Effectiveness of Horizontal Drainage System and Vertical Drainage Against Inundation in Residential Areas (Case Study of Katimbang Urban Village, Makassar City)

Rezky Amalia Putri, Rita Tahir Lopa and Riswal Karamma

September 24, 2024

Effectiveness of Horizontal Drainage System and Vertical Drainage Against Inundation in Residential Areas (Case Study of Katimbang Urban Village, Makassar City)

Rezky Amalia Putri[1*], Rita Tahir Lopa[2], Riswal Karamma[3]
[1,2,3]Department of Civil Engineering, Hasanuddin University, Makassar, Indonesia
amaliaputri2011@gmail.com, ritalopa04@yahoo.com,
riswalchiwal@gmail.com

Abstract

Katimbang urban village is one of the urban villages in Makassar city, Indonesia, whose land use is dominated by settlements, which make up 58% of the area, which indicates a lack of water catchment areas and causes inundation when it rains. The drainage system used is still conventional and unable to handle standing water effectively. This research intends to examine the effectiveness of horizontal and vertical drainage systems in managing inundation. The method used is a descriptive-quantitative approach through a survey and data analysis. The results revealed that the horizontal drainage system failed to handle the design rainfall with a 2-year return period of 129.67 mm for tertiary drainage and the design rainfall with a 5-year return period of 170.60 mm for secondary drainage, resulting in inundation at 13 points with a total inundation of 10.74 m3/sec. The effectiveness of the vertical drainage system against inundation without the use of infiltration wells and rain harvesting has been considered ineffective because it has a low soil permeability coefficient of 3x10-6 m/sec. According to the results, the use of infiltration wells can only decrease flooding by 15% and rain harvesting by 30% of total inundation.

1 Introduction

The urbanization has become one of the most important human activities on the planet (Fang et al., 2021). The global urbanization is happening on a large scale (Liu et al., 2019). The phenomenon of urbanization is always accompanied by the development of physical infrastructure facilities that still adopt “grey infrastructure” practices such as paving and concreting, which are still widely applied in urban areas around the world (Dhakal & Chevalier, 2017).

Urbanization also contributes to the occurrence of climate change phenomena, especially due to the clearing of forest land to be converted into built-up land (Dessu et al., 2020). In the context of climate change, the frequency and intensity of extreme precipitation events show an increasing trend, which exacerbates the potential of urban inundation (Hosseinzadehtalaei et al., 2020), can cause flood and drought events to become more frequent and severe (Butler et al., 2017; Sweya et al., 2018).

The intensity and frequency of extreme precipitation events are trending upward in the context of climate change, which increases the risk of urban inundation (Hosseinzadehtalaei et al., 2020). Flooding happens when drainage fails to act as a pathway for directing excess water. Unregulated land use has further exacerbated urban drainage concerns. In addition to sedimentation, the condition of damaged channels is one of the reasons of flooding (Luciana & Edijatno, 2013).

A drainage system is an infrastructure that drains rainwater and waste from the land surface to a final disposal site, such as a river (Adugna et al., 2019). It is essential to control flooding and maintain water quality and urban ecology. These drainage systems include drains, pipes, ponds, pumps, and flood control structures (Teshome Sewnet & Revathi Devi, 2020).

The new drainage system paradigm situates drainage systems in cities as the infrastructure of cities based on the idea of ecologically friendly or sustainable drainage (Vieira et al., 2014). The development of this environmentally sound drainage concept is reinforced by the Zero Delta Q principle policy, which requires that each building not cause an increase in water discharge into the drainage system or river flow system (Government regulation, 2008).

Currently, the concept of environmentally sound drainage is being developed. A sustainable drainage system is a form of drainage management that starts with utilizing rainwater, storing runoff, allowing water to seep, settling sediment, and absorbing pollutants to dispose of them slowly into the water body (Lopa & Shimatani, 2013).

The main objectives of urban drainage are to reduce flood risk, maintain water quality, and maintain ecological balance in urban areas (La Loggia et al., 2020). As a result, retaining rainfall is important to enhance the volume of water that penetrates into the earth via natural and manmade infiltration regions(Sedyowati & Suhartanto, 2015). Rainfall can be used as an alternative water supply by encouraging rainfall gathering and reuse for non-potable purposes like irrigation (Rahman, 2021).

Makassar City is one of the cities in Indonesia that is often affected by flooding problems. The high intensity of rainfall recorded at 3,722 mm/year, the geographical conditions drained by rivers, namely the Tallo River and the Jeneberang River, the topography of the area ranges from 0–25 meters above sea level and the water catchment area in this case, Green Open Space, only reaches 2,422 hectares, or around 13 percent of the total area of Makassar City, causing this area to be increasingly vulnerable to flood disasters (BPS Makassar, 2022).

Floods and inundation are still a scourge for all Makassar residents. A bad experience occurred in early 2019, when the worst flood occurred in the last decade. Flooding in Makassar City is not only influenced by relatively high rainfall intensity, topographic conditions in the form of basins, increased flow discharge, and changes in land use patterns and tides; it is also influenced by inadequate drainage systems. Even though the city administration has planned and developed infrastructure, flooding remains a severe issue (Karamma et al., 2021).

In early 2020, the South Sulawesi Regional Disaster Management Agency mapped areas considered at risk of disaster in the extreme weather season. There are 24 districts or cities categorized as red zones, including Makassar. Mapped areas or points prone to inundation in Makassar, including the Nipa-Nipa area, Antang Housing Block 10, Paccerakkang, Tamalanrea, and Panakukang (Disaster study center UNHAS, 2023).

Katimbang Village is one of the villages in Biringkanaya Sub-district. This area was only formed in 2015 as a result of the expansion of Paccerakkang Village. The largest land use in Katimbang Urban Village is settlements with an area of built and unbuilt buildings, indicating that this area is an area that has not optimally absorbed water into the ground when it rains, or in this case, there is still a lack of water catchment areas, so that inundation occurs. The level of flood hazard in Katimbang Village is divided into two levels, namely medium and high (Algafari & Surur, 2021).

Katimbang Village is one of the areas that was severely affected by flooding in early 2019. Every rainy season, it is recorded that Katimbang Village continues to experience flooding and inundation problems with high rainfall intensity and low rainfall intensity with a water level of approximately 1.5 meters (BPBD Makassar, 2019). As a result of the heavy flooding, passing automobiles experienced engine failure as drainage on the other side of the surface overflowed onto the road.

The drainage system in Katimbang Village is still done with a conventional concept where, when it exceeds its capacity, water overflows into puddles. The direct impact of inundation on buildings is the loss of building function and physical damage, both of which can be calculated into financial (economic) losses because, in addition to the costs that must be provided for repairs, there is also a loss of opportunity to carry out other activities (Ali, 2010).

The occurrence of a series of floods and inundations in a relatively short period of time and repeated annually, even occurring more than once a year, requires greater effort and innovation to anticipate them so that losses can be minimized (Isik et al., 2013)

Vertical drainage systems are essential because they are part of an effort to increase the effectiveness and efficacy of drainage systems in dealing with flooding problems in urban areas (Kanso et al., 2018).

The application of vertical drainage technology is one of the solutions to reduce inundation and improve environmental quality in Katimbang Village and other urban areas (Stefanakis, 2019). Given the concerns outlined above, the existing status of the environment, and the losses incurred, it is vital to investigate alternatives of overcoming these issues.

2 Material And Methods

2.1 Research location and Data

The research location is in Katimbang Village, Makassar City, Indonesia. Katimbang is located at coordinates 05˚08'22.40" N and 119˚31'25.50" E, with an area of 2.11 km2, as shown in Fig. 1. This village was chosen as the research location because it is a flood-prone area during the rainy season. In general, the drainage system in Katimbang Village still uses a combined drainage system, where wastewater and rainwater disposal are channeled through one channel. This is due to the limited land available for drainage.

