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MODELING OF CONSTRUCTED WETLAND FOR INCREASING THE SURFACE WATER QUALITY BY USING WATER SENSITIVE URBAN DESIGN (WSUD)

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ABSTRACT: This study intended to apply the constructed wetland for improving the water quality of the surface run-off mainly the river water of Tukad Badung. The constructed wetland consisted of four combined types such as 1) the sub-surface model without the vegetation and the surface with the combination of the sweet flag water lily vegetation; 2) the sub-surface model with the sweet flag vegetation and the surface with the water lily vegetation; 3) the sub-surface model without the vegetation and the surface with the water lily vegetation; and 4) the surface with the sweet flag vegetation and the surface with the water lily vegetation. The methodology uses the Water Sensitive Urban Design (WSUD). The result showed that the physical model-4 produced the optimal result and has the best process result of the pollutant decomposition. The result is hoped to give an input to the government to develop the constructed wetland for increasing the water quality.

Keywords: Wetland, Sweet flag, Water lily, WSUD

1. INTRODUCTION

To observe the development of water quality decreasing in the Tukad Badung River which is increasingly concerned, there is needed a study about the improvement effort of surface water quality on the river. One of the approaches that can be applied as the effort for improving the surface water quality in the urban area is by developing the constructed wetland. Cowardin et al. [1] defined that constructed wetland is a constructed transition area between the terrestrial system and the aquatic system which the water storage is near or in the surface area that is closed by the shallow water. The type of constructed wetland can be different regarding the capacity, physical and the biological characteristic where the swamp is built, including the position indicator of the landscape in it, the degree of soil saturation, the degree of soil organic decomposition, and the environmental vegetation [2].

Based on the design concept of water management for the Water Sensitive Urban Design (WSUD), the constructed wetland can be functioned for improving the surface water and the groundwater quality as the effort for maintaining the balance of water cycle [3]. On the previous research, the use of a constructed wetland system has been applied for the wastewater from many sources as the domestic wastewater [4], the agricultural wastewater [5], the farms wastewater [5], the industrial wastewater, the mining wastewater [6], the improvement of water quality due to the leachate water pollution of landfill [7], etc. The application result by using the constructed wetland system shows the satisfied enough number for the improvement effort of water quality for many kinds of wastewater.

The improvement effort of the surface water quality mainly the river water of Tukad Badung has spent much funding allocation of the Income Budget and Regional Spending (APBD) from the urban level as well as the province level through the program of clean water improvement (Prokasih) [8]. Based on the research of Life Environmental Institution of Denpasar City found that the water pollution in the Tukad Badung River is very high. the Biological Oxygen Demand (BOD) which is functioned to the unravel organic unsure in the upstream of Tukad Badung River has reached 24 mg/l and the chemical content in the water that is needed for unraveling chemical substance or Chemical Oxygen Demand (COD) has reached 36 mg/l. The value of BOD which reaches more than 20 times than the standard quality value indicates that there is happening the very high pollution of the organic material. However, the high COD value indicates that there is happening the high pollution of a chemical substance in the Tukad Badung River. Based on the final feasibility test, the Nitrate is ever more than the water quality standard such as 10.3 mg/l. It indicates that the waters are fertile for the development of phytoplankton.

This study tries to apply the constructed wetland for the surface water improvement mainly in the Tukad Badung River. By applying the constructed wetland, it is hoped the quality of the Tukad Badung River can be increased.

2. MATERIAL AND METHOD

This research is conducted in the Tukad Badung watershed where is located in the Denpasar City, Bali Province of Indonesia. Map of the location is presented in Fig. 1.

Fig.1 Map of the Tukad Badung Watershed

The model of a constructed wetland in this research is as the combined type. There are 4 models of the combined constructed wetland as follow: Model-1: a combination of the sub-surface wetland without the vegetation, and two types of the surface constructed wetland such as the surface wetland with the sweet flag vegetation and the surface wetland with the water lily vegetation. This model is presented as in the Fig. 2.

