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WATER RESOURCES POTENTIALS OF INDONESIAN LAKES, AN ECOHYDROLOGY APPROACH

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ABSTRACT

Indonesia has more than 500 lakes, some larger ones have been exploited for hydropower generation, for fisheries, irrigation, domestic water supply, transport, but many small and remote ones are still maintained and kept by nature. The origin or genesis of lakes greatly determine its physical properties hence its management style. Lakes may be grouped into tectonic, caldera, volcanic, fault related and combinations, by karstic or dissolved rocks, flood plain, or by subsidence in origin. Several lakes has been exploited without an adequate management plan such as Lakes Toba, Maninjau, Rawadanau, Tempe, Tondano, Limboto, and Sentani. Others are facing increasing pressure such as Lakes Kerinci, Ranau, Lindu, Poso, Matano, and Enarotali.

Until recently limnological surveys on Indonesian lakes were executed through sectors or discipline approach by different departments such as the public works, mining and energy, interior and health, and by R&D institutes such as LIPI and Biotrop. The results may be proper for each of their own sectors but not for an integrated management plan.

Key words: lake management; ecohydrology; lake carrying capacity

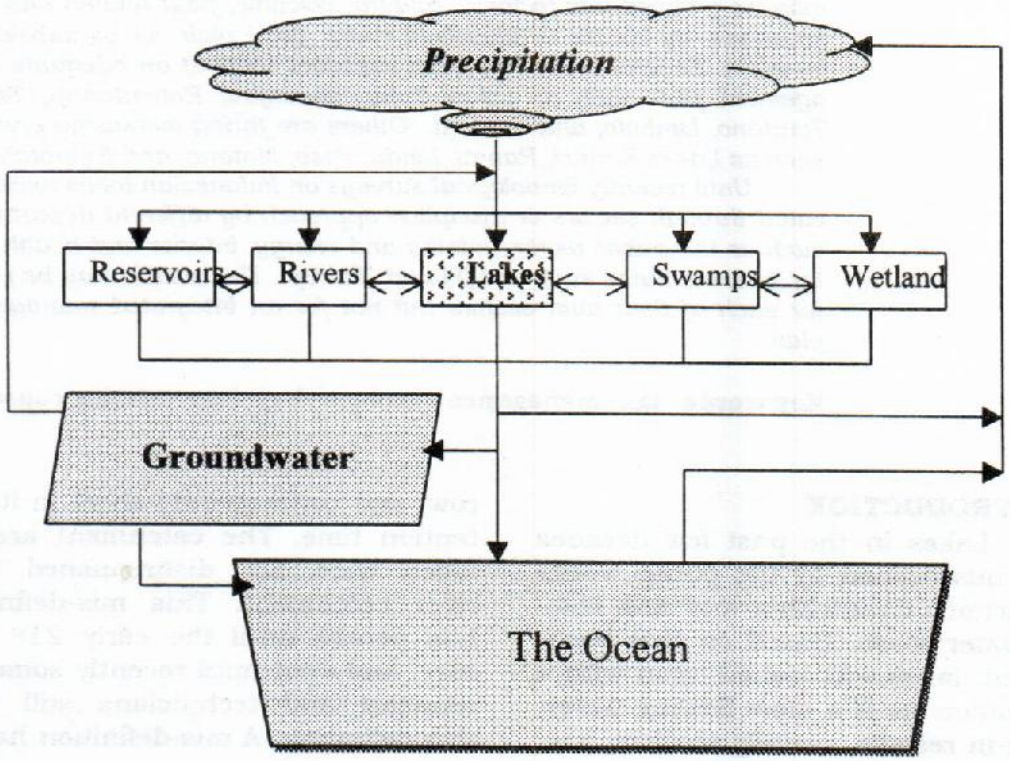
1. INTRODUCTION

Lakes in the past few decades were mis-defined by the public works as part of a river with a very slow flowing water mass. Based on this background, lakes was looked upon with a perception as if a slow flowing water, small in reserve, usually shallow, narrow, and consequently short in its retention time. The catchment area of lakes were not distinguished from river catchment. This mis-definition has persist until the early 21st century, and even until recently some bureaucrat and technicians still used this definition. A mis-definition has no

effect until it create a major management problem. As example is the long debate between the state electric company and people around lake Maninjau in Sumatera island on the origin of sudden fish kill(s) in the lake water. The electric company claimed that they did nothing wrong to the water mass, they only channeled the water into turbines. Local people claimed the outflowing river went dry and there is no more lake water fluctuations to supply the wetland ecotone that are the cause algae blooms in the water body. Both sides have right things they claimed but both sides also saw only part of the overall lake and catchment ecosystem that in reality has a very intricate interaction between the components.