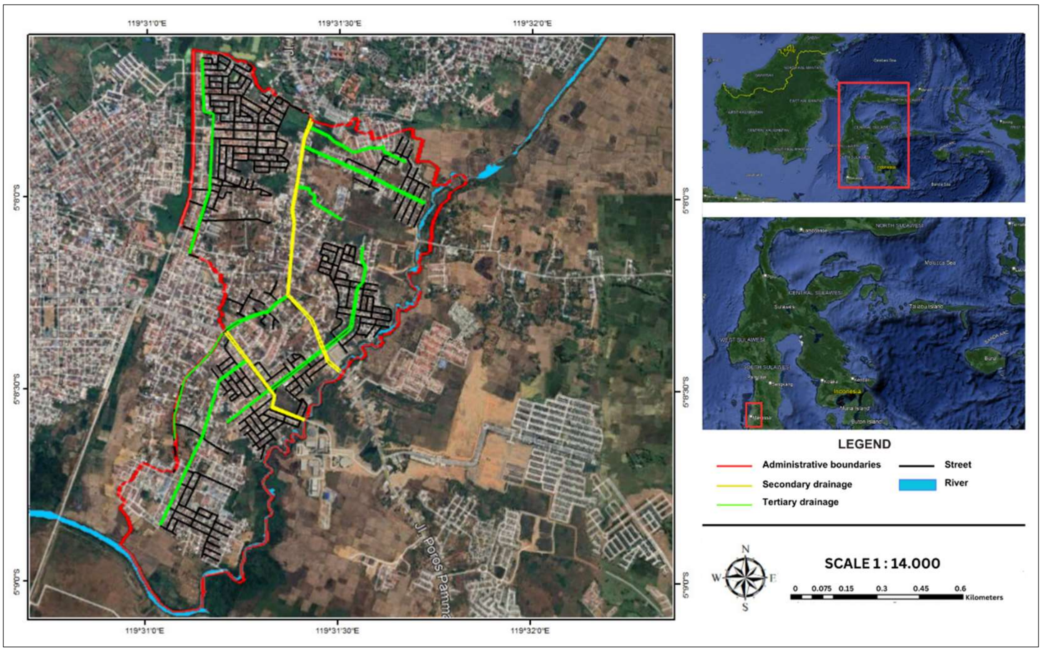

Figure 1: Research location

Site identification is performed to establish the dimensions of the drainage channel and the field conditions used to estimate the solution to the problem of flooding at that place (Singh et al., 2021). Conducting field surveys at inundation points. Measurements such as channel width, channel depth, and channel cross-section were taken to evaluate the existing drainage system in Katimbang Village.

Topographic maps, land use plans from the Makassar city geographic planning office, demographic data from the Makassar city statistical center, and 10-year rainfall data from the water resources management office were used as supporting data (Suripin, 2004). Comprehensive data gathering from these numerous sources allows for more detailed research and precise analysis to evaluate the operation of horizontal and vertical drainage systems as well as their usefulness in coping with floods in Katimbang Village.

2.2 Hydrological Analysis

The process of hydrological analysis is generally required to obtain rainfall intensity, calculate flood discharge, and determine effective drainage system planning (Zhou et al., 2013). The following steps were taken in the hydrological analysis:

- Calculate the average maximum rainfall of the region to determine the amount of rainfall that can occur in the study area using the polygon thiessen method, the following formula can be used (Sosrodarsono, 1983):

$$P = \frac{p1.A1 + p2.A2 + p3.A3 + \cdots . + pn.An}{A1 + A2 + A3 + \cdots + An} \tag{1}$$

where: P – regional average rainfall height (mm), $p1,p2...pn$ – rainfall height at the observation point (mm), $A1,A2...An$ – sub area of each rain station (km^2)

- Analyzing the design rainfall to determine the amount of rainfall that must be considered in planning the drainage system with the Gumbel method (Soewarno, 1995) and log Pearson type III method (Suripin, 2004).

$$R_T = \mathrm{R} + \frac{\sigma\mathrm{R}}{\sigma\mathrm{n}} (Y_T - Y_n) \quad (2)$$

where: R_T – planned maximum rainfall Gumbel method (mm/24h), R_2 – average maximum daily rainfall (mm/24h)), σR – standard deviation of n years, σn – expected standard deviation, Y_T – reduced variate for rainfall return period, Y_n – expected mean reduced variate

$$R_T = antilog\ \bar{X} + K_{X\,.}\ SDEV \quad (3)$$

where: R_T – planned maximum rainfall log Pearson type III method (mm/24h), $\bar{X}$ – average maximum daily rainfall (mm/24h)), Kx – frequency factor, $SDEV$ – standard deviation

- Test the suitability of the rainfall distribution used in the hydrological analysis to ensure that the selected distribution is suitable for the characteristics of the study area (Sharannya et al., 2020).
- Rainfall intensity needs to be calculated to find out how much rainfall falls in a certain period of time, which will affect the discharge of rainwater that must be handled by the drainage system. The Mononobe equation is used to convert rainfall to intensity since the rainfall information used is every day's data (Karamma & Pallu, 2018).

$$I = \frac{R_{24}}{24} \times \left(\frac{24}{t}\right)^{2/3} \quad (4)$$

where: I – rainfall intensity (mm/h), R_{24} – daily maximum rainfall (mm), t – time of concentration (h)

- The design flood discharge needs to be calculated based on the design rainfall to determine the amount of water discharge that must be handled by the drainage system. For drainage areas less than 0.8 km2 , the following formula is used (Sosrodarsono & Takeda, 1987):

$$Q = 0{,}2778.C.I.A \quad (5)$$

where: Q – maximum flood discharge (m^3/s), C – flow coefficient, I – average rainfall intensity during the concentration time (mm/h), A – area of drainage area (km^2)

2.3 Hydraulic Analysis

Hydraulic analysis is an important step in researching the drainage system in Katimbang Village, Makassar City. The following are the steps of hydraulic analysis that can be done:

- Analyze the capacity of the channel to find out how much maximum discharge can be accommodated by the drainage channel. This analysis usually uses the Manning equation to calculate channel capacity. Channel capacity is calculated using the following formula (Chow, 1992):

$$Q = V.A \tag{6}$$

$$V = \frac{1}{n}.R^{2/3}.\ S^{1/2} \tag{7}$$

where: Q – rainwater runoff discharge (m^3/s), V – flow velocity (m/s), A – wet cross sectional area (m^2), n – manning roughness coefficient, R – hydraulic radius (m), S – water level elevation difference (m/m)

- Analyze the effectiveness of vertical drainage systems, such as infiltration ponds and rain harvesting, in dealing with standing water (Boguniewicz-Zabłocka & Capodaglio, 2020). The evaluation is done to determine how well the vertical drainage system can infiltrate water into the ground or collect rainwater vertically. To calculate the dimensions of infiltration wells, the following formula can be used:

$$H = \frac{Q}{Fk}\left[1 - e\ \frac{F.K.T}{\pi R^2}\right] \tag{8}$$

where: H – water level in the well (m), Q – inlet water discharge (m^3/s), T – flow time (s), F – geometric factor (m), k – soil permeability coefficient (m/s), R – infiltration well radius (m)

- Analysis of several alternatives for handling puddles, including horizontal and vertical drainage concepts. The evaluation is based on various aspects such as channel width, channel depth, channel cross-section, sediment height, inundation area, and inundation duration (Islam et al., 2022).
- One option that is the most practicable to implement in Katimbang Village is chosen. The best choice is selected based on the technical and environmental analysis that has been completed (Tariq et al., 2020)

2.4 Verification of result with Strom Water Management Model (SWMM)

EPA SWMM 5.2 models the drainage system as a series of flows through four main sections, namely atmospheric, ground surface, subsurface, and drainage network (Rossman, 2015).

Verification of results with SWMM systematically can ensure that the drainage model created reflects field conditions well and can be used to design effective solutions for overcoming waterlogging in Katimbang Village, Makassar City.

