An ecohydrological-based management of Lake Beratan in Bedugul, Bali

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Abstract. Lake Beratan is one of waterway ecosystems located in the upper land of Bedugul, Bali and has become a tourist object which is visited by many foreign as well as domestic tourists. This is supported by a sufficiently high economic growth which, without the community's being aware of, has caused environmental problems such as the shallowing of the lake, erosion, and water pollution to such an extent that have resulted in the degradation of the function of the lake as the site of catchment. The degradation of the function of the lake can be overcome by ecohydrological-based management. This study was aimed at developing an integrated and long lasting Lake Beratan environment management concept. The study used a descriptive qualitative approach using a survey, by collecting primary and secondary data. On the basis of those data the mapping of the potentials of the lake and problems of the lake which were then integrated to formulate criteria for sustainable use of Lake Beratan waters environment resources. The determination of zonation of the lake was done based on those criteria and the community's existence consideration as well as the exising system of the lake waterway environment use. Based on the study in the field, some recommendations could be made concerning Lake Beratan waterway sustainable and integrated management.

1. Introduction

Ecohydrology studies the interaction between hydrological factors and biota components in an ecosystem and uses the interactional models as the basis for managing the environment, both the hydrological aspects such as water resource conservation, flood control and the biota aspects, especially an effort of conservation and management of the sustainable environmental productivity. Ecohydrological studies for water resource management study ecological factors that consist of vegetation system and land use in the area as the exterminating factors of water system condition in the area [1] [2].

Various ecohydrological studies for water system management environment use hydrological factors as the regulator of ecological integrity which determines the formation of various types' habitat, biodiversity, and productivity of water system environment. [3] uses ecohydrolic approach to develop the dynamic model of the habitat of fish benthic organism as the effect of water system management board action.

Lake Beratan is surface water resource which is very important ecologically, because it plays role as rain water holder in Bedugul high land. Economically, the role of the lake is very vital, since its function as water source for the people around the lake for drink, agriculture, fishery, and tourism object [4]. The presence of Lake Beratan gives an important benefit to the environment, especially as hydrological link, in

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addition to being the source of revenue for the regency through tourism sector. On the other hand, the increase in economic activity in tourism sector, industrial sector, and agricultural sector cause various problems, such as damage to watershed area, environmental pollution, the siltation of lake, and erosion [5]. The risky activities which cause worsening of lake water resource quality are waste dumping from hotels, households, agricultural waste, and oil waste transported by the water. In addition, there is a need for giving attention to the use of land around the water resource boundaries which cause damage to the environment [6] [7].

Lake Beratan today receive a high pressure, that is high sedimentation, domestic waste pollution and the rapid development of floating net cages fish farming [8] Based on the result of Quickbird Satellite Image analysis in 2005, the surface area of Lake Beratan was 3.827 km^2, while the result of Quickbird Satellite Image Analysis in 2014, showed that the surface area of Lake Beratan was 3.764 km^2. In the nine years time, the decrease in the surface area of the lake was 0.063 km^2 (1.65%) and automatically reduced the lake water volume because of the sedimentation. The sedimentation was caused by high rain fall, young soil structure, and damage in land use system in Lake Beratan rain fall catchment area. A further impact of the problem was damage to the lake water system habitat which caused a decrease in biodiversity [4]. The effort to save the lake water system environment needs to be done, which included the restoration of the lake water system environment as the habitat resources of various water biota and sedimentation rate control. This study was aimed to develop an integrated management concept of sustainable lake water environment

2. Methods

The study was conducted in Lake Beratan of Tabanan Regency, Bali. This study used ecological approach and survey method using instruments such as close-questionnaire. The ecological approach in this study emphasizes the interaction between human actions on the environment [1]. The study used primary and secondary data which consisted of hydro-climatological aspects, water system physical, chemical, and biological aspect, socio-economic aspect, and lake management institution. Based on the data, the mapping of potential and the problems of lake environment were conducted which were followed by the integration to formulate criteria of sustainable lake water system environment resource.

3. Result and Discussion

The sustainable management stressed the important of the efforts of creating the lake's water system resource function to support the life of the people around it (Act No. 7 of 2004). In general, the functions of Lake water system resources can be classified into two big groups which are closely related to each other, that is ecological and socio-economic functions. Ecologically, lake system is an ecosystem in an area in which ecological cycle occurs. The ecological cycle in general is a chained process that occurs among the components in the ecosystem.

