A Flood Water Level and Risk Analysis in Langsa River Aceh Province

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***Abstract*—Langsa river that crosses the city during high rainfall often experiences flooding around the river's border. This is due to the river which is not being able to accommodate the excess discharge so that the overflow of water has a negative impact on the facilities and infrastructure around the river. In addition, flooding is also affected by the damage of Langsa watersheds which is characterized by a decrease in the ability of storing the water. There are few information available regarding the high potential impact and inundation of floods in detail caused by flood discharge plan, so that this investigation aims to determine the height and inundation of floods for a return period of 5 and 100 years as a basic information in flood disaster mitigation in Langsa City. The scope of the analysis was carried out by several methods, namely the analysis of the maximum rainfall frequency distribution with the normal distribution method, log normal, log-Pearson type III, and Gumbel, periodic analysis of planned flood discharge with the Nakayashu Synthetic Unit Hydrograph method and analysis of water level and flood inundation with the help of HECRAS 5.01 and GIS software to encounter the risk of flood inundation of the stream. The results of this study denote that the flood discharge which occurs in the river due to the maximum daily rainfall (CH) based on the Gumbel distribution results in a flood discharge (Q5) of 361.21 m3/second with a water level of 1.0 meter. Meanwhile, the flood discharge (Q100) produces 564.65 m3/second with a flood water level of 3.0 meters and 33.86 square kilometers area of indunation. Moreover, with the availability of discharge information (Q100), it is predicted that 15 villages are potentially affected by flooding. The proposed analysis has auspicious value in the practical implementation of flood disaster mitigation in Langsa City.**

Keywords—flood water level, risk analysis, flood indunation and discharge, langsa river

I. INTRODUCTION

Floods are one of the natural disasters that often occur throughout the world; currently, in Indonesia, it is also a recurring phenomenon due to the impact of climate change, so some production sectors often suffer, especially in Aceh Province, natural disasters often occur due to climate change shocks, this incident is due to its location densely populated and dependent on climate-sensitive resources [1]. Langsa city as one of the cities in the Aceh province consists of 5 sub-districts with an area of 262.41 km2, which is crossed by the main river, namely the Langsa river with a river length of about 25.518 km [2] into one unit, namely the Watershed (DAS) according to the initial study of F. Isma [3] stated that as a result of the increase in population there was a change in land cover in line with the increase in damage from the direct watershed so that the quality of the ecosystem and the quantity of its water would decrease as a result of which the river cross-section would experience weakness in its capacity as a cause of flooding. Langsa is an area with lowlands, so it is prone to flood disasters, especially when it rains for several hours there will be flood inundation in several villages close to the Langsa river, the purpose of this study is to estimate the area of flood inundation due to flood discharge during Q5 and Q100 times. And the risk to the population and housing units affected by flooding.

The flood incident is also inseparable from the drainage system's availability (river) being unable to accommodate the maximum flow rate of a watershed as the main problem as a flood inundation around the river area. Marimin [4] submerged in floods in 10 villages. Floods caused by high rainfall in the last 3 days in Langsa made the river unable to accommodate high water discharge resulting in water rising 50 - 150 cm past the river cliffs [5], so that the culprit of this flood was high rainfall causing hundreds of houses agriculture, and public facilities and infrastructure were flooded. Some residents even died as a result of being swept away by the flood currents [6].

Previous researchers have used geographic information systems in analyzing the delineation of flood-prone areas [7-10] so that the risk of damage due to flooding can be estimated. In the study of flood discharge in the Langsa river through a hydrological process around the Langsa watershed, the first step in determining flood discharge is rainfall analysis because rain has an important role in the hydrological analysis process [11]. Rainfall analysis using the frequency distribution method and flood discharge analysis using the HSS Nakayashu method. This hydrological model is used in conjunction with HEC-RAS (Hydrologic Engineering Centers River Analysis System) from the United States Army Corps of Engineers (USACE), one of the popular software in modeling high-yield hydraulic flow systems and flood inundation visualized with GIS to see areas of impact flood in Langsa city.

II. MATERIAL AND METHODOLOGY

This research is processed quantitatively with relevant equations. The results are described qualitatively and conclusions inductively by observing the field observation points and analyzing the data to produce water level and flood inundation in the Langsa river. The research location is on the Langsa river with a watershed area ranging from 22,477.50 hectares with a river length of 62 km in the middle and downstream of the river crossing Langsa city, while its upstream is in the district of East Aceh, geographically located at 97048'50.4 "to 98001'44.4" line east longitude and 04026'6 "to 04026'49.20" north latitude, where the location of this research is shown in Figure 1.

