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The Evaluation of Urban Eco Drainage System in Makassar

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Abstract

The objective of this study is to find solution to reduce runoff in low-lying areas that are prone to flooding. The concept of environmentally friendly drainage is the right choice to be applied in reducing the potential for flooding and sediment buildup, especially in areas with small water absorption. The quantitative method used to analyze hydrological and flood discharge then evaluated canal capacity in urban area. Rainfall data and population development for 10 years are used to determine the planned discharge with a certain return period according to actual conditions. The result showed that from the 4 types of primary canals, an average of 1.03 m^3/sec can be obtained. while the evaluation results for the secondary channel obtained 7 channels with a reduced average inundation discharge of 1.97 m^3/s. It can be concluded that the application of infiltration wells is quite effective to be used as an alternative solution in reducing inundation of urban area.

Keywords: Flooding effects; infiltration wells; heavy rainfall; drainage revitalization; filtration wells

1. Introduction

Sustainable development can be applied in all construction sectors without exception in the field of drainage systems. Drainage is a rainwater distribution system that has an important role in creating a healthy environment, especially in densely populated areas such as cities [1]. In the implementation of drainage management in Indonesia, it is generally still using the old or conventional paradigm which is limited to the concept of channeling excess water as quickly as possible to water bodies. The main problem that occurs is the problem of flooding because it drains excess water faster, so the opportunity for water to enter the ground is reduced [2], [3]. Therefore, the condition of infrastructure during the dry season is drought and conversely, floods occur during the rainy season. Flood disasters must be encountered by finding alternative solutions to sustainable drainage systems in urban area.

Several previous studies stated that conventional drainage systems have many drawbacks, including the occurrence of stagnant water which is no longer due to extreme natural factors, but the catchment area is decreasing caused by high population growth [4]–[7]. Newman et al., [8] found that population, landscape and drainage system is one set. Population growth will cause the increase of demand for housing and caused clogged drainage due to the improper functioning of the garbage disposal system and regular dredging of the canals. Furthermore, Tony and Lin [9] found that a drainage system that is not integrated will make the flow accumulate in lower areas, especially sedimentation and accumulation of garbage so that the drainage channels become damaged over time. Subsequently, Amatya et al., [10] also stated that the paradigm of an environmentally sound drainage system is a good alternative, so this innovation must be developed in planning a sustainable drainage system that utilizes rainwater, stores runoff, allows water to seep, precipitates sediment and absorbs pollutants to dispose of them slowly into water bodies. Environmental drainage system is an effort to manage excess water by naturally absorbing as much water as possible into the soil or flowing it into the river without exceeding the capacity of the river [4], [11]. The simulated advanced technology by using EPA storm as One of the latest technologies for managing excess water by using infiltration wells is shown in Fig. 1.

Rainwater infiltration wells are a means of collecting rainwater and seeping into the ground, either in the form of wells, ditches, or infiltration garden plots. In addition, infiltration wells are useful to increase the volume of groundwater and efforts to overcome the effects of drought natural disasters [5], [8].

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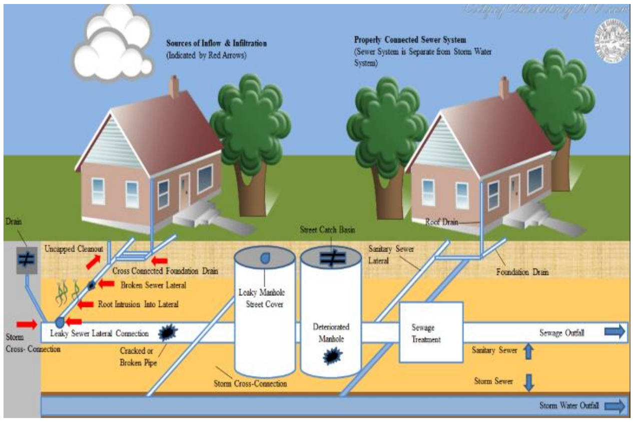

Figure 1. The simulated the DRWH by using the EPA Storm Water Management Model (SWMM) [11]

Infiltration wells are used effectively because as flood and inundation controllers, infiltration wells can absorb abundant rainwater and are also useful for conserving groundwater and reducing the rate of erosion. Therefore, reducing the amount of surface water runoff is supposed to minimize the risk of downstream flooding and pollution to urban water bodies. Based on previous studies, infiltration wells are one of the solutions that can be implemented in Makassar as an urban area. The objective of the study is to reduce surface water runoff in low-lying areas that potentially occurred flooding in Makassar.

