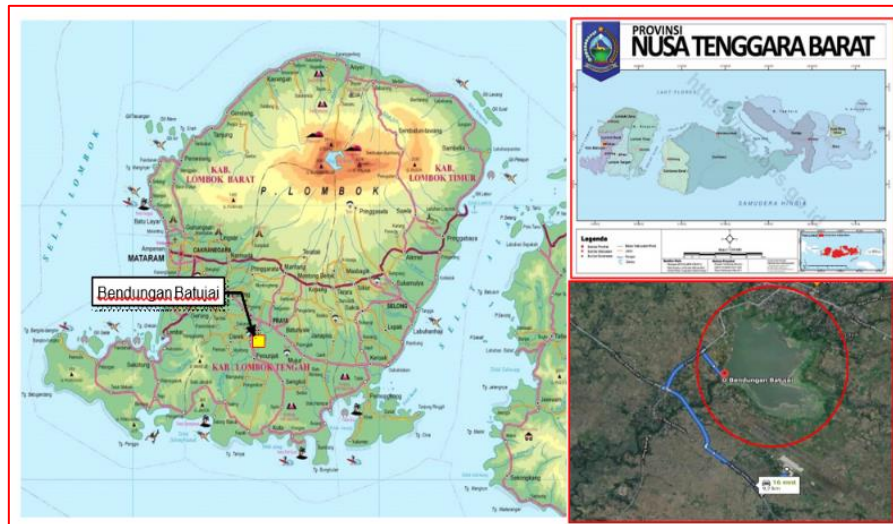

Fig. 2. Location map of the Batujai Reservoir (source: BWS NT-1)

b. Method of collecting data

Data collection was carried out through field surveys to obtain the required primary data by conducting observations in 5 (five) representative Water Catchment Areas (DTA) of the Dodokan Sub-Watershed and observing soil types. Measurement activities are focused on collecting primary and current data, such as soil infiltration rates and land cover types. Secondary data was taken from various institutions related to land management in the Dodokan watershed and collected through literature studies. This data inventory emphasizes validation to test the correctness of the land erosion data that occurred and the maps produced using GPS tools.

c. Data analysis

This research uses a case study methodology with a quantitative research method approach. The research was carried out through case studies regarding sedimentation using Water and Tillage/Sediment Delivery Model (WATEM/SEDEM) software analysis. The analysis was carried out by reviewing and recalculating the potential for sedimentation originating from the upstream Batujai Reservoir. A review was carried out on the overall sedimentation potential and identification of sediment zoning.

WATEM/SEDEM (Water and Tillage Erosion Model and Delivery Model) is a sediment transport model that predicts the amount of sediment transported to rivers each year. The program has three components: 1) soil loss assessment, 2) sediment transport capacity assessment, 3) and sediment routing. The annual sediment transport capacity is calculated by assuming it is proportional to the potential for stream erosion by applying the transport capacity coefficient. The run off pattern is calculated by considering the influence of roads and infrastructure with a dual flow algorithm. Sediment routing is recorded using a routing algorithm to transport sediment from the disposal site to the river. After the flow route, sediment is transported downslope if the local transport capacity is greater than the total volume of sediment. If the local transport capacity is less than the sediment, then deposition occurs (Alfianto & Cecilia, 2020).

4.3.   How to Research

a.   Sedimentation Modeling

Determination of the location of the sediment control building (BPS) is calculated based on sedimentation entering from each catchment area. In this research, numerical modeling will be carried out to model the contribution and sedimentation patterns of 5 tributaries that contribute to sedimentation patterns in the flooded area of the Batujai reservoir. Therefore, sedimentation analysis will be modeled in the Batujai Reservoir catchment using Water and Tillage/Sediment Delivery Model (WATEM/SEDEM) software. The output of this modeling is to obtain the potential sedimentation rate of tributaries entering the reservoir, as well as analysis of alternatives for installing check dams on tributaries to reduce sediment transport to the reservoir. The output of this modeling is to obtain an overview of sedimentation patterns in the reservoir inundation area, as well as an alternative analysis of the use of directional structure engineering and reservoir operation patterns to reduce sedimentation in the reservoir, so that at the end of the modeling we obtain recommendations for controlling sedimentation in the Batujai Reservoir.