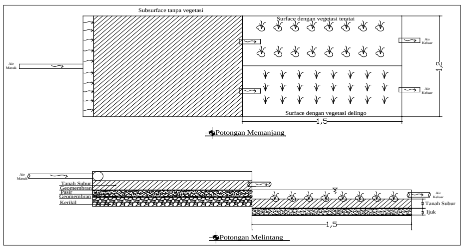

Fig. 2 Sub-surface wetland without the vegetation and surface wetland with the weet flag vegetation

Model-2: the surface wetland without the vegetation and two types of surface constructed wetlands such as the surface wetland with the sweet flag vegetation and the surface wetland with the water lily vegetation. This model is presented as in the Fig. 3.

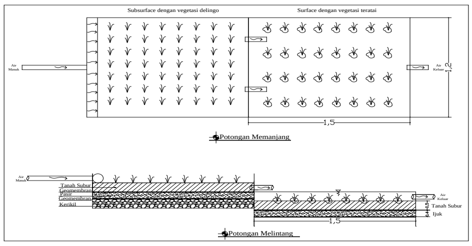

Fig. 3 Sub-surface wetland without the vegetation and surface wetland with the weet flag vegetation

Model-3: the sub-surface wetland with the sweet flag vegetation and the surface wetland with the water lily vegetation. This model is presented as in the Fig. 4.

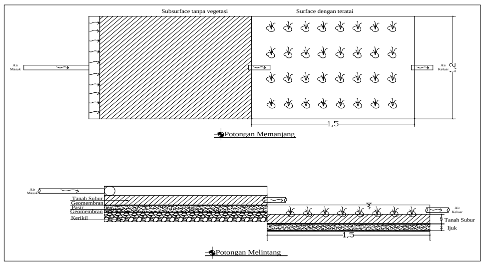

Fig. 4 Sub-surface wetland with the sweet flag vegetation and surface wetland with the water lily vegetation

Model-4: the sub-surface wetland with the sweet flag vegetation the surface wetland with the water lily vegetation). This model is presented as in the Fig. 5.

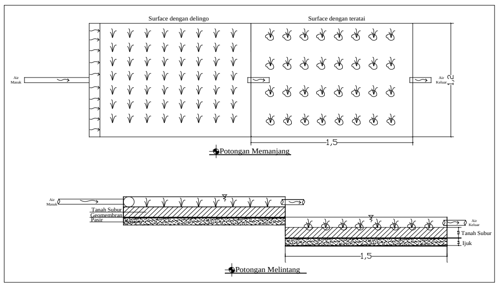

Fig. 5 Sub-surface wetland with the sweet flag vegetation and surface wetland with the water lily vegetation

Type of the water crops which have the most effectiveness vegetation of the constructed wetland in this research is the water lily and the sweet flag vegetation. The selection of the crops are due to the consideration as follow: 1) Waterlily and the sweet flag vegetation are as the crops which are fitted to be planted at surrounded river; 2) Waterlily has the local wisdom value in Bali such as it is more used in the religious activity; 3) The sweet flag vegetation is more difficult to be found so the usage as the constructed wetland vegetation is simultaneous as the sustainability effort of the water lily as well as the sweet flag vegetation. The water lily and sweet flag vegetation have not been observed yet as the constructed wetland combined vegetation as carried out in this research; and 4) Waterlily has high enough economic value due to every part of it can be utilized.

On the sub-surface wetland, the gravel (with a diameter of 4-5 m) and the width of 10 cm is put on the very bottom of the layer and there is overlaid the plastic screen (with a diameter of 0.1 cm) over it. Sand with the width of 40 cm is put over the screen. On the location of the water coming in, there is regulator tap of the inflow water which is related with the pipe of 1 dim and many holes (with a diameter of 1 cm), it is installed on the top surface along the constructed wetland. On the location of the outflow water, there is installed the pipe of 1 dim and many holes (with a diameter of 1 cm) on the bottom elongated along the constructed wetland. Then, it is carried out the observation and analysis of the components of inflow and outflow water quality, retention time, and discussion of result for knowing the performance of constructed wetland. The Water Sensitive Urban Design (WSUD) concept is appeared due to the water function in human life which needs the proportional regulation between the urban development and water demand.