Lakes are different in their geological origin and related ecological composition compared to rivers and reservoirs. Lakes are older in their creation history and are surrounded and filled with unique ecosystem components. The water retention time of most lakes may go up to years and even decades while retention time of rivers and reservoirs are in the order of days, weeks, or up to a few months. This difference in retention time bring

Figure 1. Simplified natural water routes into and out from lakes.



along different management consequences. Take an event of pollution into a river that can be observed visually and can usually be cleared up in a few days or weeks with flowing water. While pollution into a lake seldom shows direct effects and clearing the polluted waters takes a long time in the order of years to decades.

Because of the mis-defenition, lakes in the past few decades has been looked upon only as a great water body located in the high mountain ranges ready as a giant natural potential for power generation. This perception is not wrong if it does not bring along management problems related to the sustainability of these lakes, its water, faunal content of the ecosystem, and the surrounding catchment area. Sustainability and environmental carrying capacity of lakes should not be measured with the same stick with those of rivers and reservoirs. This paper with an ecohydrological background try to introduce the other side of ecosystem differences between rivers and lakes.

The ultimate aim is that during the planning phase for a lake exploitation it should be figured out and include in their plans all other components of the fragile lake ecosystem. With this approach it is expected that major lakes in Indonesia in the future will be less negatively effected or damaged and have a sustainability plan to withstand the antropogenic pressure put upon them. Figure 1 shown above is a generalized natural water routes into and out of lakes. Lakes are filled by water routes from precipitation, rivers, springs, and seepage from groundwater, on the other end it provide water to rivers, swamps, wetland, springs, and it has the capacity for recharging groundwater.

2. LAKE ORIGIN AND FORMATION

Indonesia is located in a geologically active tectonic region that created a situation where there are a great variety of lake origin. A list of lakes listed according to its size is provided in table 1.The source for making this list is from various authors and different years resulting into the fact that values of transparency may differ. In nature there are lakes that have a close genetic / origin related to tectonic origin such as lakes formed by faults and graben, both tectonic of origin, such as Lake Singkarak and Lake Matano. There are lakes formed by volcanic and related activities such as caldera formation, combinations of a volcano and tectonic depression, or they may be formed due to post volcanic activities such as the collapse of an old volcanic complex, three examples are represented by Lake Batur, Lake Toba, and Lake Bratan-Buyan-Tamblingan complex.

Other lakes in Indonesia were formed due to subsidence due to solution of the limestone or karstic rocks such as several small lakes in Kei Kecil island, Biak, and in Wonosari. There are cave-lakes in Saparua island which are underground solution caves that are important fresh water source for the local village population. Some lakes were formed due to landslides or by laharic flow that in the past that covered an existing water

way or river which then create a lake in the upper catchment area as shown by Lake Ranau and plaeo-lake Bandung. On the other end of the group we have shallow lakes that may be formed in the wide and low coastal plain, and others are formed in the broad flood plain of a geologically mature river. Examples are the 2000 sq.km Ogan Komering lake-swamp and the low lying Lake Tempe complex. Estuary lakes may be formed near the coast where strong longshore currents create mouth-bar sedimentation resulting in an elongated bar parallel to the shore, which at the end of its formation was closed from the sea. An example of this are the many small elongated lakes are in the southern coast Mimika region Papua province.

Lake genesis are important first step observations into the study of lakes, it is the primary criteria that determine the physical properties of a lake and its surrounding catchment area. Most of tectonic lakes are located in mountain ranges that has been geologically uplifted and faulted. These areas consist of old rock formations which are solid consisting of steep slopes. The tectonic sutures determine the morphology, the flow pattern of rivers, and the morphometry of the lake and lake bottom. Volcanic and related tectonic activities will form lakes that are located in the vicinity of the volcanic rock complex. The type of parent volcanic rocks determine the soil type, an acid volcanic rock such as the tuffs around lake Toba and Maninjau are less fertile compared to the basic volcanic rocks or andesite and basalts that formed the lakes Bratan-Buyan that has weathered into fertile soils and consequently also a rich biological diversity.

