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A Critical Review of Spatial Distribution Flood Level in Gorontalo City

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Abstract: The purpose of this study is to determine the condition of flood inundation levels that occur in Gorontalo City through a spatial grit-based hydrogemorphology study approach. The analysis technique uses a land unit approach as a mapping unit. Based on the results of the study, it was concluded that the area of Gorontalo City, (1) which is potentially affected by flooding is 965.83 Ha with a distribution pattern in the residential area of 450.19 Ha, a mixed garden area of 221.20 Ha, a shopping area of 185.29 Ha, and in the highway area of 70.09 Ha; (2) the height of the inundation with class G1 (0–25 cm) covering an area of 5950.46 Ha, for class G2 (25–50 cm) covering an area of 162.30 Ha, class G3 (50–75 cm) covering an area of 113.23 Ha, class G4 (75–100 cm) covering an area of 177.58 Ha, and class G5 (more than 100 cm) 252.46 Ha; and (3) the duration of the inundation, except for the sub-districts of Dembe I, Lekobalo and Pilolodaa where the duration was more than 30 days, in other areas the duration of the flood was around 10–24 hours.

Keywords: *Water Level, Flood, Gorontalo City.*

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I. INTRODUCTION

Flooding, which occurs almost every rainy season in Gorontalo City, causes various problems. A particularly concerning situation is that this flooding inundates the area that serves as the center of services and economic activities (Central Business District) and the center of government of Gorontalo City. On the other hand, Gorontalo City is the administrative center of Gorontalo Province, making this area a hub for services and economic activities, trade, transportation, communication, and socio-cultural activities. As a center for services, economic services, and government, this area has led to increased land conversion.

Another problem is that the areas affected by flooding tend to expand from year to year and inundate areas that were previously flood-free.Another possible cause of flooding in Gorontalo City is the shallowing and shrinking of Lake Limboto. Lake Limboto serves as a reservoir for water coming from the northern and western regions of Gorontalo Province. This shallowing and shrinking of Lake Limboto is caused by sedimentation. The magnitude of this sedimentation can be seen from the comparison of the lake's surface area during the dry season, where the lake's area, which was previously around 45 km2, decreases to 30 km2. During the rainy season, the lake's area does not return to its original size, for example, 45 km2. This is consistent with a study by Lihawa (2009), which found that the Alo-Pohu sub-watershed is one of the sub-watersheds contributing to sedimentation in Lake Limboto.

II. LITERATURE REVIEW

The height of the inundation that occurs is influenced by two factors, namely the infiltration factor (the ability of the soil to absorb water) and the permeability factor of different types of soil layers (the ability of the soil to pass water to the soil layers below). The condition of the structure and texture of the soil and the soil layers greatly affects the rate of infiltration and soil permeability. Permeability is a property of porous materials that allows seepage flow in the form of water to flow through the pore cavities which causes the soil to be permeable. Soil permeability is greatly influenced by fluid viscosity, pore size distribution, grain size distribution, void ratio, soil grain surface hardness, and the degree of soil saturation (source: Public Works Agency, 1987).

Permeability has the same units as the soil infiltration rate (cm/hour). Since soil permeability is equal to the infiltration rate, the more permeable the soil, the greater the infiltration rate. Soil with high permeability will result in a higher infiltration rate, which in turn will reduce the speed and amount of rain runoff and the height of ponding.

Flooding occurs when rainfall exceeds the rate of water infiltration into the soil (Asdak, 2007). When the soil is saturated and the infiltration rate reaches zero, water will no longer be absorbed by the soil and will begin to fill depressions in the surface. The greater the rainfall volume, the greater the flooding that occurs.

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Inundation or flooding in some areas of a city can occur due to several factors, including rainfall, not only because the soil is saturated with water but also because of rainfall. Rainfall that falls on the ground cannot enter the drainage system. This obstruction of surface runoff is caused by buildings, higher topography, and poor drainage systems. In some cases of urban flooding, roadside drains, which are supposed to catch rainwater, fail to function at all. This causes rainwater to pool around the road, disrupting transportation and, in extreme cases, even damaging the road itself. In such cases, the pools dry out by soaking into the ground or by evaporation. Table 1 presents the classification of flood levels according to Minister of Environment Regulation No. 17 of 2009.

