POLLUTANTS AT LAKE BUYAN (BALI, INDONESIA) AND SOLUTIONS FOR IMPROVING ITS ENVIRONMENTAL STATE

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ABSTRACT

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Lake Buyan in Buleleng, Bali, has various purposes, such as supplying water for crop and livestock farming and the domestic sector. Wastes generated by human activities in its immediate surroundings are increasing population pressures on the lake's environment. According to Gubernatorial Regulation Number 16 of 2016, the lake's water quality is in a poor state and is categorized as 'polluted'. One of the ways proposed in this research to reduce the pollution level was to build a constructed wetland, which is a waste treatment system combining aquatic plants, soil or other growing media, and microbial assemblages. Results showed that 50 sets of vertical flow constructed wetlands with a single capacity of 40 m^3 are needed around Lake Buyan. Another applicable design is concentrating wastewater flows through pipes into a 2000 m^3 constructed wetland.

Keywords: Constructed wetland, waste, water quality.

INTRODUCTION

Buleleng Regency has the potential as a tourist destination. It is located in northern Bali, extending west to east, with a 144-km long coastline. Buleleng owns numerous natural and local cultural features that can be developed into a sports tourism destination. However, this development has been less than optimal (Sudiana, 2016).

Lake Buyan is a natural body of water proposed for sports tourism in Pancasari Village, Sukasada District, Buleleng. Geographically, it is located between 8°14'9″ and 8°7'9″ S and between 115°5'18" and 115°11'20" E. The Lake Buyan Natural Park consists of varied topographies, ranging in slopes from flat (0–8%) to slightly steep (25–45%) to very steep (>45%) and elevations from 1,210 to 1,350 masl. The lake is bordered by a hill road cutting through very steep slopes to the north, flat to gently sloping residential and farming areas to the east, and forests on a very steep slope to the south and a slightly steep slope to the west connecting it to Lake

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Tamblingan. Based on the Koeppen classification, it has an Aw climate (tropical savanna, wet), with temperatures ranging from 11.54° to 20°C. The lowest temperatures (11.54–13.21°C) occur in July, August, and September, whereas the highest ones (23.15–24°C) are in May, November, and December.

Lake Buyan is used to supply water for various sectors, including crop and livestock farming and domestic. However, these anthropogenic activities generate wastes that are increasing pressure on the lake's environment. Indications of environmental stress are apparent from the low phytoplankton diversity index. Moreover, there are at least two sources of pollution in the lake: residential activities and agricultural activities. Settlements occupy two sub-villages east of the lake: Dasong and Buyan, where pollutants are generally sourced from household activities. Field observations and surveys found that these settlements typically have no sewage treatment systems for collecting gray drains from cleaning, washing, and bathing, black drains from toilets (feces and urine), and solid waste like food/kitchen scraps. Liquid waste from toilets is collected in a septic tank and then discharged to a leach field. Houses are connected to a sewer carrying off waste matter to a larger communal sewer in each village that flows to the lake. In the rainy season, rainwater carries more pollutants through the sewerage, potentially polluting the lake water. Meanwhile, domestic solid wastes are collected using a janitorial service, particularly from houses on the main road. However, some still burn or stockpile the waste (especially garden waste), which takes place near the settlements.

Based on this background, the research was intended to design an engineering measure to reduce the pollution level of Lake Buyan as part of realizing environmental sustainability.

MATERIALS AND METHOD

Wastewater dissolving and carrying many chemicals and other hazardous matter from residential areas to the lake pose grave danger to the survival of living organisms and the lake's ecological cycle. From an environmental point of view, certain types of contaminants can cause soil and water quality to degrade, harm the lacustrine biota, and damage the ecosystem. From the health aspect, polluted water is linked to numerous medical issues and the transmission of various diseases. Moreover, aesthetically, untreated wastewater causes unpleasant odor and sight and gives the lake a bad reputation.