2.5 Calibration Root Mean Square (RMSE)

A linear regression model can be evaluated using Root Mean Square Error (RMSE), which measures the accuracy of the model's projected outputs (Hodson, 2022).

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(xobs - xsim)^2} \tag{9}$$

where: *Xobs* – observation result value, *Xsim* – simulation result value, *n* – number of data

3 Result And Discussion

3.1 Overview of the research location

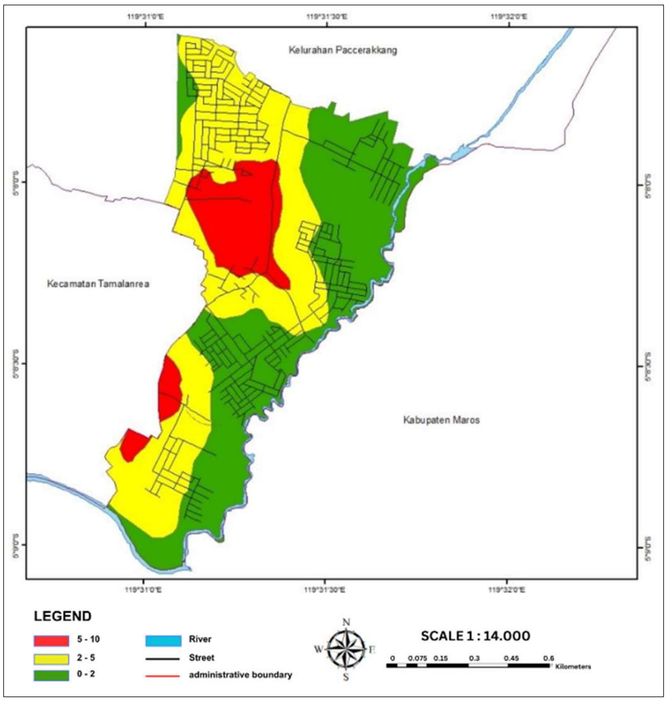

Figure 2: Map of topography

Katimbang village is located in a low-lying area with an altitude of 0–10 meters above sea level, as shown in Fig. 2. Katimbang village has the lowest slope among the surrounding villages. The element of slope is very influential on the occurrence of inundation; the lower the slope, the greater the possibility of inundation (Samanta et al., 2018). Katimbang urban village has a slope level of 0–8% (flat), which indicates that this village is vulnerable to flooding and inundation.

a.) **b.)**

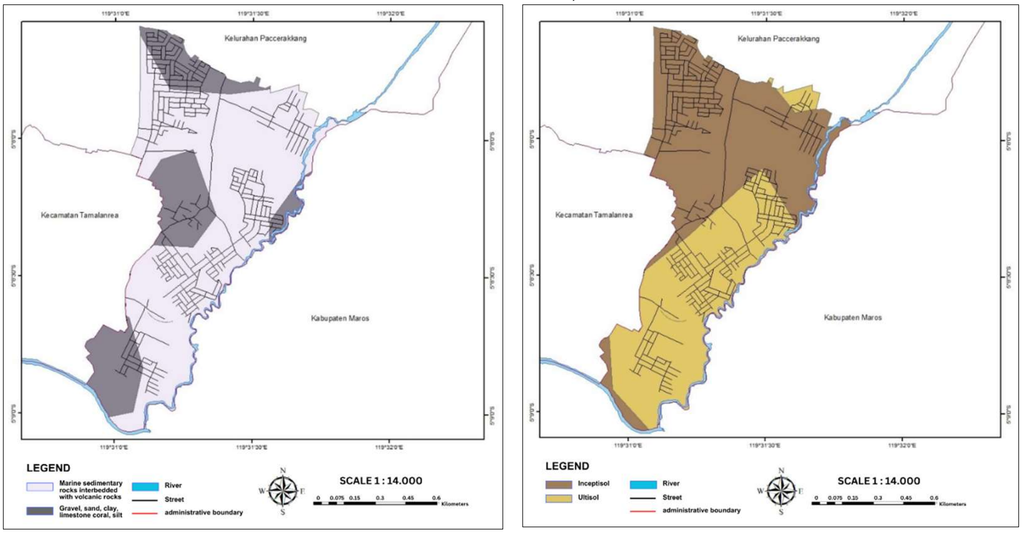

Figure 3: Map of research location: a) geology, b) soil type

The geological conditions in Katimbang village are formed by two types of rocks, namely marine sedimentary rocks interspersed with volcanic rocks and rocks of gravel, sand, clay, and coral limestone mud. Based on the tabulation results, gravel, sand, clay, and coral limestone mud are the most dominant rock types, with an area of 1.5 km2, as shown in Fig. 3. The soil types found in Katimbang Village are inceptisol and ultisol, as shown in Fig. 3. Inceptisol soils are classified as young soils with a weak level of development, characterized by a cambered horizon (Orr & Roberts, 2024). These soils are formed from a variety of parent materials, namely alluvium, sandstone, claystone, and limestone. Flooding conditions occur over a long interval of about 4–6 hours at a depth of 40–50 cm (Driese et al., 2021).

3.2 Analysis of regional average rainfall

Analysis of regional average rainfall using the Thiessen polygon method. Measurements were made at three rainfall stations located in the Tallo watershed, namely Tamangapa Kassi, Parangloe, and Senre stations shown in Fig. 4. Data on the area of influence of rainfall stations in the Tallo watershed on the catchment area using Arcgis is shown in Table 1.

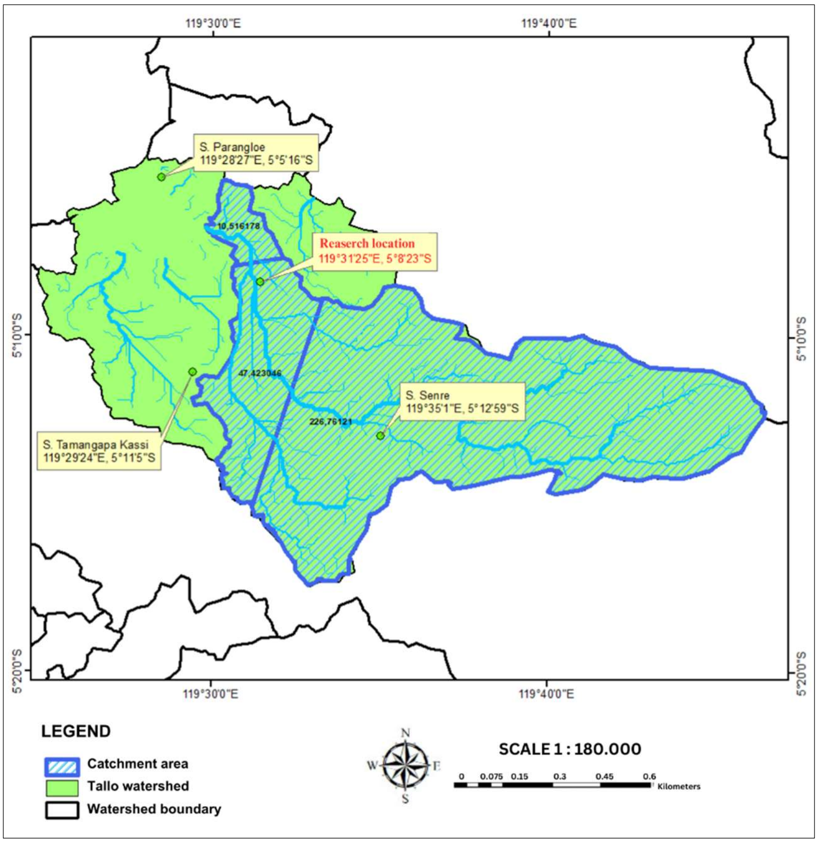

Figure 4: Influence Map of Tallo Watershed Rain Stations

No	Rainfall station	Total area of influence (Km2)	Thiessen coefficient
1	Tamangapa Kassi	47.43	0.167
2	Parangloe	10.52	0.037
3	Senre	226.77	0.796
Total Area		284.72	1.000

Table 1: Rain station area of influence

The rainfall data used is the last ten years of data, ranging from 2014 to 2023 shown in Table 2. From the data it can be seen that the year with the highest rainfall is 2019, with the amount of rainfall reaching 194.47 mm.

