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AN INNOVATIVE SUSTAINABLE APPROACH ON URBAN DRAINAGE SYSTEM OF MANADO CITY

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ABSTRACT

The aims of this research were to identify the condition and problems of the existing drainage system and its infrastructures and to conceptualize an innovative design of a sustainable urban drainage system which was expected to productively overcome the existing problems in urban drainage within the sub-district of Tuminting. However, the research was limited to reviewing the current urban drainage conditions and problems and excluding the effect of channel's structural strength in the drainage system designed. The case study was based on survey of the actual conditions on the field. Data were collected from primary and secondary sources. Engineering reviews of the physical properties of urban drainage data consisted of hydrology and hydraulic analysis. Data related to operation and maintenance of the drainage scheme under study and the available non technical problems were compiled and analyzed collectively to come up with a comprehensive appreciation of solutions to solve the city's urban drainage problems. An innovative design developed in this research basically suggested 3 construction management alternatives, namely 1) implementation of periodic and intensive O&M and R&U programs, 2) realization of integrated catchments management, 3) systematic relocation and reconstruction of the urban drainage system. Each alternative has its own rationales which principally caters for the sustainable urban drainage system that would act not only to drain excess water from urban localities but that would furthermore support land and water conservation.

KEYWORDS: urban drainage, sustainable drainage, innovative drainage

1. BACKGROUND

The increase in population and the increase in public demand on better living environments in Manado have caused such an escalating need to improve public infrastructures of the city. Land-use characteristics projected at the end of the implementation period of the city's spatial plan granted about 56.11% of the total land-use of the city area to residential and public infrastructures zones. On the other hand based on the city's Planning and Development Board data on urban drainage, there is a projected extension of the built-environment area from 275 ha to 387.94 ha by the year of 2010. This change of land-use pattern (which reduced the land coverage) predicted an increase of the city area to equal to 41%. Consequently, this development may also increase the possibility of larger surface runoff discharge as well as reduce the areas for storm water infiltration within the city surrounds. Jalan Hasanuddin, the city's main road located in the Tuminting sub district, is the road that connected the downtown areas to the villages located in the northern part of the city of Manado like Molas, Wori, Meras and others. The drainage system within this area, particularly around the Sub District office has been experiencing a serious drainage problem. It is frequently inundated during rainy season and therefore provides negative impacts to local community activities and to the condition of the road itself, i.e.: damaging road pavement and contributing to suspension of traffic flow. The drainage channels within the area were supposed to accommodate all the rain water runoff from surrounding areas which have relatively higher topography. These channels then carried the waste water into the outlet. It usually was brown due to high concentration of sediment, and it was always directly discharged into Manado bay. Occurred inundated zones generally spread over certain areas within the study location, especially over the relatively flat and hollow region. Typical land-use which is normally experiencing flooding and inundation were the residential areas and the public and socio-economic infrastructures. According to field surveys and interviews with local residents, the highest water elevation during inundation period could reach up to 1.5 meters. The inundation occurred not only annually, but also sporadically whenever there were high rainfall events. It affected various activities of the people such as schooling, office, business, traffic. Due to the complicated nature of impacts it has

on the city inhabitants it is deemed necessary to study the drainage problems along the service area to find out the cause of the problems and to seek for answers. Accordingly the research focused on the problems and the probable engineered solutions related to drainage channel system at and around the surroundings of the police station of North Manado Sector, the local market, the gas station and the sub district office of Tuminting. The expectation was that the study area would act as a pilot research for the whole city.