This study uses part of the field data and related agencies, which consist of the following:

- Profile data of the upstream Langsa river is carried out by measuring the field and the middle and downstream parts of the Aceh provincial irrigation office
- Data on family and population heads are obtained from the 2019 Langsa city statistical center agency and basic digital maps of Langsa city administration, Langsa River Basin, land cover from the Regional Development Planning Agency - BAPPEDA, Langsa city
- Soil type map data is obtained from laboratory testing by taking soil samples in each village in Langsa City
- Past maximum daily rainfall data for 10 years are obtained from PT Perkebunan Nusantara I (PTPN I)
- Land slope and land elevation data are obtained from digital elevation model (DEM) data sourced from DEMNAS with DEMNAS spatial resolution of 0.27-arcsecond or equivalent to 8 meters (http://tides.big.go.id/DEMNAS/)

Data processing uses the main software, namely, HEC-RAS 5.0.1, QGIS 3.12, Global Mapper 18, Google Earth Pro Version 7.3.3.7786.

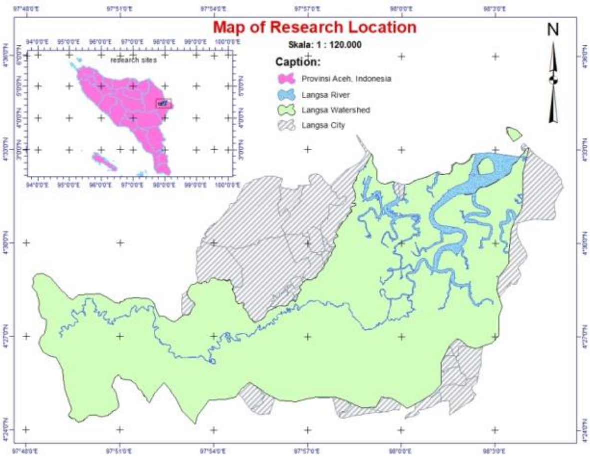

Fig. 1. Research location.

The first process in this research is to analyze the rainfall in the Langsa watershed using the following Thiessen polygon method [7].

$$CH = \frac{A_1.d_1 + A_2.d_2 + A_3.d_3 + \ldots A_n.d_n}{A} = \frac{\sum A_i d_i}{A} \quad (1)$$

Where Ai is the area of influence of the rain gauge 1,2,3,… n; di is the height of rainfall at penakar posts 1, 2, 3,… n; and A is the total area of watershed coverage.

Probability theory and analysis of the frequency of rainfall with four types of frequency distribution, namely [8,11,12]:

- The normal distribution is an analysis of the frequency of rainfall with the following equation.

$$X_T = X + k.Sx \quad (2)$$

Where : X_T : the extrapolated variable. Namely the amunt of rainfall planned for the return T year. X : average price of data $= \frac{\sum_i^n xi}{n}$. k : Gauss reduction variable. Sx: Standard of deviations $\sqrt{\frac{\sum_i^n x_i^2 - \sum_i^n x_i}{n-1}}$

- Normal log distribution with the following equation.

$$\text{Log } X_T = \text{Log } X + k.Sx \text{ Log } X \quad (3)$$

Where: Log XT: Extrapolated variation. i.e., the amount of design rainfall for the return period T year Log X: Average price of the data $= \frac{\sum_i^n \log(X_i| \;)}{n}$ SxLog X : Standard of Deviation $= \sqrt{\sum_i^n}$

- Pearson Type III log with the following equation.

$$\text{Log } X_T : \text{Log } \bar{x} + K.s \quad (4)$$

Where: Log XT is the extrapolated Variater. ie the design rainfall for the T year return period. Log X: Average price of the data $= \frac{\sum_{i=1}^n X_i}{n}$. S is Standard of Deviation. S_1 = $\sqrt{\frac{\sum_{i=1}^n (\log x_i - \overline{\log X})^2}{n-1}}$ with a return period T.Cs = $\frac{n.\sum_{i=1}^n (\log x_i - \overline{\log X})^2}{(n-1)(n-2).S_i^3}$ by: Cs = Slope coefficient

- E.J. Distribution Gumbel. with the following equation

$$X_T = X + K.Sx \quad (5)$$

Where: XT: The extrapolated variable. namely the amount of rainfall plan for return period T (year) X: Average price of data $= \frac{\sum_i^n x_i}{n}$ Sx : Standard of deviations $= \sqrt{\frac{\sum_i^n x_i^2 - \sum_i^n x_i}{n-1}}$ K : Reduction variable to calculate the reduction variableE.J. Gumbel takes a price:

$$K = \frac{Y_T - Y_n}{S_n} \tag{6}$$

YT: Reduced variate as a function of the return period T. Yn: Reduced mean as a function of multiple data (N). and Sn: Reduced standard deviation as a function of many data.