Year	Date		Rainfall station			Rainfall	Rainfall
			Tamangapa Kassi 0.167	Parangloe 0.037	Senre 0.796	average	max
2014	1	00/00/2014	0	0	0	0.00	91.54
	2	00/00/2014	0	0	0	0.00	
	3	07/12/2014	0	0	115	91.54	
2015	1	19/12/2015	142	0	90	95.35	161.79
	2	17/12/2015	137	128	23	45.92	
	3	18/12/2015	140	105	169	161.79	
2016	1	23/02/2016	90	15	13	25.93	92.93
	2	24/10/2016	30	140	24	29.29	
	3	12/02/2016	10	14	114	92.93	
2017	1	22/12/2017	145	23	25	44.97	153.86
	2	03/04/2017	60	153	48	53.89	
	3	21/12/2017	125	152	160	153.86	
2018	1	00/00/2018	0	0	0	0.00	159.64
	2	22/12/2018	0	188	47	44.37	
	3	07/02/2018	0	55	198	159.64	
2019	1	22/01/2019	140	48	110	112.72	194.47
	2	21/01/2019	10	112	237	194.47	
	3	21/01/2019	10	112	237	194.47	
2020	1	21/10/2020	150	0	0	25.05	124.03
	2	31/01/2020	20	124	23	26.24	
	3	19/10/2020	0	39	154	124.03	
2021	1	07/12/2021	190	54	0	33.73	98.00
	2	06/12/2021	146	227	0	32.78	
	3	17/01/2021	43	45	112	98.00	
2022	1	00/00/2021	0	0	0	0.00	143.98
	2	20/02/2022	0	145	154	127.95	
	3	18/11/2022	0	62	178	143.98	
2023	1	00/00/2023	0	0	0	0.00	122.91
	2	12/02/2023	0	238	56	53.38	
	3	13/02/2023	0	138	148	122.91	

Table 2: Area average rainfall data

Note: Date 00 – Rainfall data is not available.

3.3 Analysis of distribution fit fest

To determine whether the selected probability distribution function is appropriate and can represent the frequency distribution of sample data, parameter testing is required, as shown in Table 3. The parameter tests used are the Chi Squared test and the Smirnov Kolmogorov test.

No	Rainfall return period (Year)	Rainfall design (mm)	
		Gumbel	Log Pearson Type III
1	2	129.67	131.12
2	5	170.60	162.22
3	10	197.70	181.12
4	25	231.95	202.88
5	50	257.36	218.00
6	100	282.58	232.31
Chi squared test			
7	chi squared count	5.00	5.00
8	chi square critical	5.991	5.991
9	Degrees of Freedom	2	2
10	Significant Degree	5%	5%
Available		chi squared count < chi square critical	
Hypothesized		accepted	accepted
Smirnov kolmogorov test			
11	Dmax	0.079	0.103
12	Do critical	0.41	0.41
13	Significant Degree	5%	5%
Available		Dmax < Dcritical	
Hypothesized		accepted	accepted

Table 3: Conclusion distribution fit test

Based on the results of the chi squared test, the Gumbel and log Pearson type III distributions shown in Table 3 have the same value, while the Smirnov Kologorov test has the best result because it has the smallest value. When comparing the two tests, the Gumbel distribution is the best. For the calculation of rainfall design, the gumbel method will be used in the next calculation.

3.4 Rainfall intensity calculation

Then the calculation of rainfall intensity is shown in Table 4. Calculation of rainfall intensity using the Mononobe formula with 6-hour brackets

Time hours	Ratio %	Cumulative	Hourly rainfall (mm/day)			
			2 years	5 years	10 years	25 years
1	55.03	55.03	42.81	56.33	65.28	76.59
2	14.31	69.34	11.13	14.65	16.97	19.92
3	10.04	79.38	7.81	10.28	11.91	13.97
4	7.98	87.36	6.21	8.17	9.47	11.11
5	6.74	94.1	5.24	6.90	7.99	9.38
6	5.92	100	4.61	6.06	7.02	8.24
Effective rainfall			77.82	102.38	118.64	139.20
Runoff coefficient			0.6	0.6	0.6	0.6
Gumbel Rainfall			129.67	170.60	197.70	231.95

Table 4: Rainfall intensity

3.5 Analysis of design flood discharge

The design flood discharge shown in Table 5 is the rainwater discharge plus the dirty water discharge, where the rain return period used is 5 years for secondary drainage channels and 2 years for tertiary drainage channels.

No	Channel code	A km2	I mm/h	C	Pn people	Qav	Fp	Qrw m3/s	Qfw	Qdf
Secondary channel										
1	SS1	0.37	106.35	0.6	5712	0.007940	3.2	6.51	0.0254	6.531
2	SS2	0.46	77.69	0.6	7159	0.009952	3.2	5.96	0.0318	5.998
3	SS3	0.08	100.15	0.6	1233	0.001713	3.2	1.32	0.0055	1.328
4	SS4	0.33	57.86	0.6	5152	0.007161	3.2	3.19	0.0229	3.215
Tertiary channel										
1	ST1	0.06	92.59	0.6	965	0.001341	3.2	0.96	0.0043	0.961
2	ST2	0.20	71.78	0.6	3051	0.004240	3.2	2.35	0.0136	2.359
3	ST3	0.05	96.50	0.6	845	0.001175	3.2	0.87	0.0038	0.877
4	ST4	0.04	107.79	0.6	602	0.000837	3.2	0.70	0.0027	0.698
5	ST5	0.03	104.51	0.6	465	0.000647	3.2	0.52	0.0021	0.523
6	ST6	0.05	92.93	0.6	853	0.001186	3.2	0.85	0.0038	0.853
7	ST7	0.03	143.75	0.6	389	0.000541	3.2	0.60	0.0017	0.601
8	ST8	0.09	108.02	0.6	1461	0.002031	3.2	1.69	0.0065	1.697
9	ST9	0.08	103.98	0.6	1228	0.001707	3.2	1.37	0.0055	1.373
10	ST10	0.07	100.75	0.6	1033	0.001436	3.2	1.12	0.0046	1.120
11	ST11	0.08	109.62	0.6	1284	0.001785	3.2	1.51	0.0057	1.513
12	ST12	0.06	126.31	0.6	915	0.001272	3.2	1.24	0.0041	1.242
13	ST13	0.05	140.74	0.6	744	0.001034	3.2	1.12	0.0033	1.125
14	ST14	0.04	114.78	0.6	576	0.000800	3.2	0.71	0.0026	0.710
15	ST15	0.04	132.33	0.6	623	0.000865	3.2	0.88	0.0028	0.885
16	ST16	0.10	74.18	0.6	1531	0.002129	3.2	1.22	0.0068	1.223
17	ST17	0.19	57.18	0.6	2879	0.004002	3.2	1.76	0.0128	1.776
18	ST18	0.02	168.04	0.6	350	0.000487	3.2	0.63	0.0016	0.632
19	ST19	0.05	127.92	0.6	828	0.001151	3.2	1.13	0.0037	1.138

Table 5: Design flood discharge

3.6 Analysis of Hydraulics

The Manning equation is used in hydraulic analysis to calculate the channel capacity shown in Table 6. The Manning equation is used to determine how much maximum discharge the channel can tolerate.

