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Design of Eco-Drainage System for Real Estate in Indonesia

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Abstract. Land use change occurs in many cities in Indonesia. Population growth causes the expansion of residential area. Without proper planning and design, the development of residential area can increase the runoff volume. The objective of this study is to provide an eco-drainage system design for real estate in Indonesia to minimize the possible increased runoff.
The study area in this paper is a bare area of 14,602.26 m^2 in Mojokerto Regency, East Java, Indonesia which is planned to be developed into real estate. The design of eco-drainage system consists of installation of 4400 litre of rainwater storage tank and a 1200 m^3 of retention pond.
The analysis includes the estimation of peak discharge of the selected area using the Rational formula and estimation of evapotranspiration in the retention pond using Thornthwaite method.
The result of the analysis shows that 50.2 m^2 of roof surface can capture rainwater varies from 0.04 – 18.4 m^3/month. The water is used to fulfil the household water needs in the real estate such as for sanitation & waste disposal, gardening, personal washing, cleaning home, and washing clothes along the year except in August and September. While overflow of the tank occurs in January, February, and March. The excess rainfall, which is not captured, flows to the retention pond. It is used for watering public garden using a sprinkling water system. The combination of chosen dimension of storage tank and retention pond can reduce the runoff volume minimum by 48.19% in February in the study area.
The proposed design still cannot accommodate all excess rainfall due to the transformation of a bare land into real estate. Therefore, it is recommended to consider another utilization of water in the retention pond.

1. Introduction

The number of population in Indonesia continuously grows. It is more than 237 million in 2010. This number is nearly double of the number in 1971. Increasing number of population in every province contributes to the national increasing number. This situation causes the expansion of residential areas in many cities in Indonesia. The expansion of residential area, moreover in Java Island, means changing bare area, forest, or farm area into residential area. This change causes the transformation of permeable surface into impermeable surface which further will effect to the increasing of runoff volume.
A study by Kusumastuti et al. (2018) revealed an increasing peak flood discharge in Probolinggo Regency, East Java from 2010 to 2015. The main cause of it was the land use change, where dense forest, local plantations, and bare land were transformed into chemical industrial area and residential area. Merely due to land use change, the peak flood discharge increased by 1.75%.
A bare land of 14,602.26 m^2 in Mojokerto Municipality is planned to be developed into a real estate. This development may cause the increasing of runoff volume. This paper discussed the eco-drainage system which is designed as a unity of the design of the real estate. The proposed design of eco-drainage system is expected to minimize the runoff volume due to the construction of the real estate.

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Definition of eco-drainage has been stated in appendix of Ministerial Regulation No. 12/PRT/M/2014 (Ministry of Public Works of Indonesia, 2014) as an effort to manage the excess water due to rainfall by using various methods such as capturing rainwater, storing or directly using it, delivering excess rainfall into retention pond, or infiltrating it into groundwater. Various studies on implementation of eco-drainage system in different cities in Indonesia have been conducted. A study by Ardiyana, et al. (2016) observed the reduction of surface runoff by 14.49% - 92.26% in a real estate in Malang City by constructing recharge wells, bio-retention cells, and permeable pavement. Previous study by Aflakhi, et al. (2014) also had similar result when the reduction of surface runoff by 83.5% could be achieved when recharge wells and bio-retentions cells in real estate in Semarang City are constructed.
Effort on reduction of runoff volume from impervious surface was also discussed by Ladson et al. (2006). The study area is in Australia and the objective of the study is not merely reducing the runoff volume. It is also done to overcome the deterioration of river water quality due to direct delivery of surface runoff which contains of pollutants from impervious surface, such as road. The measures have been taken are installation of rainwater tanks, choosing permeable materials for road pavement, swale drain and bio-retention systems along road.

2. Study Area and Methods

Mojokerto Municipality is located at 07°33' South latitude and 112°28' East longitude, in the centre of Mojokerto Regency, East Java Province. It has a total land area of 16.47 km^2 which 702.15 hectare of it, is used as residential area in 2016 (Statistics of Mojokerto City, 2017). The normal annual precipitation in Mojokerto Regency is above 2000 mm. The temperature varies from 22.3° - 33.8°C. Data of daily rainfall from 2000 – 2015 was collected and analysed to determine the capacity of each component of the proposed eco-drainage system in this paper.