Population growth, poor sanitation, and limited wastewater treatment facilities severely contaminate surface waters, including rivers. A constructed wetland (CW) offers simple and inexpensive wastewater treatment for households to plan and operate. It is a system designed and engineered to utilize the natural functions of aquatic plants, soil or other growing media, and microbial assemblages to provide bacterial-assisted decomposition to wastewater (Greg, Young, and Brown, 1998). Although the installation requires more space, CWs are the least expensive wastewater treatment plant compared with other technologies such as activated sludge process (ASP), trickling filter, up-flow anaerobic baffled reactor (UASB), moving bed biofilm reactor (MBBR), sequential batch reactor (SBR); the operational and maintenance cost of a CW is merely 1–2% of the total amount of money used for its installation (Balpande and Mhaske, 2017; Parde et al., 2020). ASP, MBRR, extended aeration, and SBR reduce more BOD and COD and remove more suspended solids (Cakir and Stenstrom, 2005). Still, these technologies cost more for their operation and maintenance, including electricity and labor (DiMuro et al., 2014). CWs can be free surface flow or subsurface flow. The free surface flow is suitable for suburban areas as a centralized wastewater treatment plant and even a recreational area. On one side, it prevents flood and shoreline erosion (Farooqi et al., 2008; Parde et al., 2020); on the other, it creates a favorable environment for mosquito breeding, which likely leads to other problems (Pardee et al., 2020). The subsurface flow is for urban areas out of the reach of the centralized treatment facilities and is, thus, attached to every residential building. Based on the environmental challenges at Lake Buyan and relevant theories, a ‘vertical subsurface flow constructed wetland’ **(**VSSF-CW) is believed to be the most feasible design**.** Some of its advantages are (a) substantial reduction of BOD, suspended solids, and pathogens; (b) unfavorable environments for mosquito breeding unlike the free water surface or horizontal CW; (c) less clogging than horizontal subsurface flow CW; (d) occupying less space than the free water surface or horizontal flow wetland; and (e) low operational cost.

Septic tanks and Imhoff tanks are chambers for wastewater pretreatment, which reduces suspended solids, although decreased organic contents have also been observed due to additional treatments (Alvarez, 2008). Both tanks are the most common pretreatment technologies used on CWs. These systems can remove up to 50–70% TSS, thus generating primary effluents with 50–90 mg TSS/L when operating

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normally. They also stabilize sludge by anaerobic digestion, reducing the amounts of volatile solids (Metcalf and Eddy, 2003). CWs use plants that can survive in inundated environments, namely submerged or amphibious plants. Based on their life form, there are three major groups of aquatic macrophytes (Brix and Schierup, 1989; Wetzel, 2001; Cronk and Fennessy, 2001):

a. Emergent aquatic macrophytes have aerial stems and leaves and extensive root and rhizome-system, enabling adaptations to water-logged or submersed substrates. This life form comprises species like *Phragmites australis* (common reed), *Glyceria* spp. (mannagrass), *Eleocharis* spp. (spike rushes), *Typha* spp. (cattail), *Scirpus* spp. (bulrushes), *Iris* spp. (blue and yellow flag), and *Zizania aquatica* (southern wild rice).
b. Floating-leaved aquatic macrophytes include species that are rooted into the substrate, e.g., *Nymphae* spp. and *Nuphar* spp. (waterlilies), *Potamogeton natans* (broad-leaved pondweed), *Hydrocotyle vulgaris* (marsh pennywort), and those freely floating on the water surface, e.g., *Eichhornia crassipes* (common water hyacinth), *Pistia stratiotes* (water lettuce), and *Lemna* spp. and *Spirodela* spp. (duckweed).
c. Submersed aquatic macrophytes have their photosynthetic tissues entirely submersed, but the flowers are usually exposed or above the water surface. Two commonly recognized types of submersed aquatics are elodeids (e.g., *Elodea, Myriophyllum,* and *Ceratophyllum*) and isoetids or rosettes (e.g., *Isoetes, Littorella,* and *Lobelia*).

In a VSSF-CW, using plants that are highly efficient in reducing pollutant loads and have aesthetic values is highly recommended. In addition to a treatment unit for reducing pollutant loads in grey water, the wetland is expected to provide another function as a recreational area, i.e., a park. For this purpose, the study used four plants: *Cyperus alternifolius* (umbrella papyrus), *Ipomoea aquatica* (water spinach), *Iris pseudoacorus* (yellow flag), and *Thypa* spp. (cattail).

Data collection. Primary data were collected from the village chiefs and several residents through interviews and questionnaire surveys. Field surveys were also conducted to obtain noteworthy or potentially influencing events in the past, such as flooding and rainfall, document people's activities, and take photographs of the lake and its surroundings while walking through the survey areas. Secondary data were collected from research papers, related articles, web pages, and libraries.