No	Channel code	S m/m	L m	b m	h m	A m2	P m	R m	n	v m/s	Qcc m3/s
Secondary channel											
1	SS1	0.0024	1236	1.50	1.30	1.95	4.10	0.476	0.014	2.138	4.171
2	SS2	0.0022	1313	1.50	1.30	1.95	4.10	0.476	0.014	2.075	4.047
3	SS3	0.0016	612	1.50	1.20	1.80	3.90	0.462	0.014	1.719	3.096
4	SS4	0.0016	621	1.50	1.20	1.80	3.90	0.462	0.014	1.707	3.073
Tertiary channel											
1	ST1	0.0019	1008	0.63	1.00	0.63	2.63	0.240	0.014	1.221	0.769
2	ST2	0.0019	1008	0.55	0.65	0.36	1.85	0.193	0.014	1.057	0.378
3	ST3	0.0018	544	0.55	0.65	0.36	1.85	0.193	0.014	1.018	0.364
4	ST4	0.0018	534	0.49	0.50	0.25	1.49	0.164	0.014	0.922	0.226
5	ST5	0.0015	656	0.55	0.50	0.28	1.55	0.177	0.014	0.875	0.241
6	ST6	0.0015	650	0.55	0.65	0.36	1.85	0.193	0.014	0.931	0.333
7	ST7	0.0033	302	0.50	0.55	0.28	1.60	0.172	0.014	1.263	0.347
8	ST8	0.0033	298	0.55	0.65	0.36	1.85	0.193	0.014	1.375	0.492
9	ST9	0.0017	566	1.50	1.00	1.50	3.50	0.429	0.014	1.701	2.553
10	ST10	0.0017	586	1.50	1.00	1.50	3.50	0.429	0.014	1.672	2.509
11	ST11	0.0029	344	1.00	1.00	1.00	3.00	0.333	0.014	1.844	1.845
12	ST12	0.0029	342	1.00	1.00	1.00	3.00	0.333	0.014	1.850	1.850
13	ST13	0.0032	311	1.50	0.55	0.83	2.60	0.317	0.014	1.877	1.549
14	ST14	0.0032	310	1.50	0.55	0.83	2.60	0.317	0.014	1.880	1.551
15	ST15	0.0025	588	1.00	1.00	1.00	3.00	0.333	0.014	1.728	1.728
16	ST16	0.0010	915	0.50	0.50	0.25	1.50	0.167	0.014	0.710	0.178
17	ST17	0.0010	912	0.60	0.60	0.36	1.80	0.200	0.014	0.804	0.290
18	ST18	0.0038	258	0.55	1.00	0.55	2.55	0.216	0.014	1.591	0.875
19	ST19	0.0039	255	0.55	1.00	0.55	2.55	0.216	0.014	1.600	0.880

Table 6: Channel capacity

Note: S – channel bed slope; L – channel length; b – channel bed width; h – channel height; A – channel wet cross-sectional area; P – channel wet perimeter; R – hydraulic radius; n – manning coefficient; v – flow velocity; Qcc – channel capacity

3.7 Evaluation of channel capacity

Drainage channel capacity evaluation is to analyze the capacity of existing drainage channels to accommodate the design flood discharge shown in Table 7. If the channel is unable to accommodate the design flood discharge, there will be inundation due to excess runoff water. The inundation that occurs is the difference between the design flood discharge and the channel capacity. If Qdf < Qcc, then the channel is safe from inundation; conversely, if Qdf > Qcc, then the channel will experience inundation.

No	Channel code	Qdf m3/s	Qcc m3/s	Available Qcc>Qdf	QInundation m3/det
Secondary channel					
1	SS1	6.531	4.171	unsafe	2.360
2	SS2	5.988	4.047	unsafe	1.942
3	SS3	1.328	3.096	safe	-
4	SS4	3.215	3.073	unsafe	0.142
Tertiary channel					
1	ST1	0.961	0.769	unsafe	0.192
2	ST2	2.359	0.378	unsafe	1.981
3	ST3	0.877	0.364	unsafe	0.513
4	ST4	0.698	0.226	unsafe	0.472
5	ST5	0.523	0.241	unsafe	0.282
6	ST6	0.853	0.333	unsafe	0.520
7	ST7	0.601	0.347	unsafe	0.253
8	ST8	1.697	0.492	unsafe	1.205
9	ST9	1.373	2.553	safe	-
10	ST10	1.120	2.509	safe	-
11	ST11	1.513	1.845	safe	-
12	ST12	1.242	1.850	safe	-
13	ST13	1.125	1.549	safe	-
14	ST14	0.710	1.551	safe	-
15	ST15	0.885	1.728	safe	-
16	ST16	1.223	0.178	unsafe	1.046
17	ST17	1.776	0.290	unsafe	1.486
18	ST18	0.632	0.875	safe	-
19	ST19	1.138	0.880	unsafe	0.258

Table 7: Recapitulation of channel capacity evaluation

Note: Qcc – channel capacity; Qdf – design flood discharge

3.8 Analysis of inundation with EPA SWMM

An analysis of existing drainage conditions is shown to show the inundated areas in Katimbang Village by carrying out the SWMM 5.2 software simulation shown in Fig. 7. The results of the SWMM simulation are calibrated with the results of observations in the field. The rainfall return periods used are the 2 and 5-year return periods shown in Fig. 6.