2.1. Water Sensitive Urban Design (WSUD)

Water Sensitive Urban Design (WSUD) is as an approach process which integrates between the urban design and the water management. WSUD is implemented in a regional design which is integrated into the water cycle processing. This concept integrates the processing among clean or fresh water, wastewater, groundwater, rainfall, urban design, and environmental protection (Evaluating Option for Water Sensitive Urban Design –National Guide, 2007). The concept approach intends to carry out the design approach and urban design which is related to the water sources and environmental management and to minimize the impact due to the water availability on the urban surface. In the beginning, the concept is backgrounded by the water role in urban life which needs the aligned regulation between urban development and the need for water.

This concept has several important elements. The most important element is water reuse and water treatment. Rainfall and drainage water is one of the waters that is attended on this concept. In practice, this concept sees that the rainfall and drainage water management as a chance in designing a city, but not as the waste. The element is differentiated into the urban design element which is necessary to be attended in applying the WSUD such as the percent wide infiltration basin, the swales, or the ditch; the road design; the pool shelter; the gutter, the water storage tank; the roof slope; the porous pavements; type of the material for the drainage cover; the send filter; the holder wall of water flow; type of the vegetation includes the water edge vegetation and the urban forest [9].

2.2. Wetland

Wetland is a saturated water area with the typical water depth less than 0.6 m that support the growth of emergency water crops such as cattail, bulrush, umbrella plant, and canna [10]. The other definition of a constructed wetland is as a constructed swamp which is made for processing the domestic wastewater, for rainfall flow and processing the leachate or as the other wild habitat. In addition, the constructed wetland can be also used for the area reclamation of mining or the other environmental interference. According to Hammer (1986), the wastewater system of the wetland system is defined as the treatment system which enters the main factors as follow: a) Area where is flooded and supports the life of hydrophyte; b) Media where the place to grow is as the flooded soil; and c) Media can also be non-soil, but it is like the water saturated media.

Generally, there are two types of the wastewater treatment system by constructed wetland such as the surface flow constructed wetland or the Free Water System (FWS) and the sub-surface flow constructed wetland or the SSF-Wetlands [11].

2.3. Vegetation for the Improvement of Water

Stowell [12] expressed that the water vegetation had the general ability to neutralize the certain components in the waters and it is very helpful in processing the liquid wastewater treatment as well as presented by Reed [13]. He presented that the process of liquid wastewater treatment in the pool that used the water vegetation, there is happened the process of filtering and absorption by the root and the stem of water vegetation, the process of ion exchange and absorption, and the water vegetation also play a role in stabilizing the effect of climate, wind, sunshine, and temperature.

Water treatment for eliminating the iron and manganic on the groundwater can be carried out by oxidation which is followed by the separation process of suspended solid [14]. Several other physical and chemical treatments for oxidizing the iron and mangan are often used for the process of filtration aeration, filtration chlorination, and manganese greensan [15]. Besides the physical and chemical treatments, the water quality treatment can also be carried out for the biological one such as by using the vegetation as the filter in absorbing the heavy metal and the pollutant material which is known as the Biofilter method [16]. The technique of biofilter or the use of vegetation or micro-organism in absorbing the heavy metal on the soil or groundwater becomes not harmful which is now developed and to be known as the fito-remediation [17].

According to some researchers, the fito-remediation has high effectiveness because besides it is easily obtained, the use of the vegetation does not need the expensive cost too and it is environmentally friendly. Research about the vegetation ability to absorb the heavy metal was carried out by Dwiyanti and Gunadi [18] such as by using the lemna water vegetation, hydrilla, water spinach, and the riverine plant (gender) for decreasing the parameter of ammonia (NH_3), nitrate (NO_3), nitrite (NO_2), and the phosphate (PO_4) on the fish plantation waste. Vegetation that is effective to decrease the ammonia, nitrate, and nitrite is the riverine vegetation (genjer) with the each decreased value of 25.59%, 27.29%, and 26.73%, however, for phosphate is decreased by the hydrilla with the decreased value of 24.39%.