RESULTS AND DISCUSSION

Table 1 shows the water quality of Lake Buyan at five observation stations. One physical parameter was substantially high, and some chemical parameters did not meet the water quality standards: (1) turbidity of 35.69 JTU at station V, adjacent to the agricultural area in Buyan Sub-village; (2) DO levels of 5.15 mg/L (<6 mg/L) at station V; (3) BOD_5 of 15.61, 17.07, 22.27, 27.51, and 44.82 mg/L (>2 mg/L) at all the observation stations; (4) COD of 27.74, 29.95, 38.41, 47.78, and 71.07 mg/L (10 mg/L) at all stations.

Table 1. Water quality measurements of Lake Bayan (Sumarya *et al.*, 2020).

	Parameters (unit)	St. I	St. II	St. III	St. IV	St. V	Avg.	Quality Standard
Physical	Temp. (°C)	23.3	23.2	23.3	22.8	22.5	23.02	**Dev. 3°C**
	TDS (mg.L^{-1})	120	120	130	130	135	127	**1000**
	TSS (mg.L^{-1})	1.24	1.34	2.44	3.94	14.60	4.71	**50**
	Turbidity (JTU)	5.03	5.25	7.34	9.28	35.69*	12.52	**-**
	Brightness (cm)	183	193	111	88	93	133.6	**-**
Chemical	pH	7.5	7.6	7.2	7.6	7.5	7.48	**6-9**
	DO (mg.L^{-1})	6.22	6.20	6.13	6.03	5.15*	5.95*	**6**
	BOD_5 (mg.L^{-1})	15.61*	17.07*	22.27*	27.51*	44.82*	25.46*	**2**
	COD (mg.L^{-1})	27.74*	29.95*	38.41*	47.79*	71.07*	42.99*	**10**
	NO_3 (mg.L^{-1})	0.62	0.70	0.90	1.29	2.74	1.25	**10**
	NO_2 (mg.L^{-1})	0.03	0.024	0.077*	0.088*	0.051	0.054	**0.06**
	Ammonia (mg.L^{-1})	0.037	0.038	0.048	0.045	0.62*	0.158	**0.5**
	Phosphate (mg.L^{-1})	0.114	0.10	0.113	0.165	0.255*	0.149	**0.2**
Biological	Fecal coliform (MPN/100Ml)	0	0	102*	26	36	32.8	**100**
	Total coliform (MPN/100Ml)	26	34	1260*	325	315	392	1000

Water quality assessment by Sumarya *et al.* (2020) found low DO and high BOD_5 and COD averages at stations IV and V (near agricultural fields) and high fecal coliform and total coliform at station III (near residential areas). These are believed to result from the disposal of liquid waste containing high organic matter from human activities. Consequently, Lake Buyan is categorized as having poor water quality and class D pollution (or heavily contaminated). The water is thus no longer suitable for drinking water but still meets the requirements for farm irrigation.

Table 2. Data Analysis Storet Method and Pollution Level Status of Buyan Lake Waters

Location	Excessively High Parameters	Storet Index	Class	Condition	Pollution Level
Station I	BOD_5 and COD	-20	C	Moderate	polluted moderately
Station II	BOD_5 and COD	-20	C	Moderate	polluted moderately
Station III	DO, BOD_5, and COD	-54	D	Bad	heavily polluted
Station IV	DO, BOD_5, COD, and NO_2	-34	D	Bad	heavily polluted
Station V	Turbidity, DO, BOD_5, COD, Ammonia, and Phosphate	-48	D	Bad	heavily polluted
Lake Buyan	Turbidity, DO, BOD_5, COD, NO_2, Ammonia, Phosphate, Fecal Coliform, and Total Coliform	**-40**	**D**	**Bad**	**heavily polluted**

(Sumarya *et al.*, 2020).

For the centralized CW, the required volume in the tropics was estimated at 2 m^3 per person per day, which means that per 1000 people living around Lake Buyan, a CW with a 2000 m^3 capacity was needed. The calculations were as follows:

CWPT (CW volume per 1000 people (m^3) = CWPP (CW volume per person (m^3) × TP (total population) = 2 m^3x1000 = 2000 m^3.