Water and Tillage/Sediment Delivery Model (WATEM/SEDEM) is a sediment transport model that reduces the amount of sediment transported to rivers each year. The model is pixel-based with a resolution of 20m x 20m (Ardian Alfianto et al, 2016). This program is a RUSLE-based model that takes into account two-dimensional LS (topographic factor) calculations with the slope length replaced by the contribution unit area (Van Oast et al, 2002). Because the model is based on RUSLE (Revised Universal Soil Loss Equation), the model input required is in layers such as: crop management factors (c factor in RUSLE), land use, river maps, roads, soil erodibility, digital elevation model (DEM), and storage, pond or reservoir map if any (Alfianto & Cecilia, 2020).

The program has three components: 1) soil loss assessment, 2) sediment transport capacity assessment, 3) and sediment routing. The annual sediment transport capacity is calculated by assuming it is proportional to the potential for stream erosion by applying the transport capacity coefficient. The run off pattern is calculated by considering the influence of roads and infrastructure with a dual flow algorithm. Sediment Routing is recorded using a routing algorithm to reach the river, directly sent to the water catchment outlet. When sediment reaches the river, it is directly sent to the water catchment outlet (Ardian Alfianto et al, 2016). After the flow route, sediment is transported downslope if the local transport capacity is greater than the total volume of sediment. If the local transport capacity is less than the sediment, then deposition occurs (Alfianto & Cecilia, 2020).

b.   Hydraulic Modeling

The flow modeling referred to in this analysis is the modeling of the planned river transverse structures at the planned point to be reviewed for back water and inundation that occurs. Sediment control buildings, especially check dams, have a height above the river bed which is able to increase the height of the river bed if the sediment is full and if it is full of water. Therefore, hydraulic modeling needs to be carried out to review the backwater that occurs and the capacity of existing river embankments.

River modeling uses 2D Area modeling in the CIVILGEOHECRAS program. Modeling uses measured data from topographic measurements carried out by consultants and input data that has been described previously.

GEOHECRAS software from CivilGeo to model the natural flow of rivers and paths that can be affected by water, whether stable or unstable/consistent. This modeling can produce data that can be used to predict and prevent events such as flooding on river banks, or culverts under roads, or diversion of river flows into reservoirs.

4.4. Research variable

Research variables that can be identified based on the background and problems presented are as follows:

1. Area of the catchment area upstream of the reservoir, this variable describes the size of the catchment area upstream of the reservoir which is the focus of the research. The area of the catchment area can influence the amount and source of sediment entering the Batujai Reservoir,
2. Number of residents on Lombok Island, this variable reflects the human population in the area around the upstream of the reservoir. Population size can influence land use patterns, human activities, and the potential for pollution and land erosion,
3. Annual rainfall, this variable reflects the amount of rainfall that occurs in one year in the Dodokan watershed area. High rainfall can accelerate land erosion and increase sediment flow into the Batujai Reservoir,
4. Daily average evaporation, this variable describes the average level of surface water evaporation in a day in the Dodokan watershed area. High evaporation rates can affect surface water availability and increase sediment concentrations in reservoirs,
5. Availability of mainstay surface water, this variable describes the amount of surface water available as the main source in the Dodokan watershed. The availability of reliable surface water can affect the water storage capacity of the Batujai Reservoir,
6. Land surface erosion rate, this variable measures the level of land erosion in the Dodokan Sub-watershed. High erosion rates can cause increased sedimentation in the Batujai Reservoir,
7. Volume of sediment deposited in Batujai Reservoir, this variable reflects the amount of sediment accumulated in Batujai Reservoir. High sediment volumes can affect the reservoir's storage capacity and shorten its operational life,
8. Effective age of the Batujai Reservoir, this variable describes the period when the Batujai Reservoir could function well before experiencing sedimentation problems. A shorter effective life can indicate problems in the sustainability of reservoir function,
9. Changes in land use in the Dodokan Sub-watershed, this variable reflects changes in land use in the Dodokan Sub-watershed area which can affect the level of land erosion and sediment flow to the Batujai Reservoir,