2.4. Waterlily Vegetation (*Nymphaea*)

Lily (*Nymphaea*) is as the genus name for water vegetation from the tribe of *Nymphaeaceae*. In English, it is known as the water lily. In Indonesia, water lily is also used for mentioning the vegetation from the genus of *Nelumbo* (*water lily*). In the ancient era, the human is indeed often confusing between the genus vegetation of *Nelumbo* such as the water lily and the genus of *Nymphaea* such as the water lily. On the *Nelumbo*, the flower is over the water surface (not floating), the red met petals (water lily with the color of white until yellow) [18]. According to Guntur [19], the water lily can increase the household waste quality which includes the physical, chemical, and microbiological quality. The waste parameter that is tested experienced the quality increasing from it does not meet becomes meet the condition and to decrease the concentration of ammonia and phosphate [20].

2.5. Sweetflag Vegetation (*Acorus Calamus*)

Sweetflag (*Acorus calamus*) is as a genus name for the water vegetation from the tribe of *Araceae*. Sweet flag is a chronic herbal with the height is about 75 cm. This vegetation is generally live in a humid area like swamp and water on all altitudes. The stem is wet, short, forming the rhizomes, and the dirty white color. The leaf is single, lancet form, pointed tip, edge flat, the length is 60 cm, the width is about 5 cm, and has the green color. The flower is plural, hump form, pointed tip; the length is 20-25 cm, located in the armpit leaves, and has the white color. Breeding with the stem cuttings, rhizomes, or the shoots which appears from the rhizomes books. Sweet flag has fiber root [21].

Research about the ability of sweet flag (*Acorus calamus*) in decreasing the ammonia (NH3) on the hospital wastewater was also carried out by Amansyah et al. [22]. On the container of the wastewater sample which there is a sweet flag in it will be happening the decreasing of ammonia at the amount of 0.0003 mg/l or 99.48%, and on the container without a sweet flag, the decreasing only reaches 0.317 mg/l or 45.63%. The sweet flag can decrease the pH becomes neutral (6-9), and decrease the turbidity at the amount of 86.2% and 84.7%, and the efficiency of phosphate decreasing by the water spinach and sweet flag at the amount of 53.75% [23].

2.6. Indicator of Water Pollution

Some characteristics or indicators of the water quality which are suggested to be analyzed related to the utilization of the water resources for many needs such as the physical, chemical, and the biological parameters [24]. The general indicator that is used on the evaluation of water pollution is the pH or the concentration of hydrogen ion, dissolved oxygen, and the chemical oxygen demand (COD). Monitoring of the water quality in the river is needed to be followed by measuring and recording the water discharge so the relation analysis of the water pollution parameter and the river water discharge can be studied for the need of the pollutant controlling [25].

A physical parameter consists of temperature, the electrical conduct power, and the suspended load. The increasing of water temperature will cause some impacts as follow: 1) the number of dissolved oxygen in the water is decreasing; 2) the velocity of the chemical reaction is increasing; 3) the life of fish and the other water animal are disturbed; 4) if the dead temperature limit is over, the fish and the other water animal will die. The electrical conduct power is a number that presents the ability of liquid solution for conducting the electrical current. This ability is depended on the ion existence, a total of the ion concentration, the relative concentration valence of ion, and the temperature when measuring. The higher conductivity in the water, the water will be felt brackish until salty. The Total Suspended Solid (TSS) and the Total Dissolved Solids (TDS) Suspended solid is a rest material after the sample water experiences evaporation and drying on the certain temperature [26]. Solid in the waters are classified based on the diameter size of the particle as presented in Table 1.

Table 1 The classification of solid in the waters based on the diameter size

Classification of solid	Diameter size (μm)	Diameter size (mm)
Dissolved solid	$< 10^{-3}$	10^{-6}
Coloid	10^{-3} - 1	10^{-6} - 10^{-3}
Suspended solid	>1	$>10^{-3}$

Source: APHA [27]

The turbidity of waters is generally caused by suspended particles like the clay, mud, dissolved organic material, bacteria, plankton, and the other organism. Effendi [24] expressed that the high turbidity value can also complicate the effort of filtering and it reduces the effectiveness if the disinfection on the water cleansing process.