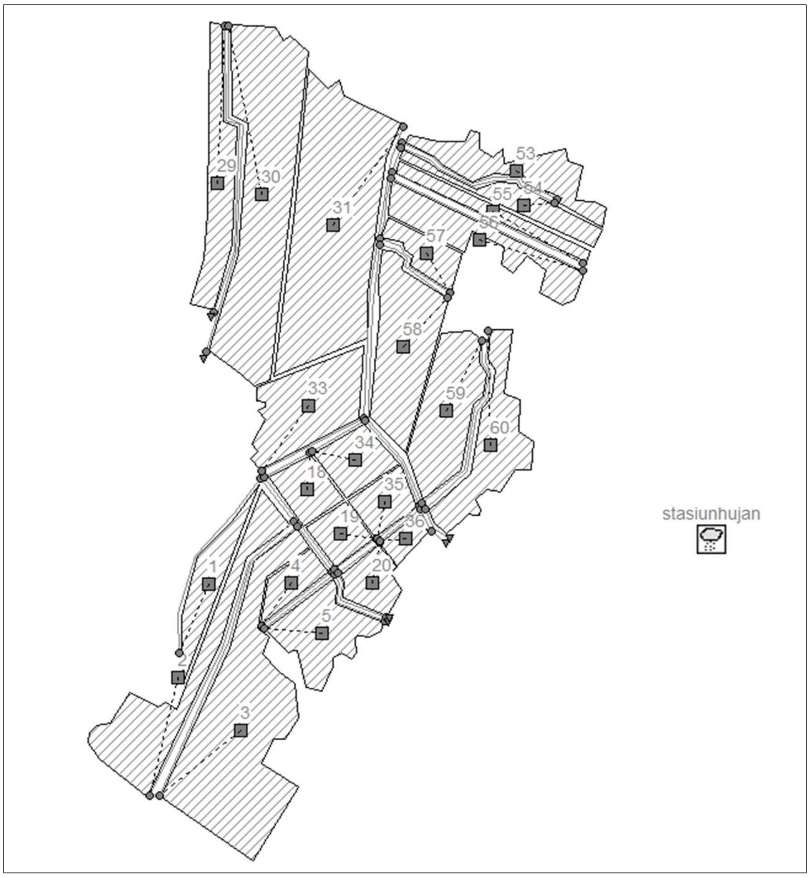

Figure 5: Model of the study area using SWMM

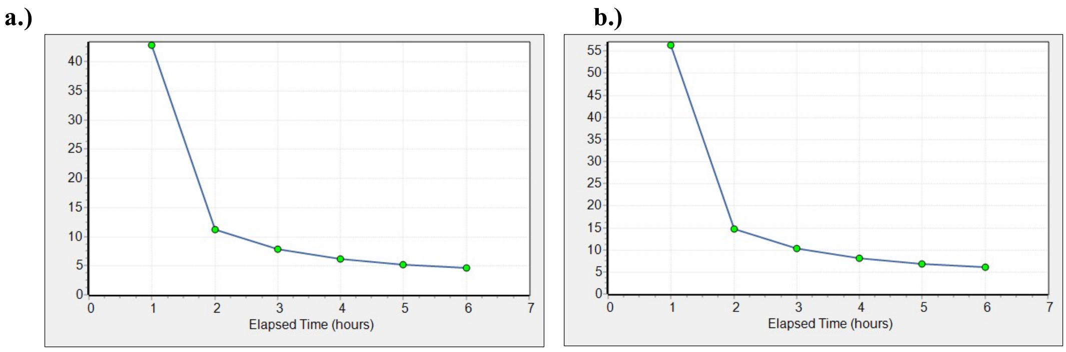

Figure 6: Graph of rainfall intensity: a) 2 years, b) 5 years

a.) **b.)**

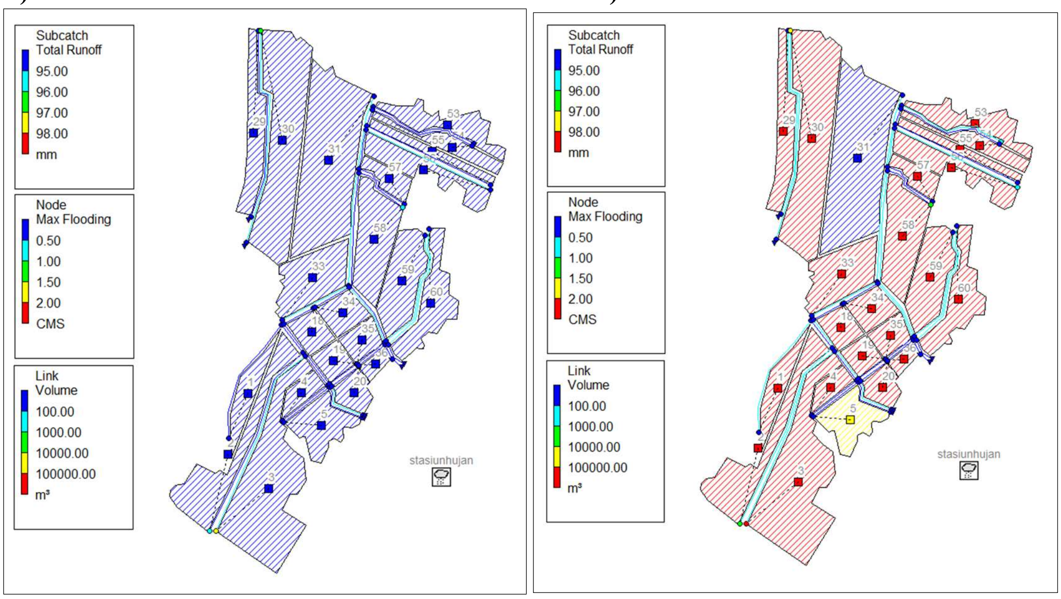

Figure 7: Swmm simulation map with rainfall return period: a) 2 years, b) 5 years

When comparing the simulation results from SWMM 5.2 software with the real-world situation, a technique known as calibration is used to verify and correct the accuracy of the results. The root mean square error (RMSE) statistical test was used in this study for calibration.

Comparing the channel discharge in the field with the simulated discharge generated by SWMM 5.2 software is shown in Table 8. Calibration was carried out during rainfall on March 9, 2024, using tertiary channel 16 (ST16).

channel Observation	Duration (minutes)	H water (m)	V (m/s)	A (m2)	Q observation (m3/s)	Q simulation (m3/s)	(Q observation - Q simulation)2	RMSE
ST16 L = 0.5 m	30	0.15	0.487	0.075	0.04	0.20	0.0267	0.13
	60	0.22	0.565	0.110	0.06	0.22	0.0249	
	90	0.35	0.654	0.175	0.11	0.20	0.0073	
	120	0.32	0.638	0.160	0.10	0.19	0.0077	
	150	0.30	0.626	0.150	0.09	0.19	0.0092	
	180	0.20	0.546	0.100	0.05	0.19	0.0183	
Total							0.0943	

Table 8: Calibration of swmm in tertiary channel 16

Note: H – height; V – velocity; A – area

From the data in Table 8, the RMSE value of 0.13 is obtained, which leads to a value of 0. This indicates that the modeling calibration is good and close to the actual conditions.

3.9 Soil permeability test

In planning a vertical drainage system, it cannot be separated from the soil permeability factor, which describes the ability of soil to pass water. This research uses soil samples in Katimbang Village at one point with a depth of 2 meters, assuming that all soil conditions in Katimbang Village are uniform.

Testing of soil samples was carried out in the Hasanuddin University laboratory using the Falling Head Test shown in Table 9. This test aims to obtain the value of the soil permeability coefficient.

sample	A	B	
sample diameter	6.51	6.51	cm
sample depth			
sample cross-section area (A= 1/4pD2)	33.285	33.285	cm2
initial elevation (h1)	206	207	cm
final elevation (h2)	205	206	cm
sample length (L)	10.2	10.2	cm
test time (t)	272	132	detik
temperature (T)	28	28	C
volume of water drained in the curette (Vw)	49	29	cm3
permeability coefficient $\left(K = 2{,}303\frac{Vw.L}{h1-h2}\log\frac{h1}{h2}\right)$	0.000269	0.000326	cm/s
K20°C= KT°C $\frac{\mathrm{h}T^{o}C}{\mathrm{h}20^{o}C}$	0.000228	0.000276	cm/s
For temperatur28 °C			
hT = 0.847			
h20= 1			
tool weight	2806		gr
tool weight + soil sample	3197		gr
weight of soil content	1152		gr/cm3

Table 9: Falling head test

From the calculation results, the average value of the soil permeability coefficient (K) at a depth of 2 metres is 3x10-4 cm/s and has a silt soil type.

3.10 Vertical drainage system

Infiltration ponds

In accordance with the initial concept of infiltration ponds, namely as a substitute for rainwater, infiltration soil that experiences pavement that causes rainwater that falls cannot directly seep into the ground. To reduce the inundation that occurs around drainage channels, infiltration ponds are built around drainage channels in areas that are still included in the catchment area of the channel (Ertan & Çelik, 2021).

The infiltration wells were planned uniformly at all points with a rectangular shape, a depth of 6 meters, and a wall construction made of unplastered masonry to make it easier for water to seep into the soil shown in Fig. 8. On the sides of the infiltration wells, a layer of coral and palm fiber was placed to act as a filter so that the water that seeps into the soil is of better quality. For the inlet and outlet channels to the sewer, a Ø4" PVC pipe is used, and a lid made of a 15-cm-thick concrete plate is placed on top of the well. The planned number of infiltration ponds is shown in Table 10.

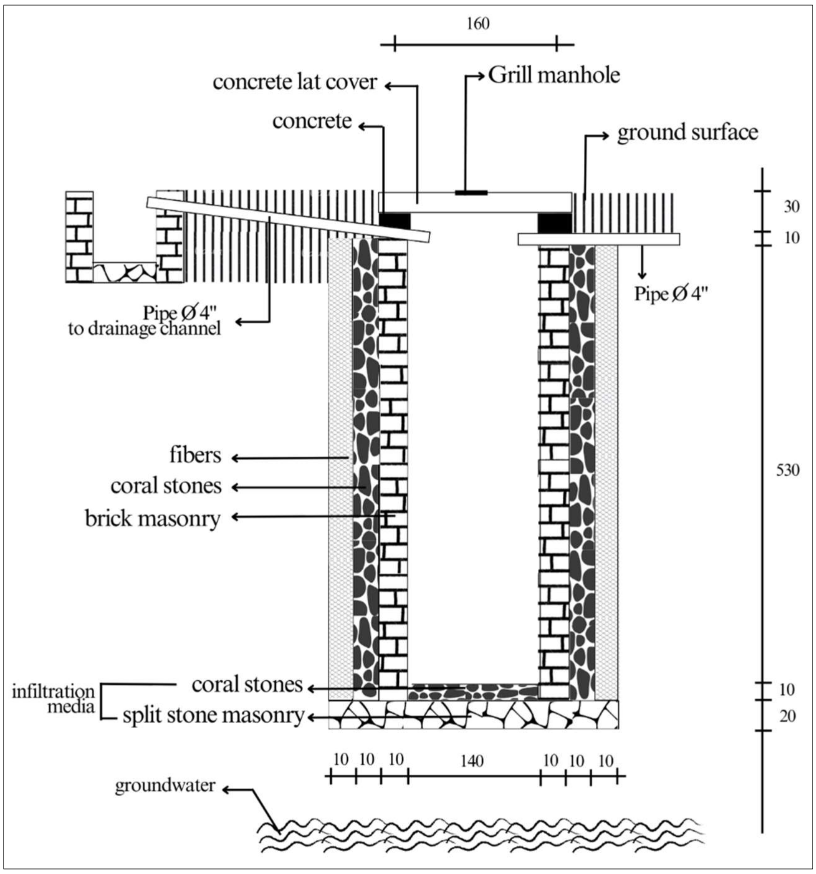

Figure 8: Infiltration ponds plan (unit cm)