2. RESEARCH METHODOLOGY

The case study was based on survey of the actual conditions in the field. Primary data were obtained consisted of in-depth interviews with experienced persons from the local agency responsible for urban drainage management and the surrounding communities within or in the vicinity of the study area. Secondary data were collected in the form of topographical maps, rainfall data, etc. These included identification of existing urban drainage problems. Hydrology review was implemented which covered the analysis of rainfall data outlier, the selection of rainfall data distribution type based on data skewness, variability and kurtosis, the application of Smirnov-Kolmogorov test to check the suitability of data distribution, the calculation of rainfall intensity and flood discharge. Hydraulic analysis basically involved the evaluation of the existing hydraulic dimensions of channels and culverts. Data related to operation and maintenance of the drainage scheme under study as well as the available non technical problems were compiled and analyze collectively to come up with a comprehensive appreciation of the city’s urban drainage system present and potential challenges, future demands and plans.

3. RESULTS AND DISCUSSION

3.1. Important features of the city urban drainage

There are four specific features that would commonly stick to an urban drainage system. They are: 1) the fundamental role it has to urban living, 2) its characters of inducing low individual costs but high total costs, 3) the rather insubstantial structures it has that are low-profile and usually behind the scenes, 4) its failure criteria which are normally determined by flooding or inundation incidences. In this study, urban drainage has been mistakenly ignored mostly by the local community and sometimes by the government of the city. People’s habit of throwing litter and garbage into a drainage channel, changes in land use of the catchment’s area, increase in discharge debit due to loss of land coverage to housing or to any other uses, the lack of sufficient maintenance of the channels like no regular sediment removal, lack of proper channel rehabilitation and upgrading practices and in particular the recurrent characteristic of inundation within the study area indicated that the existing urban drainage system failed to provide the fundamental role of the city’s drainage system to urban living.

3.2. Rainfall Analysis

Rainfall data from a 10 year measurement was obtained from Kayuwatu climate station in Paniki, Manado. This is the closest climate station to the study site and was the only station that is equipped with automatic rainfall recording devices. The equipment was capable of automatically recorded hourly rainfall depth. Rainfall data collected for the research is presented in Table 1.

Table 1. Rainfall depth in mm/day for different duration

No	Year	DURATION (Second)									
		5	10	15	30	45	60	120	180	360	720
1	1999	76,0	77,0	80,0	87,0	88,5	96,0	140,5	154,5	162,7	188,1
2	2000	11,6	19,8	25,8	37,0	54,6	56,2	78,0	84,0	90,8	104,8
3	2001	10,1	21,1	58,0	53,5	53,5	53,5	53,5	53,5	77,6	77,6
4	2002	12,0	15,5	36,0	48,5	53,1	53,9	61,7	75,6	83,0	89,5
5	2003	27,0	32,5	34,5	44,0	53,0	62,0	104,1	136,1	151,5	151,5
6	2004	67,0	67,8	71,0	85,3	95,6	103,2	106,4	112,7	158,5	158,7
7	2005	29,0	35,0	40,5	59,5	60,3	72,0	103,0	113,0	114,6	114,6
8	2006	20,0	29,4	39,4	69,4	79,4	90,8	90,8	90,8	90,8	90,8
9	2007	16,8	26,0	30,0	42,8	60,0	74,6	100,8	108,2	135,0	138,8
10	2008	10,0	20,0	27,5	40,0	44,0	58,0	76,5	80,1	81,5	81,6

Source: Kayuwatu Climate Station (2009)

3.3. Outlier data analysis

This analysis is intended to examine whether there are outliers in the observed rainfall data. It begins with first calculating the average value, standard deviation, and coefficient of skewness of in logarithmic values. The result of the analysis showed that the data contained no outliers either the high

outlier or the low one (see Table 2). The statistical parameters of rainfall data for a range of rainfall durations are presented in Table 3.

Table 2. Result of outlier test for a variety of rainfall duration values.