Generally, the value of pH illustrates how big the acidity or base of the waters. Waters with the pH – 7 is neutral, pH < 7 is said that the condition of the water is acid; however, pH > 7 is said that the water condition is base [24]. The carbonate, bicarbonate, and the hydroxide will increase the water base while the free mineral acids and carbonate acid increase the acid of water, polluted and the waters with low pH value. The limited dissolved oxygen in the water causes the water ability to clean up itself is also limited, so it is needed the wastewater treatment for reducing the materials that cause the pollution. The biological oxidation is increasing together with the increasing of waters temperature so the need for dissolved oxygen is also increasing. Ibrahim [27] said that dissolved oxygen in the waters varies between 7 to 14 ppm.

3. RESULTS AND DISCUSSION

3.1 Discharge Measurement

The discharge measurement of the wetland outflow on every wetland model is carried out regarding the procedure as follow: 1) The river water is pumped and to be flowed into the wetland by using pipe; 2) The discharge of water pumping flows into the physical wetland model as the inflow of wetland; 3) The water which is out of the wetland outlet will be stored by using the measuring tube with a volume of 1.0 liter; 4) To measure the time by using the stopwatch starting from the water enters into the tube until the tube is full filled (1 liter); and 5) To analyze the outflow by comparing the tube volume (1 liter) by the time when the tube has been full filled from the wetland outflow.

Then there is obtained the mean discharge such as 0.084 l/s. The maximum time result happens on the wetland model-2/ sub-surface with the dlingo vegetation such as 56.16 hours and the maximum discharge occurs on the wetland model-3/ sub-surface without vegetation such as 0.141 l/s. However, the minimum time result happens on the wetland model-3/ sub-surface without vegetation such as 7.10 hours and the minimum discharge occurs on the wetland model-2/ sub-surface with dlingo such as 0.018 l/s.

3.2 Chemical and Turbidity Parameters

The chemical parameter measurement on the constructed wetland is necessary to be carried out as the basis to observe the influent and effluent quality. The measurement is carried out during 14 times of experiments which starting from 17th November 2015 until 19th January 2016. The parameters which are observed is consists of the fluoride (ion-F), the nitrite (NO_2), the nitrate (NO_3N), the Biochemical Oxygen Demand (BOD), the Chemical Oxygen Demand (COD), and the Dissolved Oxygen (DO). However, the turbidity level measurement is carried out on the 6th until the 14th experiment. The measurement is carried out by the retention time during 24 hours.

The experiment of fluoride on the Tukad Badung is carried out 14 times. The amount of fluoride on the early Tukad Badung is 27.005 mg/l. The wetland model-2 has the lowest fluoride mean, while the fluoride mean of the other wetland models is 10.861 mg/l. It indicates that the combination of 2 sub-surface and surface flow systems are better than by using one flow system as seen on the wetland model-2 and 4. The good surface flow system is using the combination of two types of different vegetation as seen on the wetland model-1 which is better than the wetland model-3. However, the wetland model-2 is decreasing the fluoride parameter of 16.144 mg/l from the early Tukad Badung.

The experiment of Nitrate on the Tukad Badung is carried out 14 times. The amount of Nitrate on the early Tukad Badung is 31.48 mg/l. The wetland model-3 has the lowest Nitrate mean, while the Nitrate mean of the other wetland models is 22.68 mg/l. It indicates that the combination of sub-surface and surface flow system is better than by using one flow system as seen on the wetland model-3 and 4. The good surface flow system is using the one type of vegetation as seen on the wetland model-3 which is better than the wetland model-1. However, the wetland model-3 is decreasing the Nitrate parameter of 8.807 mg/l from the early Tukad Badung.

The experiment of BOD on the Tukad Badung is carried out 14 times. The amount of BOD on the early Tukad Badung is 332 mg/l. The wetland model-4 has the lowest BOD mean, while the BOD means of the other wetland models is 117.8 mg/l. It indicates that the combination of sub-surface and surface flow system is better than by using one flow system as seen on the wetland model-4. The good surface flow system is using the one type of vegetation as seen on the wetland model-4 and 1. However, the wetland model-4 is decreasing the BOD parameter of 154.2 mg/l from the early Tukad Badung.