2.1. Rainfall Characteristics

Data of average daily rainfall was analysed in this paper to determine the capacity of rainwater storage tank, water balance in the retention pond, and the capacity of the retention pond. The result of rainfall data analysis shows that Mojokerto Municipality received maximum daily rainfall varies from 38.94 – 77.50 mm and average daily rainfall from 0.77–15.62 mm.
Other data to be used in the analysis are data of monthly average number of rain and dry days, and average temperature. Those data were the main data to observe monthly water balance in the rainwater storage tank and in the retention pond. The complete data is presented in Table 1.

Table 1: Monthly average daily rainfall, average number of rain and dry days, and average temperature

Month	Average daily rainfall (mm)	Average number of rain days	Average number of dry days	Average temperature* (°C)
Jan	15.62	25	6	26.5
Feb	14.83	24	4	26.4
March	15.27	24	7	26.6
April	10.48	19	11	26.7
May	5.88	15	16	26.6
June	2.19	6	24	26.1
July	0.77	3	28	25.7
Aug	0.43	2	29	26.2
Sept	0.89	2	28	26.8
Oct	3.10	7	24	27.4
Nov	6.85	14	16	27.4
Dec	12.83	23	8	26.9

**Source:* http://id.climate-data.org/location/977152/

2.2. Methods

Water balance is the main principle to determine the capacity of rainwater storage tank and retention pond of eco-drainage system in this paper. It includes the volume of inflow, outflow, and Δstorage (as the different between inflow and outflow) both in the rainwater storage tank and the retention pond.

Inflow to the rainwater storage tank was obtained from the multiplication of the depth of monthly average daily rainfall and the catchment area (roof surface). While the outflow was designed differently every month in the year based on the availability of rainwater and standard of water requirement by World Health Organization (2013), i.e. sanitation and waste disposal (70 litre/day), gardening (90 litre/day), personal washing (30 litre/day), cleaning home (50 litre/day), and washing clothes (40 litre/day).

Unlike the rainwater storage tank, the retention pond has different sources of inflow, i.e. from surface runoff of the whole area of the real estate except from the roof surface and the rain which falls on the retention pond. The peak runoff flows to the retention pond is estimated using the Rational Formula (Chow and Mayes, 1979), Eq. (1). It is then used to estimate the daily runoff volume due to 4-hour rainfall. After retention pond is filled of water from surface runoff, the water is planned to be used for watering public garden in the real estate. This is considered as the outflow of the retention pond. The detail of monthly water use of the retention pond is discussed in detail in section 3.2. Water balance in the retention pond also considers the loss of water due to evapotranspiration. It is estimated using Thornthwaite method (Triatmodjo, 2009), Eq. (2).

$$Q = CIA \quad (1)$$

where:

Q = peak discharge (cfs)
C = runoff coefficient
I = rainfall intensity (in/hour)
A = catchment area (acres)

$$ET_{month} = 1.62\left(\frac{10Tm}{I}\right)^{a} \quad (2)$$

for:

$$a = 675\times10^{-9} I^{3} - 771\times10^{-7} I^{2} + 179\times10^{-4} I + 179\times10^{-4} I + 492\times10^{3}$$

$$I = \sum_{n=1}^{12}\left(\frac{Tm}{5}\right)^{1.514}$$

where:

ETmonth = monthly potential evapotranspiration (cm)
Tm = average monthly temperature (°C)
I = annual heat index

3. Design of Eco-Drainage System for Particular Real Estate

According to Law of Indonesia Number 26 (2007) article 29 verse (2), the proportion of open space in a city is at least 30% of a total land area. Therefore, a design of real estate development after the year of 2007 must consider the contribution to the total open space in the city. The design of the real estate discussed in this paper consists of 4219.9 m^2 (28.89%) of houses (roof surface) and 10389.36 m^2 (71.11%) of public and private open space. Therefore, the real estate has been designed following the legal regulation in Indonesia. The design of land use of the real estate produces 0.3154 of runoff coefficient (C). The layout of the real estate is shown in Figure 1.