No	Test	DURATION (Second)									
		5	10	15	30	45	60	120	180	360	720
1	Xh	96,51	87,72	91,54	101,4	104,5	116,4	158,1	181,9	201,8	201,8
2	Xl	4,681	10,251	18,491	29,04	37,13	42,18	49,36	51,41	60,06	60,06
3	Xa	76	77	80	87	95,6	103,2	140,5	140,5	162,7	188,1
4	Xb	10	15,5	25,8	37	44	53,5	53,5	53,5	77,6	77,6

Table 3. Statistical Parameters of Rainfall Data for a Variety of Durations

Duration (Second)	S	Slog	\bar{X}	$\log \bar{X}$	Cv	Cs	Cslog	Ck
5	288,050	0,322	335,40	2,407	0,859	1,493	0,799	0,479
10	126,245	0,229	206,46	2,255	0,611	1,469	0,867	0,485
15	75,53	0,171	177,02	2,216	0,427	1,070	0,669	0,379
30	36,53	0,133	113,26	2,035	0,323	0,819	0,506	0,329
45	23,115	0,110	85,610	1,919	0,270	0,950	0,680	0,350
60	18,634	0,109	72,02	1,845	0,259	0,659	0,464	0,286
120	12,623	0,124	45,79	1,645	0,276	0,330	-0,353	0,431
180	10,049	0,135	33,63	1,508	0,299	0,324	-0,384	0,376
360	5,736	1,130	19,09	1,263	0,300	0,372	0,211	0,225
720	3,134	0,133	9,98	0,980	0,314	0,621	0,287	0,320

3.4. Analysis of probability distribution

Hydrology analysis of rainfall data is carried out to determine the value of rainfall depth that may occur in a certain period. Accuracy of the results of the analysis will depend on the total chances a certain type of probability distribution could represent the distribution of the observed actual data. Probability distribution type conformity based on statistics parameters was reviewed. The result is presented in Table 4.

Table 4. Review on the compliance of probability distribution types based on statistical parameter

Duration	Statistical parameter condition				Obs. statistical parameter of data	Proposed distribution type to use
	Normal (N)	Log Normal (LN)	Gumbel (G)	Log Pearson III		
5	Cs≈0	Cs≈3Cv Cs=2,58	Cs=1,14 Ck=5,4	If N, LN, G not applicable	Cs = 1,493 Ck = 0,479	Log Pearson III
10	Cs≈0	Cs≈3Cv Cs=1,83	Cs=1,14 Ck=5,4	If N, LN, G not applicable	Cs = 1,469 Ck = 0,485	Log Pearson III
15	Cs≈0	Cs≈3Cv Cs=1,29	Cs=1,14 Ck=5,4	If N, LN, G not applicable	Cs = 1,070 Ck = 0,379	Log Pearson III
30	Cs≈0	Cs≈3Cv Cs=0,96	Cs=1,14 Ck=5,4	If N, LN, G not applicable	Cs = 0,819 Ck = 0,329	Log Normal
45	Cs≈0	Cs≈3Cv Cs=0,81	Cs=1,14 Ck=5,4	If N, LN, G not applicable	Cs = 0,950 Ck = 0,350	Log Normal
60	Cs≈0	Cs≈3Cv Cs=0,78	Cs=1,14 Ck=5,4	If N, LN, G not applicable	Cs = 0,659 Ck = 0,286	Log Normal
120	Cs≈0	Cs≈3Cv Cs=0,84	Cs=1,14 Ck=5,4	If N, LN, G not applicable	Cs = 0,330 Ck = 0,431	Normal
180	Cs≈0	Cs≈3Cv Cs=0,90	Cs=1,14 Ck=5,4	If N, LN, G not applicable	Cs = 0,324 Ck = 0,376	Normal
360	Cs≈0	Cs≈3Cv Cs=0,90	Cs=1,14 Ck=5,4	If N, LN, G not applicable	Cs = 0,372 Ck = 0,225	Normal
720	Cs≈0	Cs≈3Cv Cs=0,93	Cs=1,14 Ck=5,4	If N, LN, G not applicable	Cs = 0,621 Ck = 0,320	Log Pearson III

