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Reservoir saboworks solutions in Limboto Lake sedimentations, Northern Sulawesi, Indonesia

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Abstract

Limboto lake, based on the genesis formation is a low basin or lagoon that also referred to as a type of shallow lakes or lake types of exposure to flooding (flood plain) and located in Gorontalo, North Side of Sulawesi. The main problem that occurred in Lake Limboto is extensive sedimentation and reduction of the lake area. When these issues are not resolved well, the Lake Limboto would bring flood problems and local environment extinction. This research is conducted for obtaining strategic countermeasure for lake age elongation and conservation against sedimentation problems. The methodologies are literature studies, field investigations, field measurements, and collecting of community's aspirations (local intelligences). The recent Limboto Lake Countermeasure Plan should be enhanced by considering original natural function of the lake as flood inundation basin. It was to late to trap sediment inside the lake, therefore sabo technology should be implicated in more effective scheme with public participation. The inside lake sediment transport mechanism with sediment trap and Tapodu barrage water gate installation simulation scenario need to be socialized and studied thoroughly before fully implemented in order to avoiding another possible problems such as larger flooding and ecologic degradation.

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Keywords: Limboto; lake; sedimentation; trigger; solution; saboworks

1. Introduction

Limboto lake, based on the genesis formation is a low basin or lagoon that also referred to as a type of shallow lakes or lake types of exposure to flooding (flood plain) and located in Gorontalo, North Side of Sulawesi. The main problem that occurred in Lake Limboto is extensive sedimentation and reduction of

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the lake area. The process of sedimentation actually has been started since million years ago and had been accelerated until nowadays. In 1932, the area of Lake Limboto reached 7000 ha with a depth of 30 meters. Area of Lake Limboto in 1999 ranged between 1900-3000 ha, with a depth of 2-4 meters. When these issues are not resolved well, the Lake Limboto would bring flood problems and local environment extinction [1].

When these issues are not resolved well in 2025 the Lake Limboto feared would vanish from the earth of Gorontalo. This means that Lake Limboto no longer serve as a place to store excess water from rain water, runoff, and groundwater flow. Lake Limboto can no longer accommodate water from rivers in the watershed [2].

As a result, flooding all the time would threaten the Gorontalo and bury the dream to enjoy the beautiful panorama of Lake Limboto. Several problems that had been identified during conducted field investigation could be grouped into tree main problems categories, as shown at Table 1.

Likewise, analyses of the sediment yield in small reservoir and catchment areas illustrated that the sediment yields decreased with increasing catchment area [3]. The three aspects to be considered in planning sediment removal from a reservoir are [4]:

- The economics of the proposal – the cost of removing, transporting, and disposing of sediment compared with the value of the storage won;
- The environmental impact of the proposed method-the impacts associated with water quality in draw offs and downstream reaches, transportation and disposal of sediment;
- The implications for reservoir operation and water treatment.

Except the Limboto lake watershed surface area, which is approximately 920 km^2, it still has a temporary surface area. In concise, Limboto Lake still have vary coverage area during the time, start from 25 km^2 on dry season until 50 km^2 on wet season. Currently, undisturbed forest coverage covers 20% from cumulative watershed area [1].

Meanwhile, about 66% from the watershed area was used as farm land, mining land, production forest, etc. Therefore, Limboto Lake Conservation is categorized as urgent action with a goal of enhancing its position and function as major live support system for recent and next generation [2].

Survey on Limboto Lake Watershed is focused and conducted to be answers of these finding, “What happen?”, “How it happen?”, and “Why it happen?” related to sedimentation problems in that area. Moreover, this research would give explanation and discussion about the question, would sabo technology could give contribution to be the solution of sedimentation countermeasure in Limboto Lake problems?

This research is conducted for obtaining strategic countermeasure for lake age elongation and conservation against sedimentation problems. The methodologies are literature studies, field investigations, field measurements, and collecting of community’s aspirations (local intelligences).

Table 1. Problem Mapping in Limboto Lake Watershed.