To accommodate families, the CW volume per person was converted to per family. Suppose there are four people in a family. It means that the 1000 people around Lake Buyan belong to 250 families, as calculated below:

TNF (total number of the family) = TP (total population): 4 (approx. average of family members)

TNF = 1000 : 4 = 250 families

Then, the required CW volume per family was determined as follows.

CWPF (constructed wetland per family) = CW PT (CW volume per 1000 people): TNF (total number of the family)

CWPF = 2000 $m^{3:}$ 250 families = 8 m^3/family

One CW unit would not be sufficient for treating the household waste generated by all the families. Therefore, several families living within 20 m from the CW were clustered into small groups (Figure 1). Suppose one unit of CW can accommodate wastes from five families; the required CW volume is as follows.

CW PFG (CW volume per family group) = CWPF (CW volume per family) ×5 families

CW PFG = 8 m^3 × 5 = 40 m^3

A VSSF-CW with a 1m-thick substrate composed of rock arrangement that binds impurities should have a surface area of 40 m^2, as calculated below:

$$\frac{2\ m^2\ x\ 40\ m^3}{2\ m^3} = 40m^2$$

Figure 1. Structure of families accommodated by one unit of constructed wetland

Therefore, the CW volume for every five families is $40m^3$, with the dimension: 4 m (width) x 10 m (length) x 1 m (depth). Per estimates, there are 250 families around the lake. With one unit of CW for every five families, the total CWs required for the area are as follows:

TCW (total of constructed wetland unit) = TNF : 5 families = 250 : 5 = 50 units.

Table 3 summarizes the regulations on water quality standards and their classification of designations issued by the Indonesia Government based on Regulation Number 82 of 2001 on Water Quality Management and Water Pollution Control. Water quality standards are compiled based on physical, chemical, and biological parameters, while the class of water represents its designated purposes.

Table 3. Water quality standards and classification

Parameter		**Unit**	**Class I**	**Class II**	**Class III**	**Class IV**
Physical	Temperature	°C	Dev. 3	Dev. 3	Dev. 3	Dev. 5
	TDS	mgL^{-1}	1000	1000	1000	2000
	TSS	mgL^{-1}	50	50	400	400
Chemical	pH	-	6–9	6–9	6–9	6–9
	DO	mgL^{-1}	6	4	3	0
	BOD	mgL^{-1}	2	3	6	12
	COD	mgL^{-1}	10	25	50	100
	NO_3	mgL^{-1}	10	10	20	20
	NO_2	mgL^{-1}	0.06	0.06	0.06	-
	Ammonia	mgL^{-1}	0.5	-	-	-
	Phosphate	mgL^{-1}	0.2	0.2	1	5
Bio.	Fecal coliform	MPN/100ml	100	1000	2000	2000
	Total coliform	MPN/100ml	1000	5000	10000	10000

(Indonesia Government Regulation Number 82 of 2001)

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In this case, water is divided into four classes. Class I water is potable water supplies and is used for other uses that require the same water quality conditions. Class II water is used for water recreation, fishery, livestock farming, agricultural irrigation, or other uses with the same water quality requirements. Class III is designated for fishery, livestock farming, agricultural irrigation, or other purposes that require the same water quality. Class IV water is restricted for agricultural irrigation or other uses with the same water quality conditions.