Subsidence lakes are usually not very large in size but they usually consist of steep lake walls, a high water level fluctuation between rainy and dry season, and formed in limestone areas. There are examples from Kei Kecil island which are endorheic lakes with no rivers flowing out of it, they are basic water with a pH of 9. Other examples are small lakes in Biak island and in Wonosari which are filled with water during rainy season but tend to dry during the dry season, they show no surface rivers flowing out of them. The paleo lake of Bandung which is now dry and become the city of Bandung, was a former lake that was formed due to the damming or impounding of the Citarum river by lahars expelled from the explosion of Tangkubanprahu volcano. The water in the lake then slowly cause solution of the limestone wall in the Rajamandala area that created a cave-river for the Citarum channel that dried the lake 6000 years ago.

Lake-swamp such as the Ogan-Komering was formed in the broad coastal plain of east Sumatera basin where the rate of sedimentation is somewhat slower compared to the rate of rate of uplift of the regional area. This in-balance give rise to a broad swampy coastal area. River and coastal plain lakes are formed in a geomorphologically stable area where the maturity of rivers has been achieved. Shallow but large lakes may

Table 2. List of lakes in Indonesia arranged according to lake surface area.

No.	Lake (& swamp)	Island	Lake area (sq.km)	Lake altitude (m asl)	Max. depth (m)	Secchi disk (m)
1.	Ogan-Komering	Sumatera	~ 2000	20	5	< 1
2.	Toba	Sumatera	1129/1776	905	529	9
3.	Towuti	Sulawesi	560	293	203	13
4.	Middle Mahakam	Kalimantan	450	50	6	< 1
5.	Rawa Aopa	Sulawesi	380	50	6	< 1
6.	Tempe complex	Sulawesi	350	6	10	< 1
7.	Poso	Sulawesi	323	498	390	12
8.	Sentarum	Kalimantan	275	35	8	2
9.	Enarotali	Papua	195	1742	-	-
10.	Matano	Sulawesi	164	396	588	23
11.	Singkarak	Sumatera	130	364	268	3
12.	Ranau	Sumatera	125	540	229	4
13.	Maninjau	Sumatera	99	463	169	3
14.	Sentani	Papua	94	59	52	1
15.	Siak Kecil	Sumatera	90	10	5	< 1
16.	Triton	Papua	62	650?	50	-
17.	Limboto	Sulawesi	56	25	3	< 1
18.	Laut Tawar	Sumatera	55	1126	80	-
19.	Tondano	Sulawesi	50	600	20	1
20.	Anggi lakes	Papua	47	1780	-	-
21.	Kerinci	Sumatera	42	783	110	2
22.	Lindu	Sulawesi	32	950	100	2
23.	Jamur	Papua	32	107	-	-
24.	Rawa Pening	Jawa	25	463	4	< 1
25.	Surubel	Timor	22	na	-	-
26.	Ayamaru	Papua	22	20	20	-
27.	Bangkau	Kalimantan	20	10	45	< 1
28.	Batur	Bali	16	1031	91	2
29.	Diatas	Sumatera	12	1531	44	8
30	Segara Anak	Lombok	11	2030	160	+ 5
31.	Dibawah	Sumatera	11	1462	309	11

be formed in the flood plain of mature rivers, such as the Tempe and Semayang-Melintang lake complex, they are important ecosystem of the river that provide shelter for the fauna and flora in their cycle of life. The coastal lakes of Mimika region in Papua are clearly seen from air but little physical measured data are available.

From the short examples provided above it has been shown that there is a strong correlation between geology, limnology, biology, climate, pedology, and its related geo-biochemistry characters in the planning, the fate, and the antropogenic carrying capacity that determine the limits of sustainable exploitation of a lake and its surrounding catchment area. Lakes are large water bodies that are alive and have its natural heartbeat which should always be put into consideration in the planning and exploitation of lakes. Lakes are large water bodies that can provide human needs if they are treated well through an ecohydrological study and approach in determining the limits of their natural cycles. Spatial planning of areas around lakes should follow and make use of this kind of approach especially during its very early stage.