Figure 1: Lay out of the real estate with eco-drainage system (not in scale)

Runoff coefficient is an important factor contributing to the peak flood discharge as can be seen in Eq. (1). Another variable contributing the peak flood discharge using the Rational Formula is rainfall intensity. Data of rainfall intensity in this paper is estimated from daily rainfall depth which is transformed into rainfall intensity using Mononobe Formula. However, the detail of the calculation is not presented here. It is taken from a research by Wibisono and Hartono (2016). After all components have been determined, the estimated volume of runoff due to 4-hour rainfall in the study area starting in November is presented in Table 2.

Table 2: Volume of runoff in the study area

Month	Rainfall Intensity (mm/hour)	Volume of runoff (m^3/month)
Nov	8.29	2139.79
Dec	15.52	6581.25
Jan	18.91	8716.07
Feb	17.94	7938.21
March	18.48	8177.16
April	12.68	4441.83
May	7.11	1966.30
June	2.49	275.45
July	0.94	51.99
Aug	0.52	19.17
Sept	1.07	39.46
Oct	3.76	485.26

3.1. Rainwater Harvesting System

Rainwater harvesting system (RWHS) for domestic use at household scale consists of three components i.e. catchment area (roof surface), delivery system (gutters and drain pipes), and storage tank (Worm & Hattum, 2006). The capacity of the storage tank is determined based on the different between inflow and outflow. The inflow is mainly from rainfall while the outflow is from domestic water need in each house. It is estimated based on the need of water of 4 (four) members of a household. Therefore, the daily water need, such as for sanitation and waste disposal, personal washing, and washing clothes of each household is multiplied by 4 (four).

The simulation of the use of rainwater in the storage tank starts in November. That month is the second month of rainy season in the study area. It is considered that at that time, rainwater has filled the storage and can meet the water need. The monthly runoff volume is estimated based on monthly average number of rain days as presented in Table 1.