2. Literature Review

The amount of water on earth will always remain constant and its existence is absolute, it's just that its form can change according to the nature of water [12], [13]. The source of water flow will always flow from one high place to a lower place, water also changes from one phase to another which is also called the hydrological cycle. The hydrological cycle is very influential in drainage planning where there are various processes in changing the form of water, moves from one reservoir to another such as from river to sea or from sea to atmosphere through evaporation, condensation, precipitation, infiltration, surface runoff and subsurface flow [11]. Figure 2 shows the ideal drainage system considered.

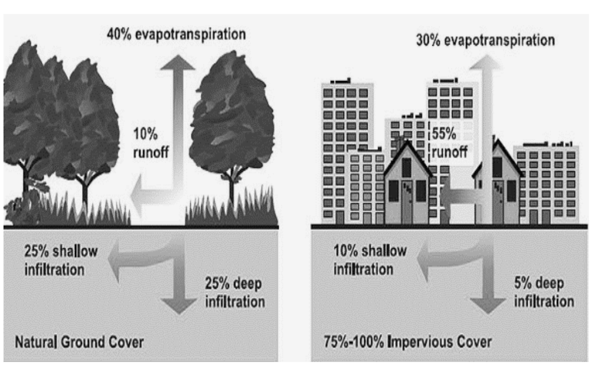

Figure 2. The difference between natural ground cover and impervious cover [14]

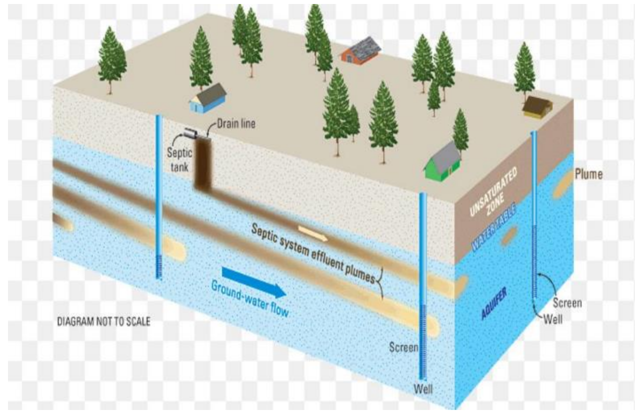

Figure 3. Infiltration wells system [15]

In the drainage system, the hydrological cycle process is very concerned to improve the drainage function as it should [14]–[16]. Ideally in a drainage system water that comes into the ground as much as possible to increase water reserves during droughts. As can be seen in Fig. 2, in the natural ground cover section water can be absorbed by the ground very well.

It can be caused in differential evapotranspiration, infiltration and surface runoff resulting from the rapid development causing the surface cover to become impermeable. There is a significant difference, therefore a hydrological analysis is needed to estimate the right method for planning the performance of a drainage system. Figure 3 shows the structure of infiltration wells in urban area. The shape and type of the infiltration well structure can be made rectangular or cylindrical with a certain depth and the bottom of the well is located above the groundwater level.

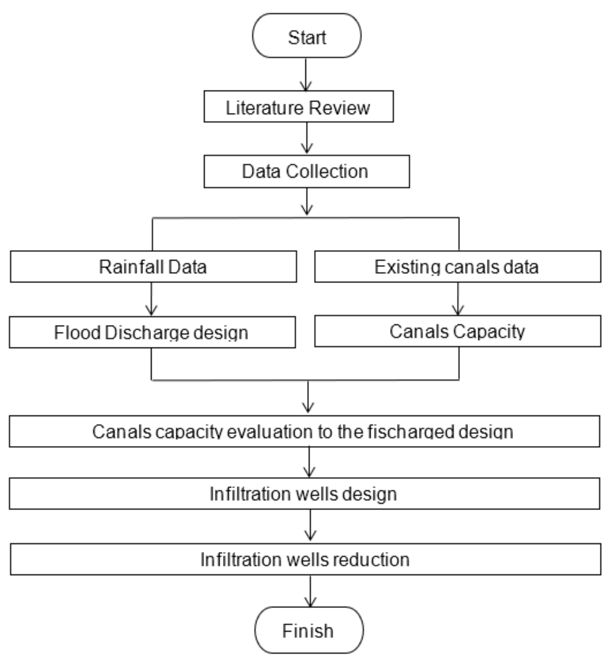

Figure 4. The Flowchart of the study

3. Research Methodology

The research location is in Panakukang District, Makassar City, South Sulawesi Province. Administratively, Makassar City has an area of approximately 175.77 km^2 consisting of 15 sub-districts and 153 sub-districts. Based on the geographical location, Makassar City is located at 5º8'6'19" South Latitude and 119º24'1738" East Longitude. Data collection is done by collecting secondary data from existing data providers. The data sources used are rainfall data for twenty years starting from 2010 to 2019 and existing canals data in Panakukang District. The flow chart of the study can be seen in Fig. 4.