Parameters to measure the health of lakes are variable, they may differ from one to the other, depending on what the end user are. There are general descriptive terms with some graduation, many are based on the various nutrient richness in the lake water, they may be based on typical temperature profile of the water column, or based on the energy or heat balance, on the light penetration, on micro and macro organism richness, or they may be based on the existing food chain completeness from the richness of the lower to the higher level in food the chain.

As an addition to this section is a brief description of lake parameters that could be collected during the study of lakes. There are at least 32 parameters, they are: # name of lake # island, province, region # latitude and longitude # altitude # lake type # natural / regulated water # lake water utilization # maximum depth # surface area # maximum length # maximum width # length of shoreline # volume of lake # replenish time # name of outlet river # volume of discharge # water level fluctuation # water quality # water chemistry # transparancy # name of rivers flowing into lake # drainage area # maximum height of drainage basin # rainfal data # other climatic factors # landuse # geological rock units # population distribution # main cities # longitudinal profile of river flowing to sea and # list of lake data / measurements.

3. LAKE AND MANKIND

Many lakes have shown its potentials to support human life, its various uses and needs, and their settlements. Several examples are, lakes Toba and Maninjau in Sumatera island, lakes Tempe and Matano in Sulawesi island, lakes Bratan and Buyan in Bali island, and lakes Sentani and Ayamaru in Papua. For many centuries these lakes have attract settlements around them and people have lived in harmony with the lake. During these harmonic interaction, traditional

wisdom-believes-taboos and religious practices have developed in making a balance between exploitation and prohibitions to the lake resources. There exist some sort of believe by the local people that these lakes are alive and something holy that should be treated well.

Many lakes have their own legend, most of them shows an intimate interaction between humans and the water mass. Many of these legends tells about faithfulness and later also un-faithfull of people to their beloved environment. Related to religion, lakes was considered as holy place such as in Bali island, where springs upstream the lakes are considered as most sacred and the rivers flowing out of these lakes are to be used by people not in a greedy way. The shore of lake Toba is considered a prominent place and should be respected by the population in their daily manners. Rivers in Nias island is consider holy so that should be kept clean not to pollute with excrements and night soil. The deep lake Matano is considered with respect, people will not sail into it if it give signs of nature power and local people do not dare to sail during night time. Springs, large trees, and water sources are looked upon with respected in the Toraja land in central Sulawesi island.

In recent developments of lake areas, many lakes were visited by people from outside the areas, by those that consider themselves modern and more educated, they 'discovered' the many unused potentials of the lake ready and free for exploitation. Exploitation of lakes are not wrong as long as it consider the overall picture of the lake carrying capacity and its limitations. The local beliefs should not be totally overrun in disbelieve, they are nature's limits that for decades were treated as culture and tradition by local people. Some of these tradition and culture may be half or not true, but also there are those that have deep and strong root in conservation practices for lake ecosystem. They should not be totally ruled out for participation by local people, it could become a useful tool in creating a management harmony by combining local people believes and a modern management plan.

4. FATE OF LAKES

The title of this section which is fate of lakes, sounds a little bit gloomy as if it is guaranteed that there will be no bright feature of all lakes at the end of its existence. In geological terms all lakes will have an end as it is part of the formation of the ever evolving dynamic earth. Present lakes in a geological scale are in average about 100,000 year old, while young lakes may be in the order of 4,000 - 10,000 years old. Very old lakes are only a few in the world, the age may be in the order of a few million years old, such as Lake Baikal, the Dead Sea, and Lake Matano are examples of old lakes. As mentioned earlier in the previous the section, one of the differences between natural lakes and reservoirs are in their geological age, reservoirs are very young where most of them are less than 100 years old. This time difference in its formation is imprinted in

the ecosystem composition, in the water mass and in the catchment area.

The fate of some lakes are determined by natural hazard occurring in the surrounding area, but the fate of most lakes are determined by the antropogenic changes due to human activities living in and around the area. Lakes has been exploited, some of them in the range of their carrying capacity, some are over-exploited. Lakes has been exploited for hydro power generation, transportation, fisheries, domestic water supply, irrigation, industrial activities, for mining purposes, recreation, for sport, micro climate regulation, and lakes are precious places for a wide variety of the diverse aquatic ecosystem. Lakes are important evaporation sources that regulate the climate and they are also an important heat reservoir that store and regulate the abundant heat from the sun.