Main Problems Categories		
Lake recovery	Lake functions dwindling	Water resources conservation
Limboto Lake Shallowing	Limboto lake natural function degradation as Flood Retention Basin	Natural protected forest reduction
Limboto Lake Surface Area Shrinking	Lake water quality degradation	Riparian forest reduction
Limboto Lake environmental damage	Fishery and Agro Business Productivity Degradation	Ground water table drop in adjacent area
	Lake Limboto esthetic and human living space function degradation (sports, recreation, tourism, etc.)	Lake Limboto water reservoir capacity reduction
Specific Problems		

2. Theoretical Background

Lake siltation is a common problem that became one of priority research fields on Water Security. Several previous researches that asses similar problems such as in Limboto Lake, had been cited here as theoretical background.

2.1. Sedimentation in natural reservoir

Limboto Lake is not the only Lake that has site specific problems. Similar story of the phenomenon that shows the lake sedimentation process was exposed by Rien, which is Tondano Lake condition. The adjacent lake, Tondano Lake, have a story of sedimentation since thousands years ago that identified by Rien [6]. Limboto Lake sedimentation problem actually influenced with catchment area and hydrologic behaviour.

2.2. Recent sabo works in reservoir problems

We should concern about emergency and small scale action in sheet erosion countermeasure. Morris (2010), provide several comparison about guidance on the type of sediment traps to use depending on expected runoff velocity, cost, ease of construction and duration required, which is hay bales, coir bales, and silt fencing. Detailed specification and explanation about that specific structure could be accessed directly in that paper. She assumes that sediment trapping in water catchments need to be monitored post rainfall to assess their effectiveness in protecting our water reservoirs [5].

Special research about sediment trap efficiency model application in small reservoir had been conducted by Gert. The theoretical-based models are probably more capable of predicting trap efficiency for small ponds with varying geometric characteristics, and some of them also provide data on effluent sediment concentrations and quality compared to empirical model [6].

One important factor that cannot be ignored in lake sediment transport based on Gregory research is turbidity. In summer, values were high and increased from the dam to upstream. Resuspension of bottom sediments is a major cause of turbidity in the lake. Turbidity was highly correlated with the quantity of wind received ('wind value') for the two days preceding the sampling date. The inverse relationship between turbidity and depth had the highest level of significance when the average depth was determined for a 750-m-radius circle around each station [7].

The observed transformations in lake are multidirectional and the entire process varies in changing tropic and hydrological conditions. Based on the research, the increase of water retention in the water body increased the lake area, but at the same time accelerated the sedimentation process of organic matter and gradual lake swallowing at the accompanying expansion of the littoral zone area [8].

Major factors controlling surface sediment composition are related to differences in geological catchment characteristics, anthropogenic land use, and counter-clockwise rotating surface water current. In some instances processes controlling sediment composition also seem to impact distribution patterns of biodiversity, which suggests a common interaction of processes responsible for both patterns [9].

Research on historical progress on lake sedimentation result that agricultural land use has escalated landscape sensitivity to such a degree that modern process rates provide a very distorted representation of process rates that occurred in the geologic past prior to human disturbance. Comparison of erosion and sedimentation rates under agricultural land use against pre-agricultural Holocene erosion and sedimentation rates indicates modern landscape process rates greatly differ from natural rates [10].

Sabo works at glance could be recognized as sediment control and management field. Therefore, sabo technology would be appropriate and need for Limboto Lake sedimentation problems. Based on recent sabo research progress in Japan, nowadays sabo models focused on four main issues: woody debris, landslide dams, slit-type sabo dams, and debris flows [11].

3. Methodology

Limboto Watershed situated on 122° 42' 0.24" – 123° 03' 1.17" East Longitude and 00° 30' 2.035" – 00° 47' 0.49" North Lalitude. Based on state administration, Limboto Lake stated on Gorontalo Province, Indonesia. Limboto watershed area was 910.04 km^2 speeded on and become a home environment of peoples in 9 districts and 70 villages. To accomplish the research's aims, recent water related planning progresses are resumed and then assessed by sabo engineering guidance, field investigation, and community expectation. Field Survey and community expectation collection had been conducted on 23-27 April 2012. In order to confide the result, several sediment transports related parameter trends are analyzed by regression and generalization method. With this understanding, the research result will be considered as feasible recommendation for better sedimentation countermeasure plan implementation.