The process of selecting the best frequency distribution method is carried out by testing the goodness of fit test method consisting of dispersion testing with skewness coefficient (Cs), Kurtosis coefficient (Ck), coefficient of variation, conformity testing with Kolmogorov-Smirnov, and Chi-squared suitability testing [13].

Synthetic Unit Hydrograph (HSS) Nakayasu (1950) has investigated the Japanese unit hydrograph and provided a set of equations to form a unit hydrograph as follows [6,11,14,15]:

$$t_g = 0\ 4 + 0.058 \text{ x } L \text{ (untuk L > 15 km)} \tag{7}$$

$$t_g = 0.21 \text{ x } L^{0.7} \text{ (untuk L < 15 km)} \tag{8}$$

The peak times and peak discharge times for the synthetic unit hydrograph are formulated as follows :

$$t_p = t_g + 0.8\ Tr \tag{9}$$

The time during discharge is equal to 0.3 times the peak discharge:

$$t_{0.3} = \alpha \text{ x } t_g \tag{10}$$

Peak time:

$$t_p = t_g + 0.8\ Tr \tag{11}$$

The peak discharge for the synthetic unit hydrograph is formulated as follows:

$$Q_p = \frac{1}{3.6} \text{ x } A \text{ x } R_0 \text{ x } \frac{1}{(0.3xt_p + t_{0.3})} \tag{12}$$

Time lag (time lag tg) is the formula:(0 < t < tp) :

$$Q = Q_p \frac{t^{2.4}}{t_p} \tag{13}$$

With: Q: discharge before reaching peak discharge (m3 / s). T: time (hour)

The arch goes down:

1) *If $t_p < t < t_{0.3}$*

$$Q = Q_p \text{ x } 0.3^{\frac{t - t_p}{t_{0.3}}} \tag{14}$$

2) *If $t_{0.3} < t < 1.5\ t_{0.3}$*

$$Q = Q_p \text{ x } 0.3^{\frac{t - t_p + 0.5xt_{0.3}}{1.5xt_{0.3}}} \tag{15}$$

3) *If $t > 1.5\ t_{0.3}$*

$$Q = Q_p \text{ x } 0.3^{\frac{t - t_p + 0.5xt_{0.3}}{2xt_{0.3}}} \tag{16}$$

Where: tg is the time of delay (hours). L is the length of the river (Km). t0.3 is the time when the discharge is equal to 0.3 times the peak discharge (hour). 1.5 t0.3 is when the discharge is equal to 0.32 times the peak discharge (hours). α is a coefficient. The value is between 1.5 - 0.3. tp is the peak time (hour); Qp is the peak discharge (m3 / s). A is the area of the DPS (km2). Tr is the duration of rain (hour) - (0.5 x tg) to (1 x tg). R0: unit of rain depth (mm). An area affected by flooding will cause the risk of flooding to the population, housing units, public infrastructure, and property, so it is necessary to look at the risk due to flooding [16]. The statement on the number of people affected by flooding is estimated in proportion to the area of inundation by the following equation (17).

$$JPDB = \frac{LG}{LW} xJPW \tag{17}$$

As a result of flooding, the impact on housing units can be estimated proportionally with equation (18) and the estimated cost of losses due to flooding with equation (19)

$$JRDB = \frac{LG}{LW} xJRW \tag{18}$$

$$BK = JRDBxStandardNilaiKerusakan\ Rumah/unit\ (Rupiah) \tag{19}$$

Where: BK is the Cost of Loss (Rupiah)

Where: JPDB is the number of residents affected by the flood (soul). LG is the inundation area (km2). LW is the area (km2). And JP is the total population per region (in person). JPDB is the number of houses affected by the flood (Unit). LG is the inundation area (km2). LW is the area (km2). and JRW is the number of houses per area (unit) with the estimated loss per house unit due to flooding [17,18].