The socio-economic function is the function which directly supports the life of community around the lake, such as fishery, transportation, and housing. The socio-economic function depends very much on the lake water system ecological condition. In the sustainable lake water system management concept, the importance of ecological and socio-economic functions is considered fairly and in an integrative way, in which the degree of the lake water system resources used has to be taken into account in order not to exceed the water system environment capacity.

3.1. Biophysical characteristics

Based on the result of a survey in 2015, the maximum depth of Lake Beratan was 20.0 m and the average depth was 12.8 m, while the water surface area was 3.76 km^2 and the catchment area was 13.49 km^2. With those measurements, the lake water volume was 46.22 x 10^6 m^3. The hydro-climatological data shows the

relation between water surface height and rainfall in water catchment area, the annual fluctuations of water of lake Beratan in dry months were +0.37 m and -0.27 m where the fluctuation rate was 0.74 m, while in wet months the fluctuations were +0.63 m and -0.67 m or the average fluctuation rate was 1.30 m. The highest inflow which occurs in February was 1.02 m^3/sec and the lowest in September was 0.03 m^3/sec. or the average was 0.37 m^3/sec. The highest outflow occurs in February which was 0.97 m^3/sec. and the lowest in November which was 0.13 m^3/sec. or the average is 0.34 m^3/sec. The highest storage occurs in December, which was 0.50 m^3/sec and the lowest in April, which was 0.09 m^3/sec. or the average is 0.03 m^3/sec. For the detail, see figure 1.

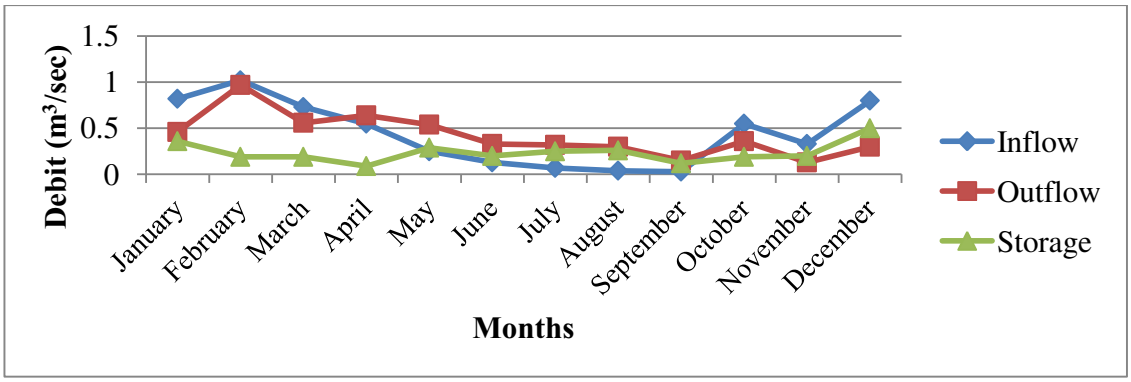

Figure 1. Inflow, outflow and storage in Lake Beratan.

The main problem of Beratan Lake water system environment is the high sedimentation rate which is 320.51 ton/year which causes the very rapid lake siltation process. Based on the 2005 and 2015 Quickbird Satellite Analysis, in ten years time, the decrease in the lake surface area was 0.09 km^2 which automatically reduces the lake volume. In plain view, the sedimentation process produces raised lands which spread in various parts of the lake water system which then stimulates the growth of riparian vegetation and the lake edge that is adapting to dry water condition characterized by the domination of wide leaf decorated grass (*Pennisetum Purpereum)*, coarse grass. While, the water turbidity level with solid suspension value reaches 18 mg/l which also causes the loss of some vegetation plants in the lake water body. Lake Beratan water fertility index shows eutrophic water system status caused by the load of organic sediment pollution from source stream through agricultural areas and residential areas around the lake. The high organic sediment pollution level is indicated from the abundance of benthic biota, especially from Tubicidae class at the lake water system bed, beside the floating net cages fish farming which also has the potential for increasing organic sediment pollution.