Deep lakes such as Lake Matano together with two lakes that lies beneath this lake, Lake Mahalona and Lake Towuti in Sulawesi island has been exploited for hydropower generation. From the Larona River that drain these three lakes it produces 255 MW of hydropower. This oligotrophic, cryptodepression, Lake Matano with a water transparency of 23 m could be called as one of the clearest lake in the world. It has been managed well, until the last three years where there are initial indications of some decline in the physical lake parameters due to forest conversions in the upper catchment area. Forest cutting for its wood and the conversion into cacao plantations has started to show some turbid water plumes flowing into the lake after heavy rainfall.

Another deep lake is Lake Toba in north Sumatera, the biggest lake in Indonesia. The water area covered 1129 sq.km and Samosir island located inside the lake if included, the total lake depression is 1776 sq.km. The 80 km long lake has its natural beauty, it is increasingly being populated during the last half century. Since two decades ago the Asahan river draining the lake produced 285 MW of hydro-electricity from two former magnificent sites, the once Sigura-gura and Tangga waterfalls. The tourism industry in the vicinity has developed vastly, hotels, restaurant, and supporting facilities were set up without adequate support to control the various pollution it produce. Initial indications in the decline of water quality is shown by the fast breeding of water hyacinths that covered bays and near shore waters. A pulp factory build at the mouth of Asahan river that drain the lake has lately created some additional pollution problems. Oil leaks from boats engines, disposed plastic, cans, and domestic wastes into the lake add the environmental stress to the water body.

Another important lake to discuss is Lake Maninjau in west Sumatera, the only lake in this island that drain its water toward the west, to the Indian Ocean. A decade ago the state electric company drilled tunnels on the lake wall and piped the lake water to turn turbines for hydropower generation. Recently the lake faced repeated events of sudden fish kills and

local people blamed to the company. The answer from the state electric company was that they did nothing wrong, they just take water and nothing else. Another option for answer came from the research community who explained that even that the company did nothing to pollute the water, but they did change the lake water cycle. Previously the lake has its natural rithym, during the rainy season provide high water to fill the wetland where fish lay their eggs and during the dry season the partly dried wetland are important places for the juvenile fish for their feed source. Now the natural fish community has declined causing an invasion of new spesies into the water mass that consumed the oxygen in the water and end up with sudden the fish kills.

Lake Tempe in south Sulawesi is another good example of uncontrolled exploitation. This is a shallow floodplain lake complex that previously was very rich in fish potentials. Rapid population growth without adequate planning has created eutrophication to the lake complex that practically left the lake without much of its freshwater fish products. Recently nearly all the lake surface has been covered by water hyacinth prohibiting transport through the lake waters.

Away from lake examples, a parameters to measure the health of lakes are variable. They may differ from one lake to the other and depend on what the end user are. There are general descriptive terms with graduation, there are water quality based on the nutrient richness, the temperature profile, the energy or heat balance, on light penetration, micro and macro organism, or they may be based on the existing food chain dynamics. The type of measure should be chosen for a specific water use. Water quality for fisheries are not the same with those working in the geothermal field. Tourists needs are not similar to the farmers. Fisheries activities may need another measure compared to those for transportation activities.

5. CONCLUDING REMARKS

As conclusion of this broad description of lakes in Indonesia, its water potentials and its limitations, it can be stated and said that many lakes in Indonesia still contain its potentials in its natural conditions especially the smaller lakes. Larger lakes in general has been more in touch with antropogenic changes and developments, some of them start to be physically, biologically, and chemically altered as a result of limited coordination in the past management between departments and sectors.

Lakes are not identical to reservoirs, they are not part of a river, a mis-conception in the bureaucratic community that should be cleared up. Lakes and its catchment area is best if managed under one coordinated management plan between responsible government departments operating in the area, between sectors, private and public stake holders, and with people living in the surrounding area. Each single lake ought to have its own management plan. An ecohydrological approach in the study of lakes and its catchment area is a strong integrated tool to bridge the various interests and

needs in a lake area, to conserve the ecosystem and regulate the developments in the coridors of carrying capacity of a lake and its catchment area.

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