III. Results and Discussion

The determination of the distribution of rainfall using the Thiessen polygon consists of 3 (three) stations located around the watershed language, namely CH Tualang Sawit Station (4o30'24,30"N; 97o49'25,25"E), CH Station Kebun Baru (4o29'16,42"N; 97o56'38,11"E), CH Kebun Lama Station (4o27'52,38"N; 97o57'47,18"E) sourced from PTPN I Directors of Langsa City. This rainfall is taken from the highest rainfall event to get the maximum average rain with the Thiessen method from these 3 stations in the form of an area of rain distribution in the language watershed from upstream to downstream, as in Figure 2.

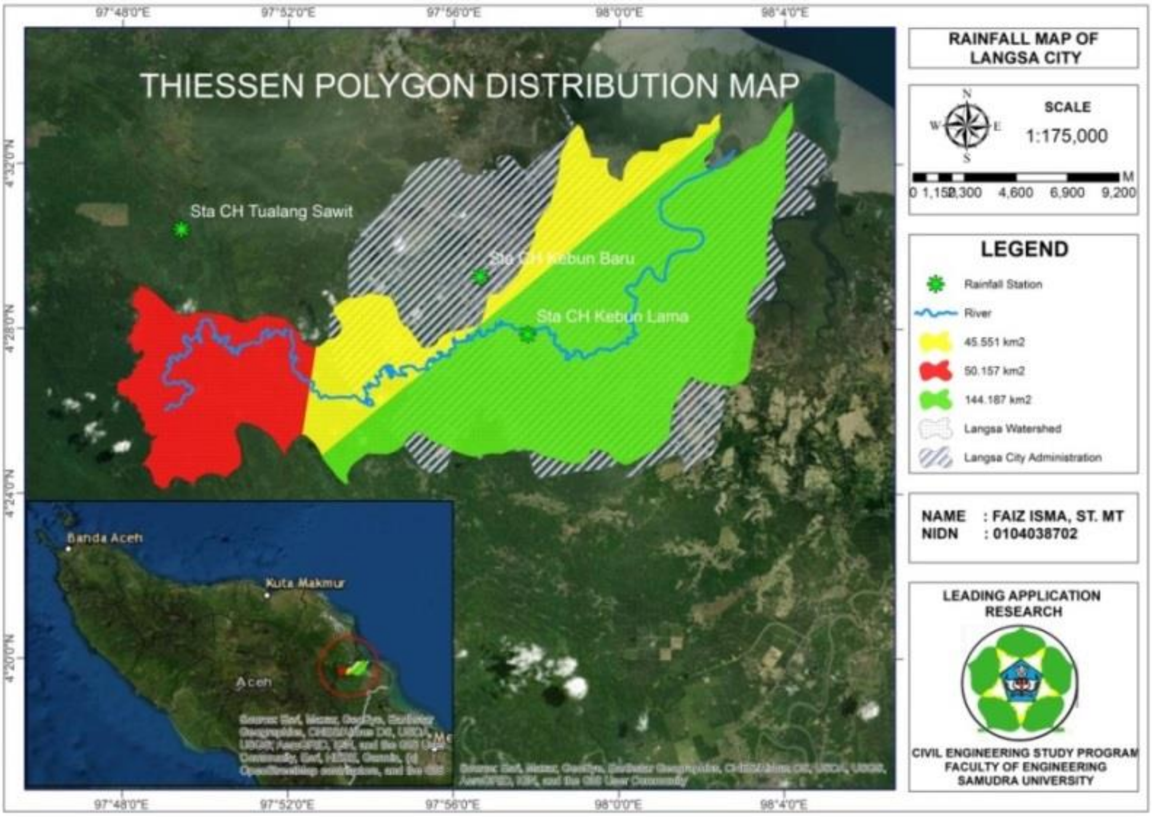

Fig. 2. Rain area with the Thiessen Polygon.

The division of thieesen is divided into 3 station points where the results of the area of thiessen are shown in Table 1 below.