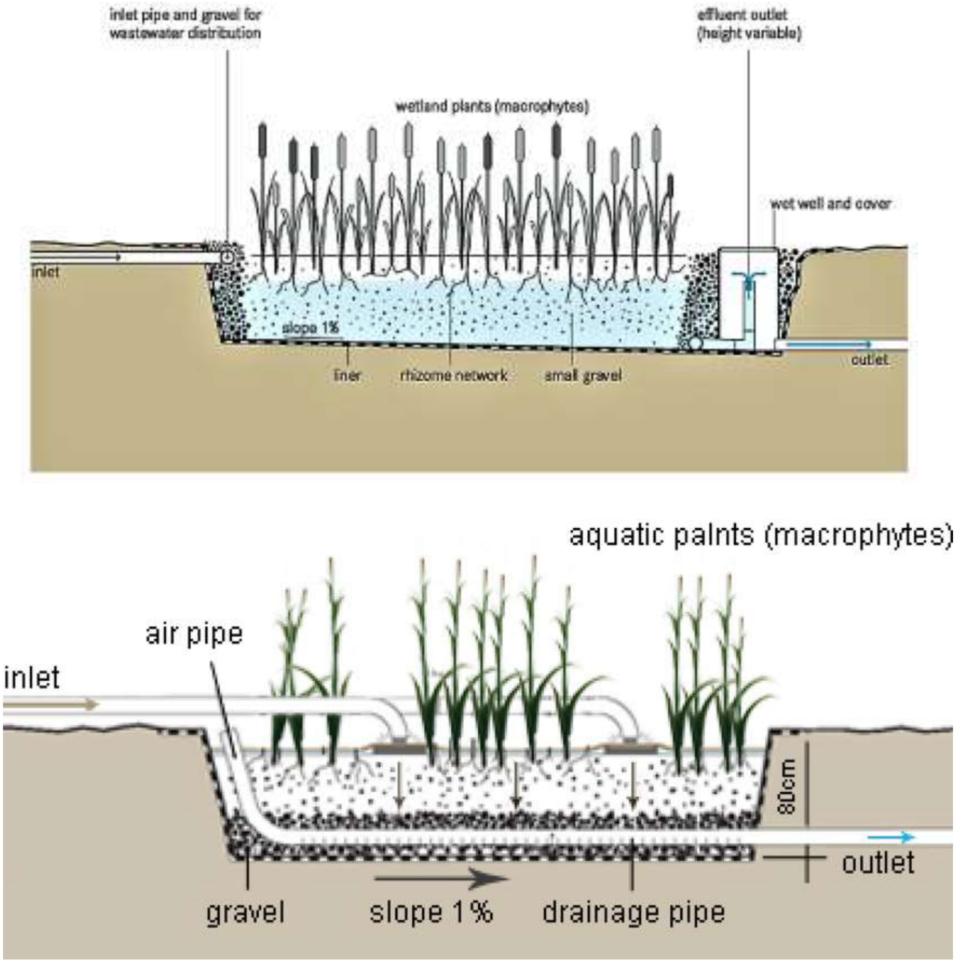

_**Figure 2**. Constructed wetland systems. Above: Horizontally constructed wetland (https://sswm.info/sites/default/files/inlineimages/TILLEY%20et%20al.%202014.%20), Below: Vertical constructed wetland (https://www.researchgate.net/profile/Orodi-Odhiambo/publication/286417697/figure/fig6/AS:669459060641793)

Figure 2 shows the CW designs proposed considering the Lake Buyan condition. CWs built with sand and gravel as the filter media and *Cyperus papyrus* could remove 95.47–99.89% of impurities from the greywater. Measurements at the outlet showed that the treated greywater meets the quality standards issued by the Minister of Environment (Regulation Number 4 of 2014) and the Indonesia Government (Regulation Number 82 of 2001), namely as class IV water (irrigation or other uses with the same water quality requirements, e.g., cleaning outdoor areas or flushing toilets). As seen in Figure 3, the red dots indicate the recommended locations for the CWs.

Figure 3. Approximate locations of the constructed wetlands with a Google Earth image of the study area in the background.

If discharged into canals, the treated greywater can dilute and neutralize pollutants in groundwater and surface water such as rivers. Also, the aquatic plants in the CW system create green space at every house or public green space on communal lands. The concept of constructed/artificial wetlands not only solves environmental pollution but also provides non-potable water sources. CW installation, operation, and maintenance are simpler and cost less than other wastewater treatment technologies.

CONCLUSIONS

Lake Buyan in Pancasari Village, Sukasada District, Buleleng, is used in various sectors, such as agriculture, livestock farming, and domestic. Over time, more synthetic or inorganic matter is used, thus introducing more contaminants to the lake. To deal with this problem, a constructed wetland design that relies on the natural functions of aquatic plants, soil or other growing media, and microbial assemblages has been proposed. Here,

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aquatic plants create green space at every house or public green space on communal lands. The constructed wetland concept not only solves environmental pollution but also creates a source of non-potable water for the agricultural sector or other uses with the same water quality requirements. The constructed wetland can be built as a centralized wastewater treatment plant with a 2.000 m^3 capacity or as a smaller system to accommodate household wastes from five families with a 40 m^3 capacity. Constructed wetlands with sand and gravel as the filter media and *Cyperus papyrus* can remove 95.47–99.89% of impurities from the greywater.

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