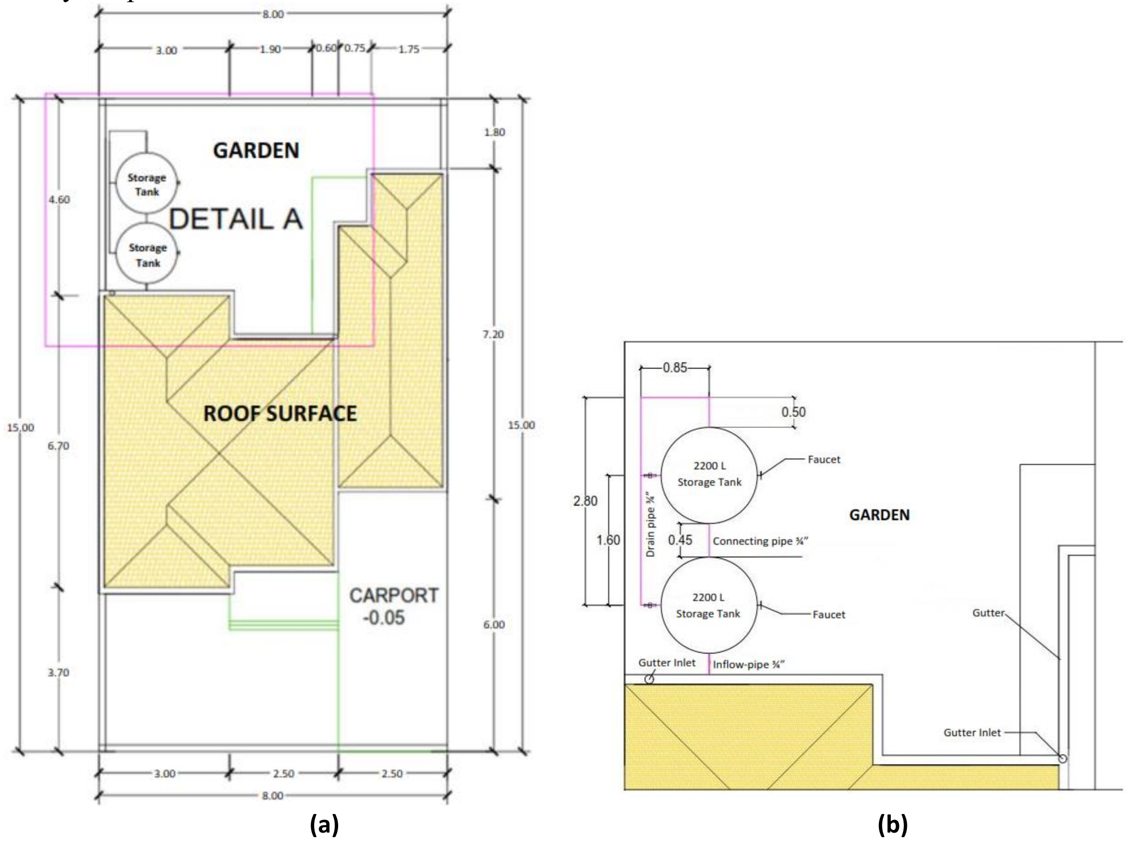

Figure 2: (a) Catchment area of RWHS; (b) Detail A of RWHS, in metre (not in scale)

Using the data of average daily rainfall data and average number of rain days which are presented in Table 1 and 50.2 m^2 of roof surface (the catchment area of the RWHS is shown in Figure 2), the monthly inflow to the storage tank is presented in Table 3. Due to the variation of monthly rainwater volume in a year, the system is designed to work at 4 (four) scenarios of water use. The first scenario, the water as much as 50 litre/day is used for cleaning home. The second scenario, the water as much as 450 litre/day is used for sanitation & waste disposal and personal washing for 4 (four) members of the household and cleaning home. The third scenario, the water as much as 610 litre/day is used for sanitation & waste disposal, washing clothes, and personal washing for 4 (four) members of the household as well as cleaning home. The fourth scenario, water as much as 90 litre/day is used for gardening. Those four scenarios of water use are applied in different month during the year. These scenarios are determined merely based on the quantity of rainwater. Further investigation of water quality may be needed.
Based on the estimation of inflow and outflow in the RWHS and accumulation of Δstorage in a year, it is determined that two storage tanks of 2200 litre capacity should be installed in a house. Therefore, it has a total of 4400 litre storage capacity. The water balance of the RWHS is presented in Table 3. It shows that in January, February, and March 4400 litre of storage tank is not adequate to accommodate the inflow from rainfall. It causes overflow, which in the end contributes to the retention pond.

Table 3: Inflow, outflow, Δstorage, and overflow of rainwater storage tank

Month	Inflow, Qin		Acc. Qin	Outflow, Qout		Acc. Qout (ltr/mo.)	Δstorage (ltr/mo.)	Overflow (ltr/mo.)
	(ltr/day)	(ltr/mo.)	(ltr/mo.)	(ltr/day)	(ltr/mo.)			
Nov	343.87	4814.18	4814.18	50(1)	1500	1500	3314.18	-
Dec	644.07	14813.61	19267.79	450(2)	13950	15450	4177.79	-
Jan	784.12	19603.00	39230.79	610(3)	18910	34360	4870.79	470.79
Feb	744.47	17867.28	57098.07	610(3)	17080	51440	5658.07	1258.07
March	766.55	18397.2	75495.27	610(3)	18910	70350	5145.27	745.27
April	526.10	9995.9	85491.17	450(2)	13500	83850	1641.17	-
May	295.18	4427.7	89918.87	90(4)	2790	86640	3278.87	-
June	109.94	659.64	90578.51	90(4)	2700	89340	1238.51	-
July	38.65	115.95	90694.46	90(4)	900	90240	454.46	-
Aug	21.59	43.18	90737.64	0	0	90240	497.64	-
Sept	44.68	89.36	90827.00	0	0	90240	587	-
Oct	155.52	1088.64	91915.64	50(1)	1550	91790	125.64	-

Note: (1)cleaning home; (2)sanitation and waste disposal + personal washing + cleaning home; (3) sanitation and waste disposal + personal washing + cleaning home + washing clothes; (4) gardening

3.2. Design of the Retention Pond

A rectangular retention pond in the study area is determined as large as 800 m^2 and 1.5 m depth. Therefore, it has capacity of 1200 m^3. The water is planned to be used to water the public garden in the real estate using a sprinkling system. Detail calculation of the sprinkling system is not discussed in this paper. The operational system of the sprinkling system is based on the number of dry days in the study area. It is presented in Table 4. In the rain days, it is considered that the garden does not need any additional water from the sprinkling system.