4. Result and Discussion

Lake siltation had form proprietary land inside lake inundation area. This proprietary area then would be occupied and plotted by nomadic resident as if they have the legal right to that land. They used it for vary reason and business. During the time, that situation result an negative impact, as the Limboto temporary inundated area had been as if individual proprietary. When that situation becomes worst means that slow but sure the people get the right for the land, Limboto Lake area would be progressively reduced. The terrains of Gorontalo Province area, story from local indigenous people, and field inspection are logic prove that historically, most of Gorontalo plain was Limboto Lake area. There was predictably a large tectonic lake that extends from east to west of Gorontalo low plain. Its process of sedimentation had started millions years ago and had leaved, as a result, recent Limboto Lake condition (Figure 1).

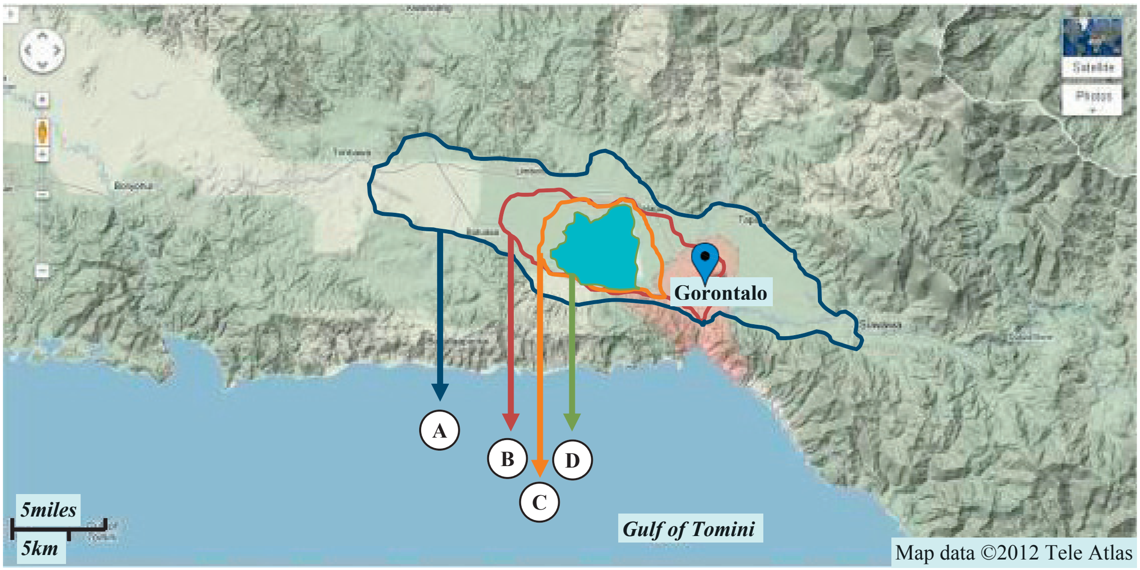

Fig. 1. Historic Sedimentation Process Prediction, Source: maps.google.com

Notes: Lake Coverage, A (Millions years ago), B (Thousands years ago), C (Hundreds years ago), D (Nowadays).

4.1. Lake Limboto Recent Condition

Lomboto watershed recent condition had shown warning indicators of barely watershed degradation. One of those indicators is total sedimentation in the lake. Table 2 and Table 3 had shown total sediment data of 7 sub watershed with high sediment supply in Limboto watershed.

The total sediment load, summaries from suspended and bed load transport, which modeled and approached with USBR (United State Bureau Reclamation) and Einstein Method [2] in 2010. That result shown that recently, Alo Pohu River becomes top contributor to Limboto sedimentation problems. Biyonga, Rintenga, and Bulota River also give about 27.6% of Limboto Lake Sedimentation.

Table 2. Sediment Supply Estimation of Limboto Lake Main Rivers [1].

Sub Watershed Name	Total Sediment Supply (ton/ yr)	%	Sabo Structure Existence	River Capacity (m^3/s)
Biyonga	562.616	8.1	2	83 – 186
Rintenga	613.035	8.9		
Bulota	199.146	2.9	1	
Marisa	731.665	10.6	1	6 – 40
Melupo	205.318	3.0	1	18 – 93
Alo Pohu	4.421.870	63.8	2	115-198
Talubango	193.383	2.8	3	
Total	6.927.032	ton/yr		

Based on the field investigation, it had been found that sediment comes from river bank sporadic land slide and sheet erosion. Firstly, the sediment settled on mountain and hill toe. Hereinafter, the sediment deposition would be transported by the flood or sufficient flow towards river channel. Therefore the sediment volume has a positive correlation with river flow capacity.