The evaluation of the most appropriate probability distribution type was carried out using a suitability test. This research utilized the method of Smirnov - Kolmogorov. Application of Kolmogorov-Smirnov test was to examine the maximum difference value demonstrated by a variety of probability functions, each compared the distribution between observed and theoretical data. The result of the Kolmogorov-Smirnov test is presented in Table 5. In Table 5, the calculated value of D_{max} for each of the rainfall durations were not greater than the required D. Thus, it can be concluded that the distribution equation obtained can be used in subsequent calculations. The calculated values of rainfall depth at a range of return periods based on a set of rainfall durations are presented in Table 6. The obtained rainfall depths were the short-period rainfall depth in mm/h (Table 6). There were 3 formulas used to calculate rainfall depth for a short-return period, i.e. the Talbot, Sherman and

Ishiguro formulas. The next step was the examination to evaluate the most appropriate formula used for any rainfall duration. The results can be seen in Table 7.

Table 5. The maximum difference value of probability functions (Dmax)

No	Duration	Type of distribution	(Dmax)	Smirnov – Kolmogorov Test requirement
1	5	Log – Pearson III	0,1230	Do < 0,41
2	10	Log – Pearson III	0,1350	Do < 0,41
3	15	Log – Pearson III	0,1150	Do < 0,41
4	30	Log – Normal	0,1220	Do < 0,41
5	45	Log – Normal	0,0600	Do < 0,41
6	60	Log – Normal	0,044	Do < 0,41
7	120	Normal	0,0620	Do < 0,41
8	180	Normal	0,1250	Do < 0,41
9	360	Normal	0,2000	Do < 0,41
10	720	Log – Pearson III	0,1100	Do < 0,41

Table 6. Calculation result of rainfall depth over particular duration

Tr	Duration									
	5	10	15	30	45	60	120	180	360	720
2	231,4	166,8	161,3	108,4	83,0	70,0	45,8	33,6	19,1	9,4
5	455,8	270,4	224,7	140,2	102,7	86,4	56,4	42,1	23,9	12,3
10	688,9	364,3	277,8	160,4	114,8	96,5	61,9	46,5	26,4	14,3
20	1037,7	489,7	341,1	179,1	125,7	105,6	66,5	50,1	28,5	16,4
25	1126,5	519,5	355,5	187,1	130,3	109,4	68,3	51,5	29,3	16,8

Table 7. The comparison of suitability of rainfall intensity formulas

No	T	I	Rainfall Intensity			Deviation M([s])		
			Talbot	Sherman	Ishiguro	Talbot	Sherman	Ishiguro
[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
						[4]-[3]	[5]-[3]	[6]-[3]
1	5	688,9	566,5	827,3	821,4	-122,4	138,4	132,5
2	10	364,3	417,4	547,2	342,3	53,1	182,9	-22,0
3	15	277,8	330,4	429,6	236,5	52,6	151,8	-41,3
4	30	160,4	203,3	284,1	139,3	42,9	123,7	-21,1
5	45	114,8	146,8	223,1	105,9	32,0	108,3	-8,9
6	60	96,5	114,9	187,9	88,1	18,4	91,4	-8,4
7	120	61,9	61,5	124,3	57,9	-0,4	62,4	-4,0
8	180	46,5	41,9	97,6	45,9	-4,6	51,1	-0,6
9	360	26,4	21,5	64,5	31,2	-4,9	38,1	4,8
10	720	14,3	10,9	42,7	21,5	-3,4	28,4	7,2
Σ([s])						63,26	976,52	38,22
M([s])						6,33	97,65	3,82

3.5. Examining the Rainfall Intensity formulas

From examining the average deviation of the 3 rainfall intensity formulas, it was identified that Ishiguro was the formula that had the smallest average deviation (Figure 1). From this formula an intensity curve was developed, with rainfall duration (t) as the horizontal axis and rainfall intensity (I) as the vertical axis. As can be seen from Figure 2, this curve then was used to determine the rainfall intensity of a 10 year return period for any value of rainfall duration (time concentration).