Based on the result of Beratan lake water quality analysis in 2015, it can be seen that the water quality is still good enough, almost all of the parameters show that the water quality standard in category A. Only Florida (F) parameter, pH and Coli bacteria show that they exceed the maximum parameters recommended, but the impact from various activities and infrastructure which have been rapidly developed around Lake Beratan have to be supervised. It does not preclude the most serious impact in the future on the existence of the lake itself. This is indicated from the examination that shows that some parameters have exceeded maximum levels. The aquatic flora and fauna of Lake Beratan generally grow as the ecosystem components of the volcanic lake, in general with low level of biodiversity. Based on the survey resulted in 2015, there are 13 species of water plants in the aquatic ecosystem of lake Beratan (*Cyperus ferax, Gygantochloa nerticilat, Panicum stagninum, Hydrocleis nymphoides, Eichomis cracifes, Panicum chamaerthaphoid, Commelina caestitosum, Polygonum caestitosum, Althenanthera sissiles,*

Althenanthera philoxeroi, Cyperus fria, Leersia hexandra, Ludwigia ascendes), 8 nekton species (*Cyprinus carpio, Puntius javanicus, Oreochromis mossambicus, Orechromis nylotucus, Clarias batrachsis, Monoptera albus, Rasbora trillineaota, Osteochilus hasselti*), 18 phytoplankton species (*Goniochloris, Osilatoria, Nostochopis, Thorea ramassisium, Tribonema, Enteromorpha, Rivolaria, Nostoc, Dinobryon, Clorobotrys, Chamaeshipon, Pediastrum, Ulotrik, Diatomae, Basicladia, Amphitrix, Gloetrichia, Goniochloris*), 9 zooplankton species (*Cyelops strenuous, Paramaecium, Euglena, Lepocinelis, Oithona, Dyatilis,Hyperia, Luciper, juvenile*), and 11 species of benthics (*Ephemera donica, Olygoceta, Lompsilis, Actinoneaceae, Anodonta, Pomecea, Balimus, Aeshna, Tryonia, Planorbis, Viviparus*).

The estimated productivity of fishery of Lake Beratan varies depending on the depth of the lake and the level of fertility of its water system. Thus, the control of the area and the depth of lake water body are very important in managing the fishery sector in the lake. Fish production of Beratan Lake in 2015 was 361.6 ton which means 57.7% of the general water system fish production. In addition, in the lake water system has also developed floating net cages fish farming which has not been harvested so that we do not know the production.

3.2. Social economic condition

The residential areas around Lake Beratan are relatively developing with good infrastructure. The lake is surrounded by three villages (Kembang Mertha, Candikuning 1, Candikuning 2). The statistic in 2015 shows the total population of three villages 4.377 with the density rate 257 people/km^2. In general, the people who live around the lake use the water directly for domestic needs through Municipal Waterworks (PDAM). The road infrastructure is generally good up to the residential area at the edge of the lake, so that the people around the lake have a very good access to various basic necessities which can be bought at Candikuning Village. Similarly, electric energy and petrol are distributed well to the residential areas around the lake. The developing infrastructure is an attraction for people who moved to the residential area around the lake. As the result, the rate of population growth will be more rapid and increase the pressure on the lake ecosystem.

The development of the residential area runs parallel to the development of agricultural tourism activities around the lake. People use the protected forest land and raised lands for agricultural field. Based on the survey in 2015, the raised lands have the area of 0.06 km^2 which have been used for growing wide leaf decorated grass as cow feed by the local people while the protected forest land of 6 Ha has been used for growing corn, chilli, string bean, banana, and cassava. The farming is done intensively as shown by the use of pesticide to control pest. The presence of the agricultural field needs to be supervised because of the presence of pesticide residue and nutrient waste which are carried by runoff entering the lake water system.

Socio-cultural survey recorded a relatively good social capital to support the lake water system environment development. This is shown by the high level of trust of the people in the government, and the high level of solidarity among community members. Similarly, there is a law or *adat* village regulation which becomes reference in managing lake water system environment, so that until now there has been no conflict among people.