4.5. Analysis Method

The methods used in this research consisted of field surveys and laboratory testing, which involved taking sediment samples in the field which were then tested in the laboratory.
The research stages carried out include the following:

1. The initial stage in starting research is to carry out direct observations (surveys) through direct visits to the study location to carry out checks.
2. This literature study aims to study and understand all aspects related to the problem being researched, including the results of previous research or previous publications, as well as literature from various relevant sources that supports this research.
3. To make data collection easier, grouping between primary data and secondary data is needed. Primary data refers to data obtained directly through observation, measurement, taking pictures (photos) and sampling in the field. Meanwhile, secondary data is data related to research obtained through references and literature by sending letters to relevant agencies and

requesting relevant data.

4. Special testing is carried out in the laboratory, Soil Test and then the data is processed in stages according to the testing steps.

4.6. Research Instruments and Process

a. Research Instrument

1. Global Positioning System (GPS) tool, this tool is used to obtain precise location data and coordinates during field surveys for data validation and making land erosion maps,
2. Interviews with Local Communities, these interviews were conducted to obtain additional information about land erosion and land use changes in the Dodokan Sub-watershed area from the perspective of local communities.
3. Water and Tillage/Sediment Delivery Model (WATEM/SEDEM) program, this program is the main tool in analyzing land erosion and sedimentation. Data such as plant management factors (c factor in RUSLE), land use, river maps, roads, soil erodibility, digital elevation models (DEM), and wadu maps are used as input for this program,
4. 2D Area Modeling in the CIVILGEOHECRAS Program, this program is used for hydraulic modeling to review backwater and inundation that occurs due to the planned river crossing and check dam.

b. Research Process

1. Preparation Stage: 1) Literature study to understand aspects related to the research problem, 2) Determining the research location and boundaries of the Dodokan Sub-watershed area which will be the focus of the research, 3) Collecting secondary data from various institutions related to land management in the Dodokan Sub-watershed through literature studies and data request letters, 4) Preparing questionnaires for field surveys,
2. Data Collection Stage: 1) Field survey to collect primary data through questionnaires and direct observation in 5 Dodokan sub-watershed areas as well as observing soil types, 2) Collecting secondary data from the results of literature studies and related institutions,
3. Data Processing Stage: 1) Validation of land erosion data and making maps using GPS tools or the results of interviews with local communities, 2) Processing of collected primary and secondary data,
4. Modeling Stage: 1) Using the Water and Tillage/Sediment Delivery Model (WATEM/SEDEM) program to carry out land erosion and sedimentation analysis, 2) Hydraulic modeling using the CIVILGEOHECRAS program to analyze the impact of structures across the planned river and check dams,
5. Data Analysis Stage: 1) Analysis of land erosion and sedimentation data using the results of the WATEM/SEDEM program to evaluate the potential for sedimentation originating from the upstream Batujai Reservoir, 2) Analysis of hydraulic modeling results to review backwater and inundation that occurs due to buildings across the planned river and check dams,
6. Conclusion and Recommendation Stage: 1) Drawing conclusions based on data analysis of land erosion, sedimentation, and hydraulic modeling results, 2) Providing recommendations for controlling sedimentation in the Batujai Reservoir based on research findings,
7. Report Writing Stage, Preparing a research report that covers all stages and research results clearly and systematically.

5. Conclusion

Based on analysis of land erosion and sedimentation data that occurred in the Batujai Reservoir, as well as the results of hydraulic modeling, this research is expected to provide recommendations for controlling sedimentation in the Batujai Reservoir. In this way, it is hoped that the reservoir's storage capacity can be maintained, and that the reservoir can continue to be utilized to meet various water needs in the surrounding area.

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