The experiment of COD on the Tukad Badung is carried out 14 times. The amount of COD on the early Tukad Badung is 971.86 mg/l. The wetland model-4 has the lowest COD mean, while the COD means of the other wetland models is 593.52 mg/l. It indicates that the one surface flow system is better than by using two flow systems as seen on the wetland model-4. The good surface flow system is using the one type of vegetation as seen on the wetland model-4 than wetland model-1. However, the wetland model-4 is decreasing the COD parameter of 378.34 mg/l from the early Tukad Badung.

The experiment of DO on the Tukad Badung is carried out 9 times. The amount of DO on the early Tukad Badung is 828.1 mg/l. The wetland model-2 has the biggest DO mean, while the DO mean of the other wetland models is 478.19 mg/l. However on the wetland model-1 for the experiment-12, 13, and 14 indicate the big result of DO parameter. It happens because there is maybe happened the error sampling. The wetland model-3 has the smallest turbidity than the other wetland models such as 270.92 mg/l. However, the wetland model-3 is decreasing the turbidity of 557.18 mg/l from the early Tukad Badung. Based on the Healthy Ministry Rule of Indonesian Republic No. 416/Menkes/Per/IX/1990 about the clean water condition: MPN Coliform = 50 (non-piped water), MPN Coliform = 10 (piped water), and MPN E.Coli = 0. Based on the literature study as above, it can be concluded that by using the combined wetland with many kinds of vegetation, the effectiveness of pollutant reduction is described below.

Table 2 present the effectiveness of reducing parameter percentage on the wetland system for model-1, 2, 3, and 4. Based on the comparison model of the wetland physical model on this research, the biggest reduction of BOD, COD and DO parameter is on the wetland physical model-4.

Table 2. The effectiveness of reducing parameter percentage on the wetland

No	Area	Parameter					
		Fluoride (Ion-F)	Nitrate (NO_3-N)	BOD	COD	DO	Turbidity
1.	Wetland model-1	59.7	14.4	35.1	33.4	68.4	-
2.	Wetland model-2	59.8	27.1	16.4	17.0	70.4	42.3
3.	Wetland model-3	57.2	28.0	34.1	8.1	81.5	67.3
4.	Model wetland-4	56.5	18.9	46.4	38.9	88.0	47.6

A wetland that produces the smallest turbidity parameter or the best is on the physical model test-3. Based on the model test as above, it can be concluded that the physical model-4 produce the most optimal result due to the some selected backgrounds as follow: a) The biggest retention power of inflow to the wetland system is the physical model-2; b) Based on the comparison of wetland physical model in this study, the largest parameter of the fluoride reduction is in the physical model-1; c) Wetland which reduces the biggest value of BOD and COD pollution parameters is the physical model-4 from the initial conditions, wetland which produces the greatest oxygen content (DO) is the physical model-4 with the addition of 88% of the initial conditions; and e) For the bacteriological parameter test results, the physical model-1 and the physical model-3 have the smallest coliform and e-coli bacteria on the wetland outflow if it is compared with the other wetland models.

4. CONCLUSIONS

Based on the analysis as above, it can be concluded as follow: The concept of wetland is one of the constructed suffix efforts that are applied on the river in the urban area for reducing the load of the river water pollutant. The pollutant load of the urban area, one of them is dominated by the fluoride and the nitrate pollutant content. Based on the fourth physical model test as above, it can be concluded that the physical model-4 produces the most optimal result and has the best pollutant decomposition process. The wetland performance in this research shows that the physical model-4 is able to reduce the content of BOD parameter in the amount of 46,4%, COD parameter in the amount of 38,9%, and produces the greatest DO in the amount of 88% of the initial conditions. Generally, the result shows that the system of wetland performance design is able to reduce the content of water pollutant material into better quality. The water lily and the sweet flag are good for the selected type of the wetland vegetation and the wetland will have better performance by using the constructed suffix. The combination of the surface and the vegetation has the higher potency of pollutant content absorption, so the condition of the wetland area itself mainly the physical model-4 is as the condition that has the highest fertility of the pollutant.

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