In a long river, the coarse sediment agradated before reach the lake, whether some amount suspended load keep flowing through pass until limboto lake, which make sedimentation spots around the lake (Figure 2). That figure support previous statement that around Limboto Lake, there are a lot of illegal settlement. The settlement had been flooded when lake surface elevation is 4.5-6 m asl.

As an exception, deepest lake depth area still cannot been examined, but it has been predicted that the lowest spot stated around 0 m asl. Lake surface elevation when measurement had been conducted was 3.24 m asl. That map was a compilation of field survey by Limnology Centre, LIPI October 2006 with several map sources that were Indonesian Terrain Map (RBI, Bakosurtanal, 1:50.000), Year 1991, and TM Landsat Image Year 2002.

Table 3. Sediment Transport Related Factors of Limboto Lake Main Rivers [2].

Sub Watershed	Area	River Length	Erosion	Sediment Volume	Bed Material	Sedimentation Indeks	Bed Load Contribution
	(km^2)	(km)	(ton/th)	(m3/th)	d_{60} (mm)	(Is)	%
Biyonga	60	12.83	367.142	11045	0,48	0,1515	56.000
Meluopo	27	5.23	61.671	6167.09	0,61	0,0679	24
Marisa	64	11.28	78.683	7867.74	0,61	0,0102	4
Alo	342	13.03	249.936	12876.21			
Pohu	124	19.59	216.266	18750.45			
Rintenga	53	18.4	34.116	2957.89			
Talubongo	20	10.22					
Bulota	25	9.17					
Alopohu	150	3.62			0,67	0,0426	16