No	Channel code	H m	k m/s	F m	Qip m3/s	QInundation m3/s	number of infiltration ponds	Max capacity m3/s
Secondary channel								
1	SS1	6	0.000003	3.85	0.0013	1.57	200	0.26
2	SS2	6	0.000003	3.85	0.0013	2.02	250	0.33
3	SS4	6	0.000003	3.85	0.0013	0.88	100	0.13
Tertiary channel								
1	ST1	6	0.000003	3.85	0.0013	0.31	40	0.05
2	ST2	6	0.000003	3.85	0.0013	1.48	145	0.19
3	ST3	6	0.000003	3.85	0.0013	0.37	40	0.05
4	ST4	6	0.000003	3.85	0.0013	0.25	30	0.04
5	ST5	6	0.000003	3.85	0.0013	0.05	5	0.01
6	ST6	6	0.000003	3.85	0.0013	0.32	40	0.05
7	ST7	6	0.000003	3.85	0.0013	0.24	30	0.04
8	ST8	6	0.000003	3.85	0.0013	0.89	100	0.13
9	ST16	6	0.000003	3.85	0.0013	0.68	70	0.09
10	ST17	6	0.000003	3.85	0.0013	1.67	150	0.2
Total						10.74	1200	1.58
Reduced inundation								15%

Table 10: Analysis of infiltration ponds

Note: H – water depth in infiltration ponds; k – soil permeability coefficient; F – geometry factor; Qip – infiltration pond discharge

Rainwater harvesting

The planned alternative is a rainwater harvester. Rainwater harvesting is a method to collect and utilize rainwater that falls on the roof of a building or house (Pala et al., 2020). The rainwater is then channeled through gutters or pipes (Dao et al., 2021). Rainwater harvesters use a water tank with a capacity of 300 liters, which has dimensions of 0.69 m wide and 1.02 m high. Planned rainwater harvesters are placed in subcatchments that affect inundation points, with 1 rainwater harvester per house. The planned number of rainwater harvesting is shown in Table 11.

No	Channel code	QInundation	I	C	L	water harvested	Number of homes	Total quantity of water harvested
		m3/s	mm/h		km2	m3/s		m3/s
Secondary channel								
1	SS1	1.57						
2	SS2	2.02						
3	SS4	0.88						
Tertiary channel								
1	ST1	0.31						
2	ST2	1.48						
3	ST3	0.37	37.258	0.6	0.00011	0.00068	4674	3.193
4	ST4	0.25						
5	ST5	0.05						
6	ST6	0.32						
7	ST7	0.24						
8	ST8	0.89						
9	ST16	0.68						
10	ST17	1.67						
Total		10.74	Reduced inundation					30%

Table 11: Analysis of rainwater harvesting

Note: I – rainfall intensity for 2 hours; C – coefficient of runoff; L – average house roof area

4 Conclusion

The performance of the horizontal drainage system is unable to accommodate rainwater with a 2-year return period for tertiary drainage and rainwater with a 5-year return period for secondary drainage, resulting in inundation at 13 points with a total inundation of 10.74 m3/det. The effectiveness of the vertical drainage system against inundation in Kelurahan Katimbang is considered ineffective. In accordance with the conditions of the research location, the application of infiltration ponds is only able to reduce inundation by 15% and rainwater harvesting by 30% of the total inundation.

The application of vertical drainage systems to overcome inundation is not limited to infiltration ponds and rain harvesting; the application of various other types of vertical drainage can determine what type of vertical drainage is most effective in overcoming inundation according to the conditions of the area. Develop and seek alternative solutions for the application of infiltration ponds with low-permeability soil types so that infiltration ponds can function effectively on low-permeability soil types.

References

Adugna, D., Lemma, B., Jensen, M. B., & Gebrie, G. S. (2019). Evaluating the hydraulic capacity of existing drain systems and the management challenges of stormwater in Addis Ababa, Ethiopia. *Journal of Hydrology: Regional Studies*, *25*(September), 100626. https://doi.org/10.1016/j.ejrh.2019.100626

Algafari, A., & Surur, F. (2021). Strategi Penanganan Banjir di Kelurahan Katimbang Kecamatan

Biringkanaya Kota Makassar. *Jurnal Pendidikan Geografi Undiksha*, *9*(2), 68–81.

Ali, M. (2010). *Kerugian Bangunan Perumahan Akibat Rob Dan Arah Kebijakan Penangannya Di Kelurahan Bandarharjo Kota Semarang*. Skripsi, Universitas Diponegoro.

Boguniewicz-Zabłocka, J., & Capodaglio, A. G. (2020). Analysis of alternatives for sustainable stormwater management in small developments of Polish urban catchments. *Sustainability (Switzerland)*, *12*(23), 1–20. https://doi.org/10.3390/su122310189

BPBD Makassar. (2019). *Tanggap Darurat Bencana*. BPBD Makassar.

BPS Makassar. (2022). *Makassar Dalam Angka*. Badan Pusat Statistik Makassar.

Butler, D., Ward, S., Sweetapple, C., Astaraie-Imani, M., Diao, K., Farmani, R., & Fu, G. (2017). Reliable, resilient and sustainable water management: the Safe & SuRe approach. *Global Challenges*, *1*(1), 63–77. https://doi.org/10.1002/gch2.1010

Chow, V. Te. (1992). *Hidrolika Saluran Terbuka (Open Channel Hydrolics) Terjemahan*. Erlangga.

Dao, D. A., Tran, S. H., Dang, H. T. T., Nguyen, V. A., Nguyen, V. A., Do, C. V., & Han, M. (2021). Assessment of rainwater harvesting and maintenance practice for better drinking water quality in rural areas. *Aqua Water Infrastructure, Ecosystems and Society*, *70*(2), 202–216. https://doi.org/10.2166/aqua.2021.076

Dessu, T., Korecha, D., Hunde, D., & Worku, A. (2020). Long-Term Land Use Land Cover Change in Urban Centers of Southwest Ethiopia From a Climate Change Perspective. *Frontiers in Climate*, *2*(December), 1–23. https://doi.org/10.3389/fclim.2020.577169

Dhakal, K. P., & Chevalier, L. R. (2017). Managing urban stormwater for urban sustainability: Barriers and policy solutions for green infrastructure application. *Journal of Environmental Management*, *203*(August), 171–181. https://doi.org/10.1016/j.jenvman.2017.07.065

Disaster study center UNHAS, H. U. (2023). *Petakan Titik Rawan Genangan Di Makassar*. Antara News.