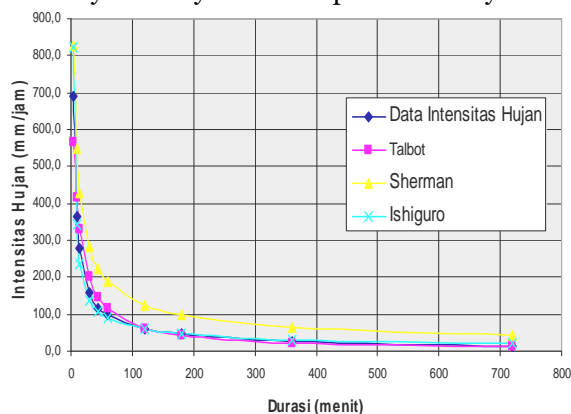


Figure 1. Comparison among 3 rainfall intensity formulas

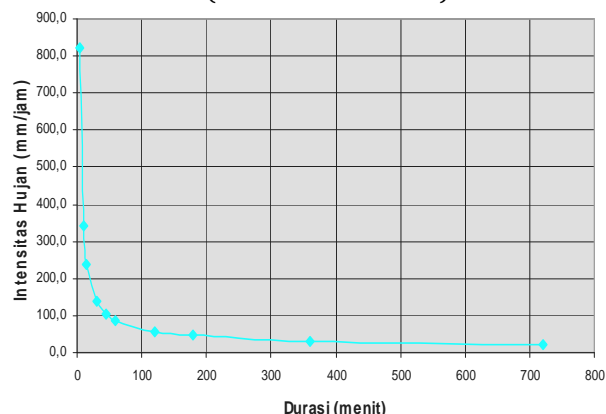


Figure 2. Rainfall intensity curve

3.6. Calculating the designed discharge

Designed discharge for a drainage channel was calculated using the rational method. Complete calculation results for each channel segments for the study area can be seen in Table 8.

Table 8. Calculation of Design Discharge (Qdes) at planning and design sites

No	Channel	Catchment Area (A) (Ha)	s (m)	LL (m)	C	S	V (m/s)
1	S (1 - 2)	0,0450	45,00	60	0,5	0,008	0,40
2	S (3 - 2)	0,1013	90,00	125,00	0,5	0,026	0,40
3	GG I						
4	S (4 - 5)	0,2640	90,00	155,00	0,5	0,065	0,40
5	S (5 - 6)	0,1964	35,00	55,3	0,5	0,089	0,40
6	S (7 - 6)	0,2869	95,00	115,00	0,5	0,055	0,40
7	GG II						
8	S (8 - 9)	0,2530	95,00	98,60	0,5	0,005	0,40
9	S (9 - 10)	0,1950	62,50	64,20	0,5	0,023	0,40
10	S (19 - 17)	0,2600	85,00	125,03	0,5	0,016	0,40
11	S (18 - 17)	0,1600	60,00	64,20	0,5	0,008	0,40
12	GG III						
13	GG V						
14	S (15 - 16)	0,2126	105,00	110,00	0,5	0,004	0,40
15	S (12 - 11)	0,0940	80,00	96,40	0,5	0,020	0,40
16	S (13 - 14)	0,2138	75,00	89,40	0,5	0,005	0,40
17	GG IV						
18	S (20 - 21)	0,4000	100,00	115,00	0,5	0,004	0,40
19	S (22 - 23)	0,7050	125,00	118,00	0,5	0,001	0,40

No	t _i minute	t _s minute	t _c minute	I (mm/hour)	Q design m ³ /s	Remarks
1	16,665	1,875	18,540	198,984	0,0124	
2	18,647	3,750	22,397	236,442	0,0333	
3					0,0480	
4	14,623	3,750	18,373	153,580	0,0563	
5	4,459	1,458	5,917	633,179	0,5336	
6	11,795	3,958	15,753	138,923	0,0554	
7					0,1724	
8	33,540	3,958	37,499	119,478	0,0420	
9	10,289	2,604	12,894	114,229	0,3132	OUTLET
10	24,131	3,542	27,672	112,489	0,0406	
11	17,012	2,500	19,512	108,185	0,0240	
12					0,0951	
13					0,0951	
14	42,075	4,375	46,450	103,709	0,0911	OUTLET
15	16,337	3,333	19,670	189,989	0,0248	OUTLET
16	31,078	3,125	34,203	169,845	0,0504	
17					0,0504	OUTLET
18	44,976	4,167	49,142	99,993	0,056	OUTLET
19	100,562	5,208	105,770	62,405	0,061	OUTLET