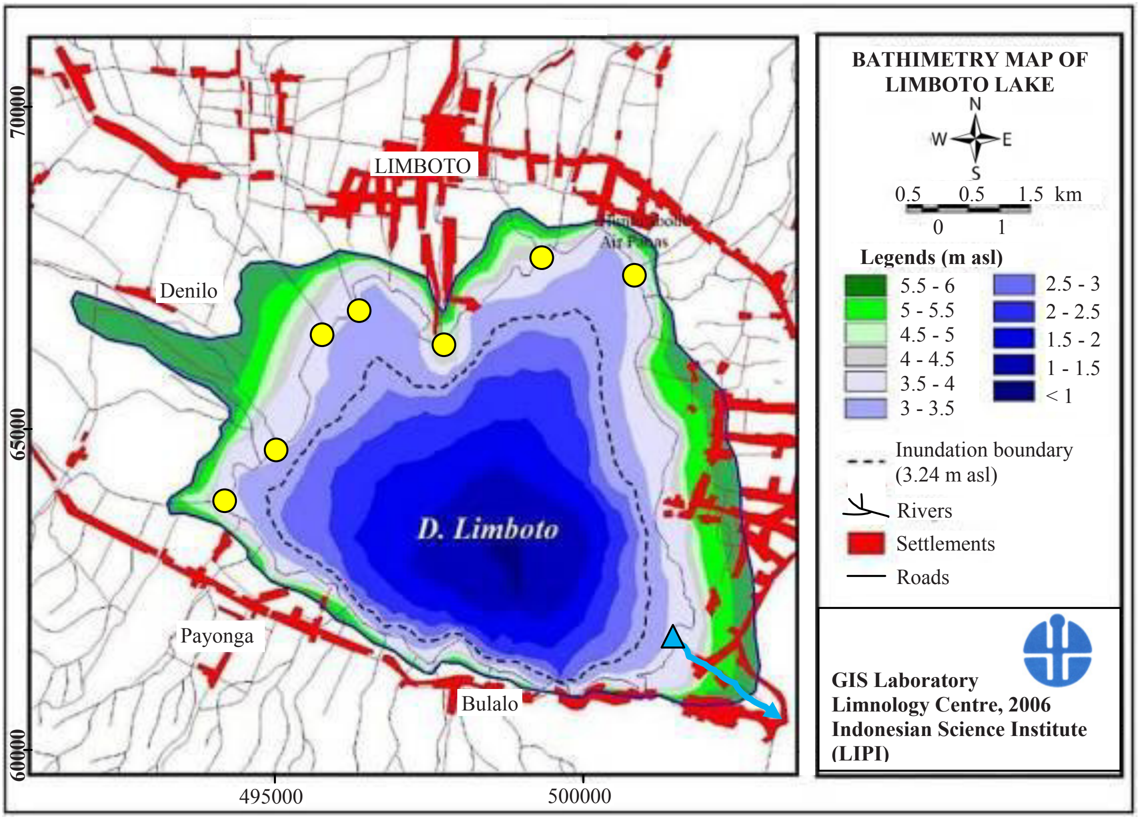

Fig. 2. Schematization of Sub Watershed Coverage of Limboto Lake Main Rivers
Note: Main Sediment Transport Inlet symbolized by ○ and Sediment Transport Outlet by △.

4.2. Lake Limboto Masterplan

The main water related master plan of Limboto Lake Sedimentation Problems is focused on five main points (Figure 3), which are inside lake body sediment trap, Tapodu barrage water gate, Lomboto Greenbelt Lake Boundary, sediment dredging, and sabodam (sediment catchment dam) in high sedimentation river in Limboto Watershed [1].

West Sediment Trap capacity 2.615.869 m^3 designed to accommodate Alopohu, Marisa, and Moluopo River sediment supply (Qs= 3.726.601 m^3/ year), which would be full in 0,72 year or 8,6 months. Meanwhile, East Sediment Trap capacity 6.574.794 m^3 designed to accommodate Biyonga, Bulota, and Talubongo River sediment supply (Qs= 664.218 m^3/ year), which would be full in 8 years. The sediment traps need the maintenance effort that is annual dredging of ± 6,574 million m^3 materials per year [2].

Based on the field investigation and public interview, the dredged material would be dispose in lake edge. It had been found that this work is very sensitive to social conflict if it do not equipped with dredged material using authority regulation [12]. The inside lake sediment transport mechanism with sediment trap and Tapodu barrage water gate installation simulation scenario need to be socialized and studied thoroughly to avoid other potential problems like flood and ecosystem degradation.