Driese, S. G., Nordt, L. C., & Stinchcomb, G. E. (2021). Soils, Chemical Weathering, and Climate Change in Earth History. In *Hydrogeology, Chemical Weathering, and Soil Formation* (Issue January). https://doi.org/10.1002/9781119563952.ch2

Ertan, S., & Çelik, R. N. (2021). The assessment of urbanization effect and sustainable drainage solutions on flood hazard by gis. *Sustainability (Switzerland)*, *13*(4), 1–19. https://doi.org/10.3390/su13042293

Fang, J., Wahl, T., Fang, J., Sun, X., Kong, F., & Liu, M. (2021). Compound flood potential from storm surge and heavy precipitation in coastal China: Dependence, drivers, and impacts. *Hydrology and Earth System Sciences*, *25*(8), 4403–4416. https://doi.org/10.5194/hess-25-4403-2021

Government regulation, R. of I. (2008). *Peraturan Pemerintah No 26 Tahun 2008 tentang Rencana Tata Ruang Wilayah Nasional*. Sekretariat Negara.

Hodson, T. O. (2022). Root-mean-square error (RMSE) or mean absolute error (MAE): when to use them or not. *Geoscientific Model Development*, *15*(14), 5481–5487. https://doi.org/10.5194/gmd-15-5481-2022

Hosseinzadehtalaei, P., Tabari, H., & Willems, P. (2020). Climate Change Impact On Shortduration Extreme Precipitation And Intensity–Duration–Frequency Curves Over Europe. *Journal of Hydrology*, *590*(1), 1–10.

Isik, S., Kalin, L., Schoonover, J. E., Srivastava, P., & Lockaby, B. G. (2013). Modeling Effects Of Changing Land Use/Cover On Daily Streamflow: An Artificial Neural Network And Curve Number Based Hybrid Approach. *Journal of Hydrology*, *485*(1), 103–112. https://doi.org/10.1016/j.jhydrol.2012.08.032

Islam, A., Sarkar, B., Saha, U. D., Islam, M., & Ghosh, S. (2022). Can an annual flood induce changes in channel geomorphology? *Natural Hazards*, *111*(1), 1019–1046. https://doi.org/10.1007/s11069-021-05089-7

Kanso, T., Tedoldi, D., Gromaire, M. C., Ramier, D., Saad, M., & Chebbo, G. (2018). Horizontal and vertical variability of soil hydraulic properties in roadside sustainable drainage systems (SuDS)-nature and implications for hydrological performance evaluation. *Water (Switzerland)*, *10*(8). https://doi.org/10.3390/w10080987

Karamma, R., Lopa, R. T., & Hatta, M. P. (2021). The Revitalization of Makassar Urban Drainage System Based on Eco Drainage Retention Pond. *INTEK: Jurnal Penelitian*, *8*(1), 47. https://doi.org/10.31963/intek.v8i1.2811

Karamma, R., & Pallu, M. S. (2018). Comparison of Model Hidrograf Synthetic Units (HSS) with the Model of Hidrograf Observations on DAS Jeneberang Gowa Regency, Indonesia. *International Journal of Innovative Science and Research Technology*, *3*(2). www.ijisrt.com617

La Loggia, G., Puleo, V., & Freni, G. (2020). Floodability: A New Paradigm for Designing Urban Drainage and Achieving Sustainable Urban Growth. *Water Resources Management*, *34*(10), 3411–3424. https://doi.org/10.1007/s11269-020-02620-6

Liu, Z., Ding, M., He, C., Li, J., & Wu, J. (2019). The Impairment Of Environmental Sustainability Due To Rapid Urbanization In The Dryland Region Of Northern China. *Landscape and Urban Planning*, *187*(1), 165–180.

Lopa, R., & Shimatani, Y. (2013). Evaluation Of Early Effects Of The River Restoration Project In The Kamisaigo River Japan. *International Proceedings of Chemical, Biological and Environmental Engineering (IPCBEE)*, *59*(1), 124–130.

Luciana, R. F., & Edijatno, S. F. (2013). Analisa Sistem Drainase Saluran Kupang Jaya akibat Pembangunan Apartemen Puncak Bukit Golf di Kota Surabaya. *Jurnal Teknik Pomits*, *1*(1), 1–5.

Orr, T. J., & Roberts, E. M. (2024). A review and field guide for the standardized description and sampling of paleosols. *Earth-Science Reviews*, *253*(April), 104788. https://doi.org/10.1016/j.earscirev.2024.104788

Pala, G. K., Pathivada, A. P., Velugoti, S. J. H., Yerramsetti, C., & Veeranki, S. (2020). Rainwater harvesting - A review on conservation, creation & cost-effectiveness. *Materials Today: Proceedings*, *45*(January), 6567–6571. https://doi.org/10.1016/j.matpr.2020.11.593

Rahman, A. (2021). Rainwater harvesting for sustainable developments: Non-potable use, household irrigation and stormwater management. *Water (Switzerland)*, *13*(23). https://doi.org/10.3390/w13233460

Rossman, L. A. (2015). *Storm Water Management Model User's Manual Version 5.0. Cincinnati*. National Risk Management Research Laboratory.

Samanta, S., Pal, D. K., & Palsamanta, B. (2018). Flood susceptibility analysis through remote sensing, GIS and frequency ratio model. *Applied Water Science*, *8*(2), 1–14. https://doi.org/10.1007/s13201-018-0710-1

Sedyowati, L., & Suhartanto, E. (2015). Kajian Pengaruh Sistem Drainase dan Ruang Terbuka Hijau Eksisting pada Kawasan Ruas Jalan Utama Kota Malang (Suatu Upaya Pengendalian Genangan Di Daerah Perkotaan). *Jurnal Media Teknik Sipil*, *13*(1), 56. https://doi.org/10.22219/jmts.v13i1.2544

Sharannya, T. M., Al-Ansari, N., Barma, S. D., & Mahesha, A. (2020). Evaluation of satellite precipitation products in simulating streamflow in a humid tropical catchment of india using a semi-distributed hydrological model. *Water (Switzerland)*, *12*(9). https://doi.org/10.3390/w12092400

Singh, A., Dawson, D., Trigg, M., & Wright, N. (2021). A review of modelling methodologies for flood source area (FSA) identification. *Natural Hazards*, *107*(2), 1047–1068. https://doi.org/10.1007/s11069-021-04672-2

Soewarno, S. (1995). *Hidrologi: Aplikasi Metode Statistik untuk Analisis Data*. Nova.

Sosrodarsono, S. (1983). *Hidrologi Untuk Pengairan*. Pradnya Paramita.

Sosrodarsono, S., & Takeda, K. (1987). *Meteorologi (Meteorology): Hidrologi Untuk Pengairan*. Pradnya Paramita.

Stefanakis, A. I. (2019). The Role of ConstructedWetlands as Green Infrastructure for Sustainable Urban Water Management. *Sustainability (Switzerland)*, *11*(24). https://doi.org/10.3390/su11246981

Suripin. (2004). *Sistem Drainase Perkotaan Yang Berkelanjutan*. Andi.

Sweya, L. N., Wilkinson, S., & Chang-Richard, A. (2018). Understanding Water Systems Resilience Problems In Tanzania. *Procedia Engineering*, *212*(1), 488–495. https://doi.org/10.1016/j.proeng.2018.01.063

Tariq, M. A. U. R., Farooq, R., & van de Giesen, N. (2020). A critical review of flood risk management and the selection of suitable measures. *Applied Sciences (Switzerland)*, *10*(23), 1–18. https://doi.org/10.3390/app10238752

Teshome Sewnet, M., & Revathi Devi, A. (2020). A review of recent studies on urban stormwater drainage system for urban flood management. *Preprints*, *October*, 1–15. https://doi.org/10.20944/preprints202010.0295.v2

Vieira, A. S., Beal, C. D., Ghisi, E., & Stewart, R. A. (2014). Energy intensity of rainwater harvesting systems: A review. *Renewable and Sustainable Energy Reviews*, *34*(June), 225–242. https://doi.org/10.1016/j.rser.2014.03.012

Zhou, Q., Panduro, T. E., Thorsen, B. J., & Arnbjerg-Nielsen, K. (2013). Adaption to extreme rainfall with open urban drainage system: An integrated hydrological cost-benefit analysis. *Environmental Management*, *51*(3), 586–601. https://doi.org/10.1007/s00267-012-0010-8