3.3. Lake Beratan management strategy

The FAO (1976) concept of water resource management suggests the division of river area management into three clusters, that is village area management, watershed sub area management, and watershed area management. When it is implemented in lake water system environment management, the concept can be placed in the context of village area management or watershed sub area, in which people's participation is very important as a subject and at the same time the object of lake water system management. The lake

water system management has to cover coordinating efforts to achieve sector objectives optimally by considering the holding capacity of the lake water system environment. Information knowledge about lake water system ecosystem, which includes the component structure and ecological process as well as the community social-economic are needed both for determining the limit of the environmental holding capacity and for determining the value of interest of each sector involved. For this reason, there is a need to develop the lake water system management institution which is participative in nature, in which the government through the related department or offices plays an important role as the facilitators. The actions that need to be done are:

- The empowerment of people through the socialization activities concerning the rules for managing the lake, educating people on the functions of the lake environment.
- Developing a monitoring system and evaluation of the lake environment which is integrated with the lake environment information system.
- Forming a forum for coordinative meeting which involve all the shareholders to write the framework and the structure of institutions.
- Attempting to have a legal agreement in the management which has been determined to become an Act, Government Regulation, and Legally Binding local regulation.
- Implementing the policy and strategy to achieve the objective and writing a master plan for the lake water system area, in writing the master plan, the local people have to involve to gather with the government, the stakeholders and relevant experts.

The lake water system management needs the division of water system area into zones of use which are agreed by all parties involved. In the context of integrated water management (IWRM) World Lake Forum divides the functions of lake water system into four zonings, that is, tourism, residential area, fishery and transportation, the context of sustainable development prioritizes socioeconomic functions, while the consideration from the ecological function perspective gives more stress on water resource conservation and biological resources as the integral part in the creation of the sustainability of socio-economical functioning condition.

3.4. Functions of Lake Beratan

The development of lake functions criteria is intended to optimize the use of human resource potential for the sustainable welfare of the community. In developing lake functions criteria, sector grouping is required to facilitate their application, and has to consider the relations among the sector components to maintain the continuity of the ecological process which is the basis for the sustainability.

3.4.1. Tourism. [11] states that one form of a lake ecosystem management is based on the wet land national strategy, that is, by putting aside a part of the area which has protected endemic and unique bio natural resources to be developed into a conservational area. Hence the tourism criterion consists in the use of various resources and characteristics of the environment. Every lake water system is unique. As an attraction, the lake water system offers some categories of tourism products with different market shares. Lake is not a single destination but is an attraction with other tourism objects.

The activity of tourism in Lake Beratan is associated with natural and cultural tourism object, which is more oriented toward ecotourism. The attractions offered in Lake Beratan such as parasailing, banana boat, ski boat, trekking using a bike, travelling around in boat and fishing. Cultural attractions which can be presented are temples and mosques in addition to the farmers' activity in the field which are also enjoyed by foreign tourists, then, there also scientific tourism in Bedugul Botanical Garden which is managed by Indonesian Institute of Science (LIPI).

3.4.2. Animal Husbandry. Farmers around Lake Beratan besides growing crops in the dry land, also raising cattle such as cows, goats, pigs, ducks, and chicken. Most of the farmers raise cows and goats because they are easier to rise and it is easy to find feed for them. Farmers use sediment land and empty land to grow wide leaf decorated grass (*Pennisetum Purpereum).*

3.4.3. Agriculture. Agricultural sector depends on the availability of fertile land and irrigation system that continues on along the year with enough water supplies while from the environmental aspect, there is a need for cultivation technology that produces the least waste (FAO, 1976). Agricultural activities in catchment area in Lake Beratan are done intensively and the area belongs to a dry agriculture land. Farmers in this area grow crops such as cabbages, mustard greens, green vegetables, broccolis, salad, string beans, eggplants, cucumbers, potatoes, carrots, chillies, paprika, cassavas, corns, strawberries, oranges, and coffee. Thus, various treatments with agricultural activities such as fertilizing and using pesticide have a direct effect on the lake environment.

The effort to overcome the impact of agricultural waste can be done by protecting the lake water system with wet land vegetation which serves to absorb pollution from humus and pesticides before the runoff from the agricultural land enter the lake. In relation to the need for water resources, the lake water body can be considered as water reservoir for dry season.

3.4.5. Residential Area. The criteria of the residential area function are based on three main factors, namely: security, health, and comfort. Lake water system environment area is flooded regularly along with the rainfall in rainy season. This problem can be anticipated by selecting a higher location from maximum water surface and by selecting a house design that is adaptable to the flood.

Health factor is related to the availability of clean water resources for drinking and bathing, washing, and using toilet, sanitation system, both liquid and solid waste, and the risk of disease epidemic. Health factor is closely related to the holding capacity of lake water system. The community around Lake Beratan generally uses lake water directly for households, the potential for the pressure from household waste and also pollution into lake water system should be watched out.