The catchment area of surface runoff calculation is the whole area of the real estate without the roof surface. The detail of inflow-outflow-Δstorage in the retention pond is presented in Table 4.

Table 4: Monthly water balance in the retention pond

Month	Inflow			Outflow			ΔStorage (m^3/mo.)	Overflow (m^3/mo.)
	Rainfall* (m^3/day)	Surface runoff# (m^3/day)	Total (m^3/mo.)	Evapotransp. (m^3/day)	Watering (m^3/day)	Total (m^3/mo.)		
Nov	5.48	152.67	1481.93	4.23	34.27	675.11	-	-
Dec	10.26	285.98	4557.91	4.03	34.27	395.10	4162.81	2962.81
Jan	12.50	228.96	6036.38	3.84	34.27	320.69	5715.69	4515.69
Feb	11.86	217.21	5497.70	3.39	34.27	238.84	5258.86	4058.86
March	12.22	223.75	5663.25	3.80	34.27	353.97	5309.28	4109.28
April	8.38	153.52	3076.19	3.68	34.27	487.36	2588.83	1388.83
May	4.70	86.09	1361.78	3.70	34.27	659.36	702.42	-
June	1.65	30.15	190.79	3.32	34.27	922.04	-	-
July	0.62	11.38	36.00	3.22	34.27	1056.21	-	-
Aug	0.35	6.30	13.29	3.52	34.27	1099.38	-	-
Sept	0.71	12.96	27.33	3.75	34.27	1071.99	-	-
Oct	2.48	45.52	336.03	4.29	34.27	951.24	-	-

*Note: *rain falls on the retention pond, #the catchment area excluding the roof surface*

3.3. Reduction of runoff volume

RWHS and the retention pond is designed to minimize the runoff volume. The reduction of runoff volume due to the construction of the eco-drainage system is presented in Table 5.

Table 5: Reduction of runoff volume in the study area

Month	Surface runoff without eco-drainage system, Q_1 (m^3/mo.)	Surface runoff with eco-drainage system, Q_2 (m^3/mo.)	Contribution from RWHS, Q_3 (m^3/mo.)	Runoff volume reduction, $\Delta Q = Q_1 - Q_2 + Q_3$	
				(m^3/mo.)	%
Nov	2139.79	-	-	2139.79	100.00
Dec	6581.25	2962.81	-	3618.44	54.98
Jan	8716.07	4515.69	0.47	4200.85	48.20
Feb	7938.21	4058.86	1.26	3880.62	48.89
March	8177.16	4109.28	0.75	4068.62	49.76
April	4441.83	1388.83	-	3053.00	68.73
May	1966.30	-	-	1966.30	100.00
June	275.45	-	-	275.45	100.00
July	51.99	-	-	51.99	100.00
Aug	19.17	-	-	19.17	100.00
Sept	39.46	-	-	39.46	100.00
Oct	485.26	-	-	485.26	100.00

The percentage of runoff volume reduction which is presented in Table 5 varies from month to month in a year. In the peak of rainy season, January, the highest overflow is detected.

4. Conclusions and Recommendations

4.1. Conclusions

Following the legal regulation of Indonesian, the real estate has been designed to have more than 30% of open space. An eco-drainage system has been designed as a unity of the design of the real estate in order to minimize the possible increased runoff. By constructing rainwater harvesting system and retention pond, it shows that the proposed design could reduce the surface runoff in rainy season though the reduction is still below 70%.

4.2. Recommendations

To obtain zero excess rainfall to be drained out from the real estate, it is recommended that another utilization of water in the retention pond should be considered. Therefore, the dimension of the retention pond should be adjusted to have bigger capacity.

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