Table 1 High Inundation Assessment Score Due to Flooding

No	Class	Flood/Inundation	Qualification
1	I	there has never been any flooding in a period of 1 year within a time > 24 hours	Not vulnerable
2	II	floods that cover land for > 24 hours, occurring irregularly in periods of less than one month	Less vulnerable
3	III	during one month of the year the land is regularly covered by floodwaters for a period of > 24 hours	Somewhat vulnerable
4	IV	During 2-5 months of the year, it is regularly hit by floods lasting > 24 hours.	Prone to
5	V	For a period of six months or more the land has been regularly flooded for > 24 hours	Very Vulnerable

Source: Minister of Environment Regulation No. 17 of 2009

The aforementioned problems also occur in the rapidly developing city of Gorontalo. Poor urban development and planning have resulted in increasingly limited water catchment areas and poor drainage systems. This is particularly true in the city center. In this area, whenever heavy, prolonged rainfall occurs, flooding immediately occurs. This flooding occurs because there are virtually no water catchment areas and the existing drainage system is not functioning properly.

III. RESEARCH METHODS

This research took place in Gorontalo City, Gorontalo Province, North Sulawesi. This location was chosen because Gorontalo City is the provincial capital. Given the city's vast size, the area is divided into 108 grids, with 46 representing lowlands. This research btook place for 10 (ten) months from December 2009 to October 2010.The land unit approach is used to describe floodwater levels. Land units are mapping units that combine administrative maps, floodwater levels, and land use.

Measurement of inundation height was carried out systematically every 250 m x 250 m. Measurement of inundation height was carried out during and immediately after flooding based on the following types of land use: for road use (3.17 km2) as many as 13 samples, shopping areas (2.49 km2) as many as 10 samples, residential areas (11.38 km2) as many as 44 samples and mixed gardens (49.68 km2) as many as 194 samples.

The results of the inundation height sample measurements were validated with the 2008 “Quickbird” image at predetermined points. The mapping technique uses the overlay method. Data processing and analysis use Arch View GIS software.

IV. RESULTS AND DISCUSSION

The high flood locations cover 4 (four) sub-districts out of six sub-districts in Gorontalo City. The four sub-districts are West Kota Sub-district, Dungingi Sub-district, South Kota Sub-district, and East Kota Sub-district, which cover 15 (fifteen) villages with a total flooded area of 25.3 km2. The number of flood events that occurred in Gorontalo City during 2010 was 6 events, namely on May 22, June 21, July 20, August 5, August 7, and September 11. An illustration of the high flood in Gorontalo City is presented in Figure 1.

- *Object of Observation*

Neighborhoods II & III, Rajawali Road Section, and Kasuari Road.

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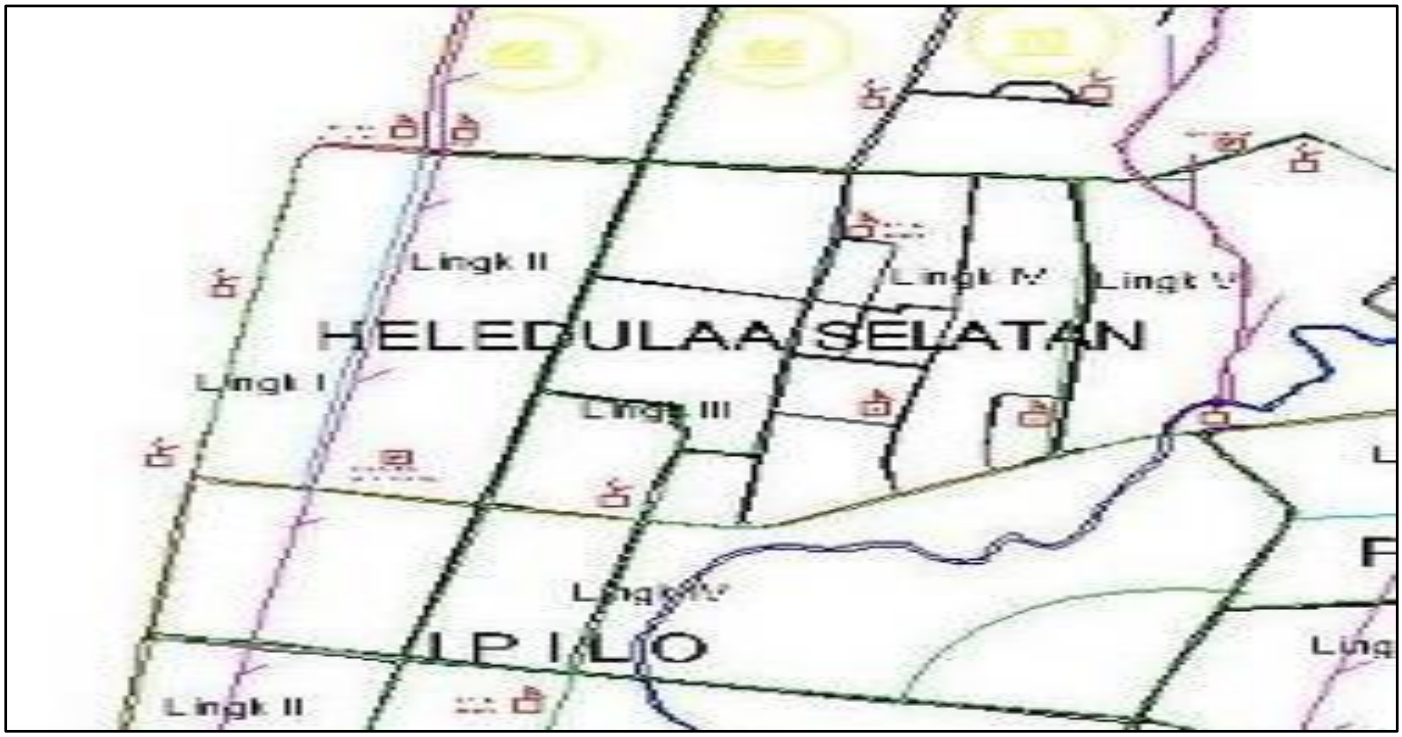