4. Result and Discussion

4.1. Hydrology analysis

Rainfall is used to determine the planned discharge with a certain return period according to actual conditions. Design rainfall analysis aims to obtain the amount of design rainfall at each specified return period. The maximum planned rainfall with a certain return period can be determined by analyzing the maximum daily rainfall data. Table 1 shows the analysis of hydrology.

To determine the appropriate method, the magnitude of the statistical parameter must first be calculated. The parameters to be measured include the calculated average ($\overline{X}$), standard deviation (Sx), slope coefficient of skewness (Cs), coefficient of variation (Cv), and kurtosis coefficient (Ck). Of the several types of distribution, it is necessary to calculate and choose one type of distribution, before carrying out the calculation for selecting the type of distribution, a parameter calculation for the statistical distribution test is carried out which can be seen in Table 2.

From the results of the statistical distribution test parameters in Table 2, the appropriate type of distribution is then determined.

Table 1. The rainfall data for 20 years

No	Years	Average (mm)	No	Years	Average (mm)
1	1999	243.133	12	2010	299.333
2	2000	223.392	13	2011	242.042
3	2001	324.575	14	2012	187.250
4	2002	198.108	15	2013	276.333
5	2003	174.517	16	2014	197.433
6	2004	180.900	17	2015	232.633
7	2005	192.125	18	2016	235.342
8	2006	181.133	19	2017	276.792
9	2007	234.525	20	2018	231.192
10	2008	219.125	21	2019	215.450
11	2009	181.042			

Table 2. The Statistical parameters

NO	YEAR	X	X^2	(X1-X)	$(X1-X)^3$	$(X1-X)^4$
1	1999	243.133	59113.8	17.115	5014	85813.56
2	2000	223.392	49903.8	-2.626	-18.113	47.567
3	2001	324.575	105348	98.557	957336	94352284.5
4	2002	198.108	39246.912	-27.910	-21739.887	606749.89
5	2003	174.517	30456.1	-51.501	-136600.34	7035080.52
6	2004	180.900	32724.8	-45.118	-91842.9	4143752.991
7	2005	192.125	36912.1	-33.893	-38933.6	1319570.9
8	2006	234.525	55001.9	-44.885	-90425.3	5237.64
9	2007	219.125	48015.8	8.907	615.675	2257.8
10	2008	181.042	32776.1	-6.891	-327.490	28892334.9
11	2009	242.042	89600.4	8.507	-90980.4	65926.9
12	2010	187.250	58584.2	-8.77	-394082.3	667611.6
13	2011	276.633	35062.6	9.324	-4114.3	1915.334
14	2012	235.23	76360.1	6.615	-58266.03	7557.420
15	2013	276.333	55385.7	50.774	127381	6645979.5
16	2014	197.333	534423.45	-10.005	289.523	716.542
17	2015	232.633	65221.1	7.823	-23355.700	12472.334
18	2016	235.192	103248	8.993	-1180.214	5324.67
19	2017	215.450	38979.2	10.342	810.520	4091953.314
20	2018	226.018	39223.1	-23.554	138.494	124733.45
AVERAGE		226.018				160664044.4

In determining the type of distribution, it will be carried out by means of dispersion measurements. In these measurements, the distribution test factors must be known as follows:

- Standard Deviation (Sx)

$$Sx = \sqrt{\frac{\Sigma\,(Xi - X)^2}{(n-1)}} = \sqrt{\frac{34117.085}{20}} = 41.3019 \quad (1)$$

- Coefficient of Skewness (Cs)

$$Cs = \frac{n\,.\,\Sigma\,(Xi - X)^3}{(n-1)\,.\,(n-2)\,Sx^3} = \frac{22407114}{26772965.45} = 0.837 \quad (2)$$

- Sharpness/Kurtosis Coefficient (Ck)

$$Ck = \frac{n^2\,.\,\Sigma\,(Xi - X)^4}{(n-1)\,.\,(n-2)\,.\,(n-3)\,Sx^4} = 0.064 \quad (3)$$