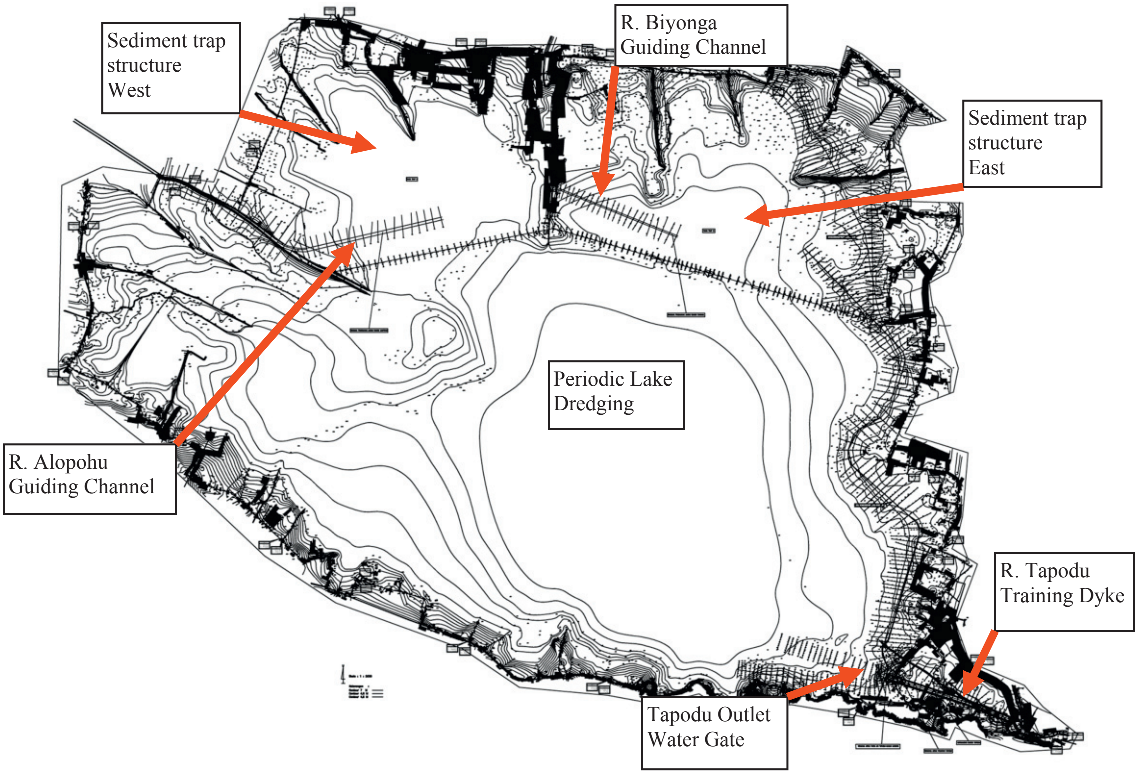

Fig. 3. Schematization of Sub Watershed Coverage of Limboto Lake Main Rivers

4.3. Key factor of implementation

A water related project could have a good success result probability if the river equilibrium condition could be maintained. A balance sediment transport scenario should be referred in river engineering planning. Naturally, there is a sediment transport mechanism in a lake, but when the sediment balance was disturbed (excess sediment supply), the sediment would settle inside the lake. Therefore, the plan on installing Tapodu barrage water way in Limboto lake outlet should accommodate lake natural sediment transport mechanism.

The origin of Limboto Lake existence was as flood retention basin. If this function replaced by sediment trap function, naturally flooding problem would be happen, except we could built training dyke all around the lake. Without good commitment and mechanism in annual lake dredging enrolment, inside lake sediment trap just would be new proprietary land for nomadic residence as proven before.

Based on sabo engineering theory [13] and application experience, it would be more effective when sediment collection is conducted before it reaches the reservoir, for example by sabo dam function enhancement. The existing sabodam in Limboto watershed had shown a good effectively in trapping sediment, such shown by Biyonga River Sabodam that had been full capacity with stone and silty coarse material. Sand pocket structure and settling pond would be a good alternative beside of inside lake sediment trap because it catch sediment before it flow farther. By this phase, community empowerment on sand and stone mining would be complementary project beside of annual dredging activity.

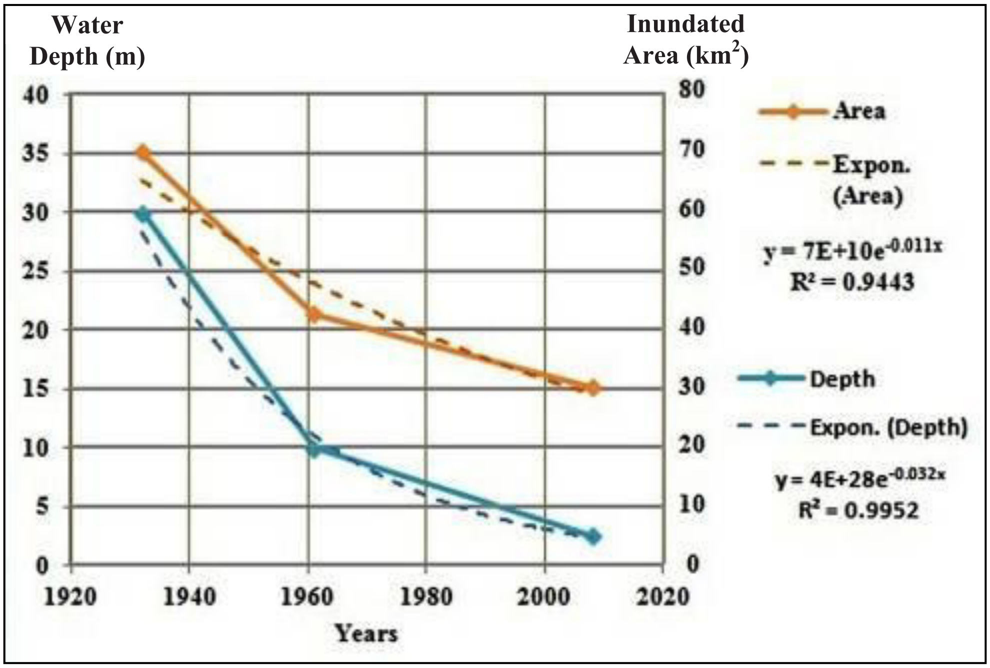

Fig. 4. Schematization of Sub Watershed Coverage of Limboto Lake Main Rivers

Based on historical data of area and depth dynamic of Lake Limboto, an exponential regression equation that explain area and depth reduction versus time had been displayed on Figure 4. The equations are detailed in Equation1 and Equation 2, where A (km^2), h (m), and t was representative of lake area, lake depth, and year.