Fig 1 Neighborhoods II & III, Rajawali Road Section, and Kasuari Road

➢ *Observation Result*

Flood conditions on Jalan Rajawali, Heledulaa Selatan sub-district, neighborhood III often inundate residential areas (Fig. A), the height of floodwaters in neighborhood III reaches 1 (one) meter (Fig. B). The Tanggidaa Channel on Jl. Cokroaminoto is the Right Bolango Primary Channel (PBN Ka Channel) the condition of the channel on this road is quite good with concrete construction (Fig. C), this channel was built with quite large dimensions with the intention of reducing the height of the water puddles caused by the overflow of the Serdadu River and the Tamalate River, but this cannot reduce the overflow of water in this area during the rainy season, because until now there is still flooding. The main problem with this channel is because several connecting channels which are known by the community as "Tapila" drainage channels have become built-up areas.

Fig 2 (A) Illustration of the Height of Flooding in Gorontalo City

Fig 2 (B) Illustration of the Height of Flooding in Gorontalo City

Fig 2 (C) Illustration of the Height of Flooding in Gorontalo City

Table 2 Flood on May 22, 2010, in Gorontalo City during a 24-hour period.

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Table 2 Flood Locations May 22, 2010

No	Location	Flood Height (m)	Duration of Flooding (hours)	Information
1	Padebuolo	0.2–0.60	10	Dutula Serdadu Coast
2	South Heledula'a	0.4–1.00	16	all families based on administration
3	Heledula'a	0.2–0.60	15	some sub-districts
4	Ipilo	0.2–0.40	10	Dutula Serdadu Coast
5	Bugis Sub-district	0.2–0.40	10	Dutula Serdadu Coast
6	Tent	0.0–0.25	-	Dutula Bulango coast
7	Siendeng	0.2–1.00	18	Dutula Bulango coast
8	Biau	0.2–1.10	18	Dutula Bulango coast
9	Biawoo	0.2–0.80	17	Dutula Bulango coast
10	Limba B	0.2–0.40	8	some families, especially in rice fields
11	U-1 Competition	0.2–0.40	8	some families, especially in rice fields
12	Molecular W	0.2–0.40	8	Dutula Bulango coast & rice fields
13	Piloloda'a	0.4–1.50	24	Dutula Tapodu border
14	Lecobalo	0.4–1.50	24	Limboto Lake border
15	Dembe	0.4–1.50	24	Limboto Lake border

Source: 2010 Field Research Results

Table 2 shows that the worst-hit sub-districts of Pilolodaa, Lekobalo, and Dembe I were submerged for at least 274 houses within a full day. Geographically, these three sub-districts are divided into lowlands and hilly ridges. The lowlands consist of the Limboto Lake sedimentary plain, specifically on the right-hand side of the Gorontalo City highway toward Batudaa.The left side of the road is a row of foothills that did not experience flooding. The elevation of the plain on the right is less than 25 meters above sea level (m-asl), with a slope of 0–5%. Meanwhile, the left side of the Gorontalo-Batudaa highway is more than 25 m-asl with a slope of more than 40%. In addition to the villages of Pilolodaa, Lekobalo, and Dembe, the South Heledulaa village is also a village that is experiencing quite worrying conditions. Judging from the administrative area, the entire village was submerged in floodwaters for almost 10 (ten) hours with the height of the inundation varying between 40 cm and 120 cm.