- Coefficient of Variation (Cv)

$$Cv = \frac{Sx}{Xi} = \frac{41.3019}{226.018} = 0.17 \quad (4)$$

The result show that Cs = 0.837 and Ck = 0.064, the analysis will use the Pearson Log Distribution III, based on a comparison of distribution requirements and frequency distribution tests. Furthermore, from the results of the statistical analysis of the parameters using the Pearson Log III, it is possible to calculate the design rainfall analysis for various return periods. The results of the calculation of rainfall with the Pearson Log Type III method, are as follows:

- Average ($Log\ \bar{X}$)

$$Log\ \bar{X} = \frac{\Sigma x}{n} = \frac{49.2998}{21} = 2.3476 \quad (5)$$

- Standard Deviation (Sx)

$$Sx = \sqrt{\frac{\Sigma\,(Log\ Xi - Log\ \bar{X})^2}{(n-1)}} = \sqrt{\frac{0.1163}{20}} = 0.0762 \quad (6)$$

- Coefficient Skewness (Cs)

$$Cs = \frac{n\,.\,\Sigma\,(Log\ Xi - Log\ \bar{X})^3}{(n-1)\,.(n-2)Sx^3} = \frac{22407114}{26772965.45} = 0.4984 \quad (7)$$

Furthermore, the results of the statistical parameter analysis using the Pearson Log III, can be calculated from the design rainfall analysis for various return periods can be seen in Table 3.

4.2. Flood discharged analysis

In the calculation of rainwater discharge, the rational method is used. The magnitude of the runoff coefficient (C) is influenced by the topography of the land. The C value is taken from the average runoff coefficient value of each land use designation in Panakukang District.

- catchment area, A = 0.19 km^2
- runoff coefficient, C = 0.81 with length of canals, L = 2951.81 m
- Slope, S = 0.00023
- Flow velocity in the channel, v = 0.98 m/s
- Surface flow time,

  t_o = $0.0195\ L_o^{0.77}\ S^{-0.385}$
  = $0.0195\ 67.37^{0.77}\ 0.00023^{-0.385}$
  = 12.47 minute
- Stream time in the channel,

  t_s = L / v x 60
  = 2951.81 / 0.98 x 60
  = 50.20 minute
- Concentration time,

  t_c = t_o + t_s
  = 12.47 + 50.20
- Design rain intensity, I = 202.3 mm/hrs
- Rainwater Runoff Debit (Q_1)
  = 0.2778 x C x I x A
  = 0.2778 x 0.81 x 202.38 x 0.19 = 8.67 m^3/s

Table 3. The rainfall design

T (Period)	k	Log $\bar{X}$	Sx	Rainfall design (mm)
2	-0.083	2.3476	0.0762	219.43
5	0.808	2.3476	0.0762	256.58
10	1.323	2.3476	0.0762	280.86
15	1.714	2.3476	0.0762	300.86
25	1.910	2.3476	0.0762	311.32
50	2.310	2.3476	0.0762	334.01
100	2.685	2.3476	0.0762	356.72

- Average Domestic Effluent Debit (Q_2)
  = 0.00000139 x Pn
  ➔ with Total population (Pn) = 317.68 ppl
  = 0.000442 m^3/s

Design flood discharge (Q_{design}) is rainwater discharge (Q_1) plus domestic discharge water discharge (Q_2), where the Rain Return Period (PUH) used is 5 years for secondary drainage channels and Rain Return Period (PUH) 10 years for drainage channels that can be seen in Figs. 5 and 6. The following is an example of design discharge analysis on the Urip Sumohardjo 1 Primary Canal (SP. US1):

Q_{design} = Q1 + Q2 = 8.67 + 0.000442 = 8.67 m^3/second

Downspouts and gutter systems are a structure's first defense against over-saturation from stormwater. They are often drained into an aluminum extension, buried drainpipe, rain barrel, or other solution. The evaluation of the capacity of the drainage channel is to analyze the capacity of the existing drainage channel to accommodate the design flood. If the channel is unable to accommodate the design flood discharge, inundation will occur due to excess runoff.