$$A = 7 \times 10\text{^}(10e^{-0.01.t}) \quad (1)$$

$$h = 4 \times 10\text{^}(28e^{-0.03.t}) \quad (2)$$

So when there are no adaptive action to manage Limboto Lake sedimentation, based on Equation 1 and Equation 2, in 2025, inundation area in Limboto Lake would just remain 7 km^2 by the depth of 4 m, an apprehensive condition that called lake vanish event.

Good comprehension on specific river characteristic would be very helpful in considering the appropriate solution for sediment trapping problem. In all river downstream point, which river water entering the lake, the river slope are very small, means that the river is flat. As a case study on downstream Marisa River, the water velocity is about 28 seconds for 3 m distance or about 10.71 cm per second (floated leave method). This condition makes the flow is calm (Figure 5) and prone to sedimentation. On the other hand, these conditions need thoroughly consideration in considering cross ricer structure elevation in order to avoiding flood caused by backwater effects [14]. The other specific case also shown by Alo River that has small river slope and short upstream peak (around 150 m asl). These river characteristics lessen water capacity in transporting coarse sediment. The long length of Pohu River reduce coarse sediment from its early upstream and provide sufficient space for river structural sediment controlling works (Figure 6).

Fig. 5. Visual condition of Limboto Lake input river downstream flow characteristic

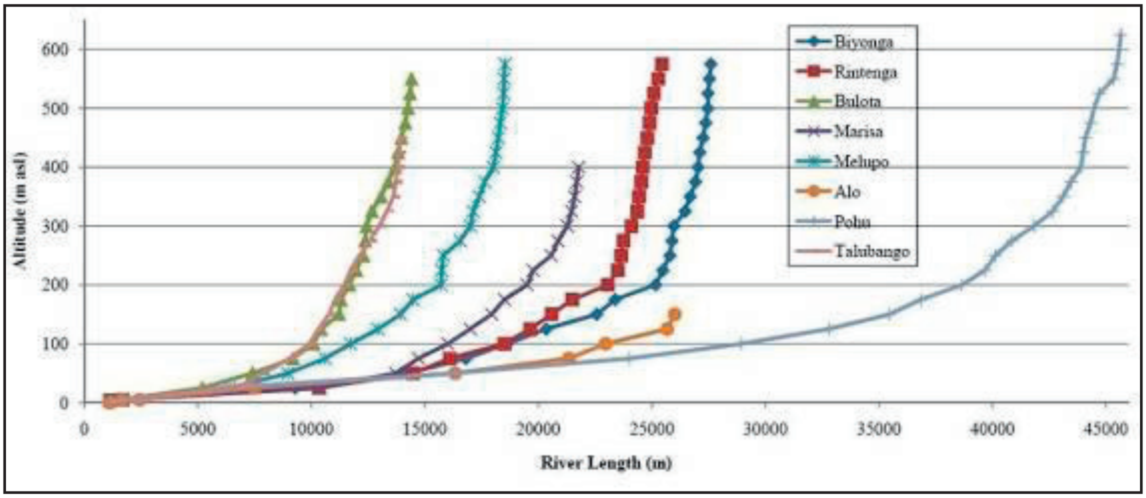

Fig. 6. Long profile of 8 (eight) main river on Limboto Lake watershed

The existence of riparian forest also needs to be maintained because of its function as river flow splitter [15]. Based on field investigation, there is a sufficient sediment deposit on riparian forest adjacent location. It also absorb nutrient from suspended sediment for its food, therefore trap an amount of suspended load that transported in river flow.

5. Conclusion

The recent Limboto Lake Countermeasure Plan should be enhanced by considering original natural function of the lake as flood inundation basin. It was too late to trap sediment inside the lake; therefore sabo technology should be implicated in more effective scheme with public participation. The inside lake sediment transport mechanism with sediment trap and Tapodu barrage water gate installation simulation scenario need to be socialized and studied thoroughly, for example by using HEC-HMS v4.0 new tools for sediment and water quality modeling [16].

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