Pilolodaa, Lekobalo, and Dembe I sub-districts were the worst affected because they were flooded for more than 24 hours on May 22, 2010. The reality shows that the flooding in these three sub-districts lasted for almost a full year, starting from May 22, 2010, to June 2011. The flooding that occurred for almost a year in the three sub-districts was due to the overflowing of Lake Limboto. Geographically, the location of the three sub-districts affected by the flood is on the border of Lake Limboto. The spatial distribution of the height of the flood in Gorontalo City is presented in Figure 3.

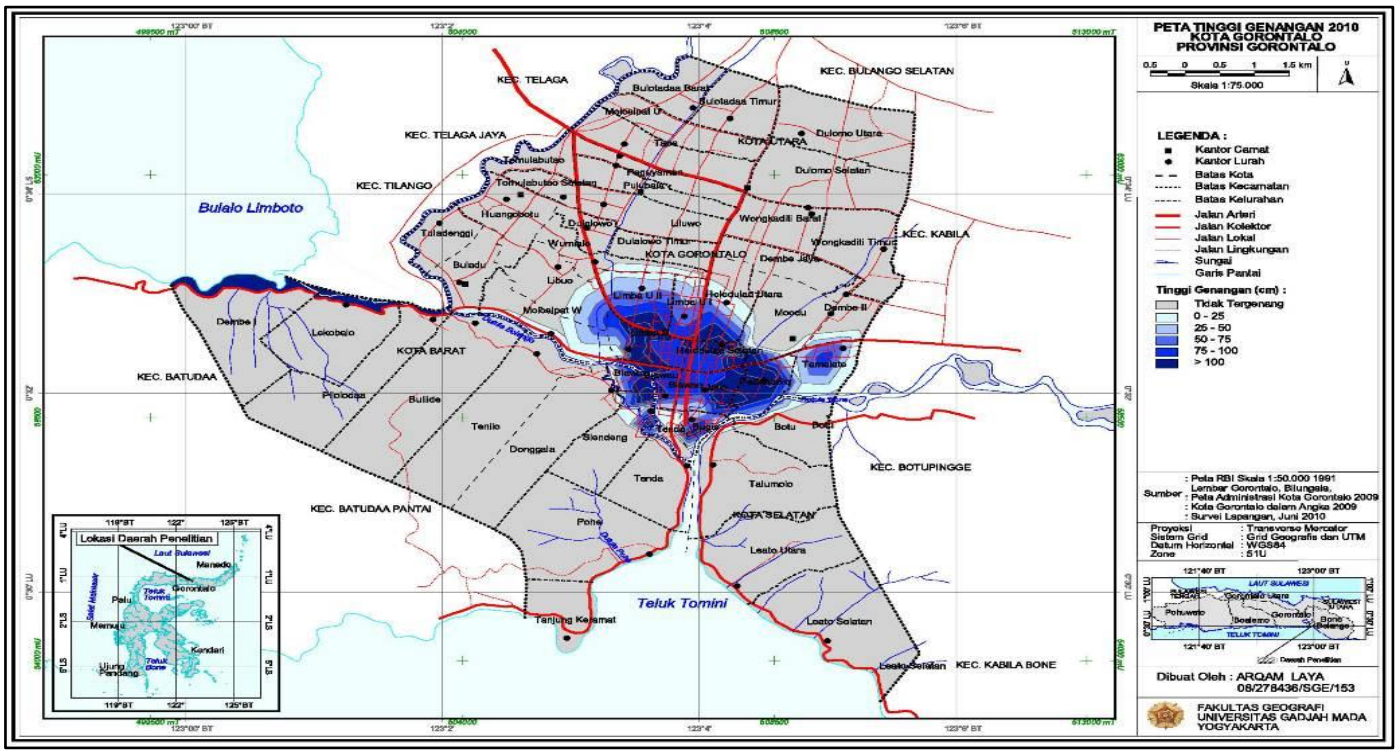

Fig 3 Flood Height Map of Gorontalo City

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The spatial distribution of inundation based on flood height can be seen in Figure 3 with classifications of 0-25 cm, 25-50 cm, 50-75 cm, and 75-100 cm, as well as more than 100 cm, which is the classification of inundation height and is marked with increasingly darker colors. Based on the mapping results, the area of inundation height is obtained as presented in Table 3.