Comfort factor is related to the accessibility of residential location to public facilities such as schools, hospitals, markets, jobs, and transportations. Residential areas around Lake Beratan have generally been equipped with transportation to obtain the basic necessities of the people.

3.4.6. Transportation. The criteria of transportation function needs to consider security, comfort, to smoothness of the traffic, and efficiency factors. The four factors are related to three elements, namely: biophysical condition, water system, and people who use the transportation and the vehicles used. The biophysical aspect of water depth determines the smoothness of transportation traffic, so that the effort to maintain the lake water system at a certain depth level according to the capacity of the means of transportation which will be developed have to be done.

Water flow determines the security and comfort of water transportation; thus, the determination of water transportation route needs to consider the patterns of water movement to select secured route. The effect of climate on water movement pattern needs to be considered since strong wind can cause dangerous water waves for small boats used for transportation. The development of shelters along the transformation route needs to be done to protect people who are trapped in a dangerous condition. Another thing that needs to be considered to develop water transportation is anchoring facility in the public area, like parking lots for cars that are safe and comfortable.

3.4.7. Fishery. The fishery function in the lake water system has to consider fish eco-physiological aspect and the variety of species, water system environment condition, and the condition of the community who

get the benefit from fishery resource management effort. The first principle is that fish is viewed as resources since it gives benefit. From the view of the variety of types of fishery development in Lake Beratan is focused on fishery for food, while fishing can be done as part of lake tourism development.

According to [6] [7] water resource living environment cycle can be divided into 4 types of habitat, namely spawning ground, nursery ground, feeding ground, and playing ground. Fishery resources in Lake Beratan water system can be divided into two big groups, namely: lake local fish and introduced fish. Lake local fish is the native fish in the lake water system such as *Osteochilus hasselti, Rasbora trillineaota, Monoptera albus.* The introduced fish is introduced in the lake water system to increase the lake productivity; these include *Cyprinus carpio*, *Puntius javanicus*, *Oreochromis Mossambicus*, *Orechromis nylotucus,* and *Clarias batrachsis*. The development of floating net cages fish farming needs lake water system as water resource for media for fish growth, for this purpose, there is a need for good water quality that is suitable for fish growth, the adequate amount of water and water circulation that keeps oxygen supply in water and removal of feed waste and metabolism.

3.4.8. Zoning. Zoning in the lake is based on the function criteria of the lake to optimize the use of resource potential for the continuous welfare of the people. Zoning also considers the availability of zones, forms of zone proposed and their spread in Lake Beratan water system which can be seen in figure 3. Some forms of zoning are synergistically oriented to increase the productivity and preservation of fishery resources in lake water system which consist of the development of the edge of the lake and riparian vegetation, the development of zone of artificial wetland, and the management of floating net cages fish farming. These zonings are also oriented to control the inflow and distribution of waste in the lake water system. In addition, it is also proposed to determine lake's boundary areas by considering the condition of residential areas and the existing infrastructure.

Lake water fluctuation is a factor which plays the most important role in determining the zoning of the lake, and to accommodate the possibility of using the lake function as water resource conservation area, the development of zoning is done in some alternative lake water surface heights and the optimal water surface level suggested is 0.74 m from the zero surface level of Lake Beratan water. The effort to manage the lake water system environment needs to implement environment engineering technology, especially to adapt the water system condition to the changes of the environment which have been occurring. The aim of implementing environment engineering is to use as maximally as possible the lake water system resources in a sustainable way for the welfare of the community.

4. Conclusion

Based on the result of the study that has been done, briefly it can be concluded that: The lake management should be done in an integrated way between the central government and the local government by involving the community to participate actively. The management is done to maintain lake water potential sustainability. The actions that need to be done are: The empowerment of people through the socialization activities concerning the rules for managing the lake, educating people on the functions of the lake environment. Monitoring system and evaluation of the lake environment which is integrated with the lake environment information system could be developed. Forum for coordinative meeting which involve all the shareholders to write the framework and the structure of institutions should be arranged. Legal agreement in the management which has been determined to become an Act, Government Regulation, and Legally Binding local regulation could then be implemented. Implementing the policy and strategy to achieve the objective and writing a master plan for the lake water system area, in writing the master plan, the local people have to involve together with the government, stakeholders and relevant experts.

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