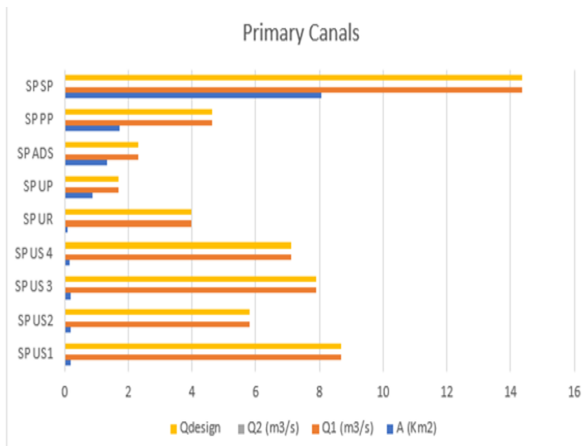

Figure 5. The Flood discharge design for primary canals

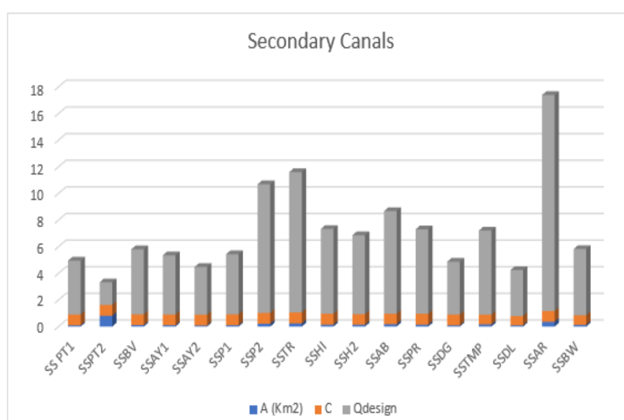

Figure 6. The Flood discharge design for secondary canals

The inundation that occurs is the difference between the design flood discharge (Qranc) and the channel capacity (Qsal). Table 4 shows the comparison of Q_{design} and Q_{canals}. A drainage system consists of piping that conveys sewage, rainwater, or other liquid waste to a point of disposal, either in the sewer system or septic tank. Its main objective is to collect and remove wastewater and keep sewer gases out of the building.

It can be said that there are several canals is not fulfilling the requirements. Therefore, infiltration wells are planned in several locations that experience inundation, where the Q_{canals} does not meet the Q_{design}. The volume of the infiltration well can be calculated using the cylinder volume formula.

$$V = 1/4\, \pi\, d^2\, x\, h \quad (8)$$

where, V = Infiltration well volume; d = Diameter of the infiltration well; h = depth of infiltration well. The amount of reduction that can be carried out by infiltration wells is shown in Table 5.

From Table 5, infiltration wells are quite effective as an alternative solution in reducing inundation that occurs in Panakukang District. These findings are in line with the statement from previous research that said that soakaways & infiltration wells provide stormwater attenuation and thus groundwater recharge. The main benefit is that it offers minimal net land take with a good volume reduction and peak flow attenuation. Easy to build and operate, they can be grouped and linked together to drain large areas including highways [10], [15], [16]. An accurate estimate of infiltration rate is crucial in hydrology, agricultural and civil engineering, irrigation design, and soil and water conservation. Infiltration is the vector for solutes into the soil profile and is a determining factor for their concentration in the runoff.

Table 5. The amount of reduction of inundation in Makassar

Code of Canals	Q_{design}	Qcanals	Vinfiltration	Reduction of Inundation
PRIMARY CANALS				
SP.US1	8.68	6.21	2.36	-0.11
SP.US3	7.91	6.77	2.36	1.22
SP.US4	7.12	5.38	2.36	0.61
SP.UR	3.99	2.89	2.36	1.27
SECONDARY CANALS				
SS.PTY1	4.04	2.47	2.36	0.80
SS.P1	4.51	4.17	2.36	2.02
SS.P2	9.66	9.31	2.36	2.01
SS.TR	10.54	10.40	2.36	2.22
SS.DL	3.45	3.24	2.36	2.15
SS.AR	16.22	16.11	2.36	2.25
SS.BW	4.97	4.86	2.36	2.25

5. Conclusion

The term "flood" refers to any episode entailing the overflowing of water or flowing of water in areas usually not submerged. In urban areas, two main phenomena are generally related to the occurrence of flooding: the overflow of watercourses (fluvial or overbank flooding) and the generation of stormwater during precipitation events (flash flooding). The result showed that from the 4 types of primary canals, an average of 1.03 m^3/sec can be obtained. while the evaluation results for the secondary channel obtained 7 channels with a reduced average inundation discharge of 1.97 m^3/s. It can be concluded that from nine primary canals and 17 secondary canals that were studied, over four primary canals and seven secondary canals need to build infiltration wells due to they do not meet the requirements $Q_{canals} > Q_{design}$.

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