Table 3 Classification of Flood Height in Gorontalo City

No	Flood classification	Area (Ha)	Wide (%)	% of Area Gorontalo City
1	Very low 0–25 cm	242.78	25.12	3.64
2	Low 25– 50 cm	162.37	16.80	2.43
3	Medium 50–75 cm	131.17	13.57	1.96
4	Height 75–100 cm	177.54	18.37	2.66
5	Very tall > 100 cm	252.52	26.13	3.78

Source: Analysis of the 2010 Gorontalo City Flood Map

The distribution of inundation height based on very low classification is 242.78 Ha or 3.64% spread across Dungingi District covering an area of 15.32 Ha, West City 60.27 Ha, South City covering an area of 52.83 Ha, Central City covering an area of 17.153 Ha, East City covering an area of 86.76 Ha and North City District covering an area of 10.39 Ha. This very low inundation height often inundates almost all districts in Gorontalo City although it is localized in several sub-districts, for example for North City District it is spread across Dembe II Sub-district, Dungingi in Libuo Sub-district and Central City in Wumialo Sub-district. For East City and South City Sub-districts almost all sub-districts are hit by floods.

The distribution of low classification inundation height with a height of 25-50 cm is still spread across five sub-districts. The sub-district that is free from flooding in this classification is Kota Tengah Sub-district. The distribution area is 162.37 Ha, namely Kota Utara Sub-district covering 6.01 Ha, Kota Barat Sub-district covering 12.36 Ha and Dungingi Sub-district covering 13.59 Ha and the rest is spread across Kota Selatan Sub-district and Kota Timur Sub-district. In Kota Utara Sub-district and Kota Tengah Sub-district for the distribution of inundation height with a moderate classification of 50-75 cm is no longer found. The distribution of this flood height is Kota Timur Sub-district covering 68.74 Ha followed by Kota Selatan Sub-district covering 61.66 Ha, Kota Barat Sub-district covering 12.36 Ha and Dungingi Sub-district covering 13.59 Ha. High flood levels (75–100 cm) and very high levels (above one meter) are located in the South, East, and West Kota sub-districts. The distribution of flood levels, based on the previous description, is presented in Table 4.

Table 4 Distribution of Flood Height by District

KEC	G1	G2	G3	G4	G5	Grand Total
Dungingi	409,058	13,593	11,007	1,519		435,177
West City	1563,094	12,356	3,706	0.008	66,394	1645,558
South City	997,618	61,653	56,301	88,620	78,861	1283,053
Central City	485,245					485,245
East City	1194,554	68,690	60,226	87,435	107,202	1518.107
North City	1299,901	6,017				1305,918
Grand Total	5949.47	162,309	131,240	177,582	252,457	6673.058

Source of Inundation Map Analysis of Gorontalo City 2010

The spatial distribution of inundation height is associated with land use conditions, including residential areas, highway areas, mixed-use areas (plantations, fields/dry fields, and shrubs), rice fields, and shopping or office areas. The classification of inundation height in each class based on the extent of flooding in each land use is presented in Table 5.

Table 5 Classes of Inundation Height and Their Relationship to Land Use

K_PL	G1 (Ha)	G2 (Ha)	G3 (Ha)	G4 (Ha)	G5 (Ha)	Total (Ha)	Impacted (Ha)
Jl	143,584	10,625	8,432	17,145	19,160	198,946	70,089
Pk	825,748	11,218	5,785	2,606	19,183	864,540	60,910
Pm	783,916	53,267	47,095	94,813	159,002	1,138,093	450,190
PT	89,984	39,640	39,410	48,551	32,079	249,628	185,288
Sb	2,062,371	0.966	0.522	0.107	10,054	2,074,017	16,060
Sw	1,111,721	37,708	23,212	7,427	7,819	1,187,883	136,677
Tg	835,663	0.304	1,594	2,720	1,920	842,201	7,555
TA	97,509	8,577	5,175	4,207	3,245	118,713	39,059
Total	5,950,460	162,305	131,225	177,576	252,462	6,674,021	965,828

Source: Results of Land Use Map Analysis 2010

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➢ *Description:*

G1 to G5 are classes of Inundation, Jl = Road, KC = Mixed Fields (Pk = Plantations, Tg = Fields/Dry Fields, Sb = Shrubs), Pm = Residential, Sw = Rice Fields, and Pt = Shops. TA = Body of Water.