The calculations and review of the existing channel dimensions were carried out based on a capacity requirement as such that the existing channel capacity (Qcap) should be larger than the designed discharge for the channel (Qdes) or $Q_{cap} \geq Q_{des}$. Had any of the existing channels do not meet the capacity requirements ($Q_{cap} \geq Q_{des}$) a review on the segment's dimension will have to be carried out to decide on any remedial actions. *What the analyzed data presented.* Most segments' hydraulic properties demonstrated sufficient channel capability to contain waste water discharge resulted from the whole catchments at the area under study. However, from direct observation and interviews it was identified that the severe inundation events occurred annually mostly during rainy season at times when domestic waste discharge and high sea level due to high tide were concurrent. A short-termed solution presented a modified design of channel' dimension and the blockage of a certain culvert. This was implemented referring to the existing drainage network system. In general, the design might further involve the improvement of existing structures which experiencing problems. The remedial activities might consist of improving additional channel capacity or replacing with new channels and/ or new structures. Providing regular and affordable operation, maintenance, rehabilitation and upgrading of the urban drainage system. This alternative may be effectively carried out in a sustainable way only if the management of drainage system accommodate and exercise a significant amount of control from the local community. This option may incur a certain amount of budget which needs to be secured annually by the government to regularly provide suitable designs and constructions to overcome the recurrent inundation problems of the study area.

The second alternative was to introduce an integrated management for the whole drainage catchments, ie. from the upstream of the catchments to the outlet. This will include: a careful evaluation of the spatial plan related to areas allocated for future development, a relatively accurate estimation of upcoming water balance to provide several sustainable urban drainage management scenarios, implementation of exclusive action plan that deal with certain urban drainage issues at a certain time, the use of early warning system as a means of flood mitigation program. However since there was a lack of comprehension demonstrated by the local community on the fundamental role of a well maintained drainage system to urban living, it will be the government task to encourage the local community and to provide a clear, consistent mind-set on the management of urban drainage within the neighborhood. Though it may involve a huge amount of investment, the third alternative could commence as a pilot project for the city in the future. It strongly considered the relocation of the community to temporarily live in public housings and the reconstruction of the residential environment which at present was perceived as an intolerable and unmanageable slump area. This notion may induce a significant impact on the socio-cultural and economic aspects of the affected community. However, it may create an engineered environment where the drainage system are carefully designed and constructed, as well as resourcefully equipped with adequate management infrastructures to ensure the sustainable management of urban drainage within the drainage catchments area.

4. CONCLUSION

The evaluation on existing drainage channels within the study area revealed that the hydraulic dimension required for most of the channels complied with the channels capacity requirements. Hence a few rehabilitation works needed basically involved the modification of channel dimension and the alteration of flow direction.

However, the probability of inundation to occur was substantially high because of the relatively plain topography of the study area. This indicated most of the long cross section slope of the channel was mild to very mild and the velocity of the flow was frequently quite small. This condition was perfect for generating sedimentation along the channel segments, followed by a gradual decrease in the channels' capacity. The lack of routine maintenance added up to provide an ideal condition which lead the sub district into flood prone areas.

An innovative design developed in this research basically suggested 3 construction management alternatives, each has its own rationales which principally cater for the sustainable urban drainage system that would act not only to drain excess water from urban localities but that would also support land and water conservation. The three alternatives are:

- 1) implementation of periodic and intensive O&M and R&U programs,
- 2) realization of integrated catchments management,
- 3) systematic relocation and reconstruction of the urban drainage system.

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