The analysis results show that the flood-affected area in Gorontalo City is 965,828 Ha or 14.47% of the total area. Based on the percentage of the area, it can be concluded that this area is vulnerable to flooding because almost one-fifth of the research area is a flood-affected area. Residential areas are the largest areas that are often hit by floods, namely 450,190 Ha or 39.56% of the total residential area, followed by shopping areas covering 185,288 Ha or 74.23% of the shopping area, then 136,677 Ha or 11.51% of the area of rice fields, while 70,089 Ha or 35.23% of the area of the highway area is inundated, the remaining 84,525 is a flood-affected area which is a mixed field area in the form of plantations, bushes and dry fields. Overall, if a flood occurs based on the percentage of the area described above, the economic losses incurred will be quite large because almost all shopping centers have been inundated, as well as most residential areas and highways have been flooded.

The analysis results also show that for each land unit area can be described as follows, namely the area of residential areas in Gorontalo City is 1138.039 Ha with an area affected by flooding of 450.190 Ha with the widest inundation height, namely the G5 land unit of 159.002 Ha. Class G5 has a flood height above 100 cm, spread across the sub-districts of Dembe I and Lekobalo as well as Pilolodaa which is the border of Lake Limboto. Next, class G1 covers 96.013 Ha, followed by class G4 covering 94.813, followed by class G2 and class G3 of 47.095 Ha which is the smallest.

The shopping area in Gorontalo City covers an area of 249,628 Ha and the area affected by flooding is 185,288 Ha. The largest area affected by flooding is class G4, namely a flood height of 75 – 100 cm covering an area of 48,551 Ha, followed by class G2 covering an area of 39,640 Ha, then the G3 land unit covering an area of 39,410 Ha, following class G5 covering an area of 32,079 Ha, and the smallest class G1 covering an area of 25,608 Ha. Class G5 where the flood height is above 100 cm for shopping areas is spread in South Kota District covering an area of 25,036 Ha spread across the sub-districts of Biawoo, Limba UI, Limba U-II and in East Kota District covering an area of 7,043 Ha spread across the sub-districts of Bugis, Ipilo, South Heledulaa and North Heledulaa. The rice fields in Gorontalo City cover an area of 1,187,883 hectares, of which 136,677 hectares were affected by the flood. The largest flood-affected rice field area is class G1 with an area of 60,511 hectares, followed by class G2 with an area of 37,708 hectares, then class G3 with an area of 23,212 hectares, then class G5 with an area of 7,819 hectares, and then the smallest is class G4 with an area of 7,427 hectares.

The analysis of the highway area was carried out because usually during the rainy season, the highway usually functions to drain surface water runoff and continue it to the final disposal site such as rivers or drainage channels that are quite smooth. The highway referred to here is the national road, provincial road and city district road, excluding connecting roads in each sub-district or village. The total area is 198,946 Ha and for the highway that is often hit by flooding is 70,089 Ha with the height of the inundation varying according to the land unit in order from the largest, namely class G5 covering 19,160 Ha followed by class G4 covering 17,145 Ha, class G1 covering 14,727 Ha, class G2 covering 10,625 Ha and the smallest is class G3 covering 8,432 Ha.

The mixed field area consisting of plantations, dry fields and bushes covering an area of 3780.758 Ha, of which 84.525 Ha (2.24%) were affected by the flood. The largest affected class was class G5 covering an area of 31.157 Ha (accumulation of tg = 1.920 Ha, sb = 10.054 Ha and 19.183 Ha) which is a former rice field that is no longer cultivated and has become bushes and plantations spread across the West City District, in addition to dry fields and plantations spread across the East City District.

V. CONCLUSION

Flood characteristics (affected area, height of inundation, duration of inundation) are as follows:

- The affected area is 965.83 Ha with a distribution pattern, namely a residential area of 450.19 Ha, a mixed garden area of 221.20 Ha, a shopping area of 185.29 Ha, and a highway area of 70.09 Ha;
- The height of the G1 class (0–25 cm) covers an area of 5950.46 Ha, for the G2 class (25–50 cm) covers an area of 162.30 Ha, the G3 class (50–75 cm) covers an area of 113.23 Ha, the G4 class (75–100 cm) covers an area of 177.58 Ha, and the G5 class (more than 100 cm) covers 252.46 Ha;
- Duration of flooding, except for Dembe I, Lekobalo and Pilolodaa sub-districts where the duration was more than 30 days, then for other areas the duration of flooding was around 10–24 hours.

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