TABLE I. RAINFALL STATION IN LANGSA WATERSHED

No.	Rainfall Station Name	Large (km^2)	Koef. Thiessen
1	Kebun Baru	50.157	0.209
2	Kebun Lama	144.187	0.601
3	Tualang Sawit	45.551	0.190
Total		239.895	1

Table 1 states that the Thiessen Sta CH Tualang Sawit polygon area is 15.643 km2 with a Thiessen coefficient of 0.076, the area of Sta CH Kebun Baru is 45.551 km2 with a Thiessen coefficient of 0.222. An area of CH Kebun Lama is 144.187 km2 with a Thiessen coefficient of 0.702 where the maximum daily rainfall each year from tualang oil palm station, the highest occurred in April at 120 mm/hour, Sta CH for old gardens had the highest rain in November 2019 at 115 mm/hour. Sta CH for new plantations was the highest in December 2014 at 107 mm/hour. For each month in 10 years, maximum rainfall data multiplied by the Thiessen coefficient in equation (1) produces the maximum average daily rainfall in Table 2.

TABLE II. AVERAGE DAILY MAXIMUM RAINFALL OF LANGSA WATERSHED

No.	Tualang Sawit (TSW)	Factor Thiessen	Kebun Lama (KLM)	Factor Thiessen	Kebun Baru (KBR)	Factor Thiessen	Average
1	120	0.209	124	0.601	107	0.190	119.9
2	120	0.209	124	0.601	107	0.190	119.9
3	120	0.209	115	0.601	105	0.190	114.1
4	90	0.209	105	0.601	93	0.190	99.6
5	90	0.209	105	0.601	93	0.190	99.6
6	87	0.209	94	0.601	78	0.190	89.5
7	84	0.209	88	0.601	66	0.190	83.0
8	82	0.209	81	0.601	66	0.190	78.4
9	82	0.209	69	0.601	66	0.190	71.1
10	80	0.209	64	0.601	56	0.190	65.8

Table 2 explains that the maximum average daily rainfall in the Langsa watershed is 119.90 mm. The lowest is 63.00 mm, so the maximum average daily rainfall is used in determining the rainfall plan for the return periods 2, 5, 10. , 25, 50, and 100 years with normal distribution log-normal distribution, Pearson type III log distribution, and Gumbel distribution as frequency analysis

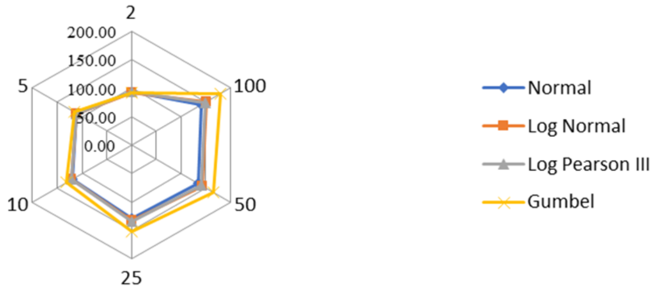

Fig. 3. The probability distribution of the maximum rainfall frequency for the planned return period.

Figure 3 describes the 4 frequency distributions with a normal distribution resulting in R2 of 94.10 mm; R5 of 110.70; R10 for 119.40 mm; R25 of 127.86 mm; R50 of 134.62 mm; R100 is 140.15 mm, log normal distribution produces R2 of 92.20 mm; R5 of 110.42; R10 of 121.36 mm; R25 of 133.04 mm; R50 of 143.18 mm; R100 of 152.05 mm, pearson III log distribution produces R2 of 92.58 mm; R5 of 110.54 mm; R10 of 121.25 mm; R25 of 133.38 mm; R50 of 141.56 mm; R100 is 149.30 mm, the Gumbel distribution produces R2 of 91.40 mm; R5 of 115.24 mm; R10 of 131.02 mm; R25 of 150.96 mm; R50 of 165.75 mm; R100 is 180.43 mm, then the goodness of fit test method is tested with the dispersion test of the skewness coefficient value of 0.0505 <1.1396, the kurtosis coefficient of 1.8641 <5,4002, the Kolmograov and Smirnov distribution test obtained a Dmax value of 0.1643 <Dcr of 0.32, and the chi squared test (χh2 count of 1 <χh2 Critical of 5.991 is used to analyze flood discharge times using the Nakayashu method with a river basin area of 298.89 km2 with a flow coefficient (Cw DAS langsa) of 0.48 and the length of the river is 62.8 km with the assumption of rain for 6 hours [14] with a rain ratio of 55% for the 1st hour, 15% for the second hour, 11% for the 3rd hour and 5 by 7%, and the 6th hour of 5% produces runoff discharge during the HSS Nakayashu plan in Figure 4.

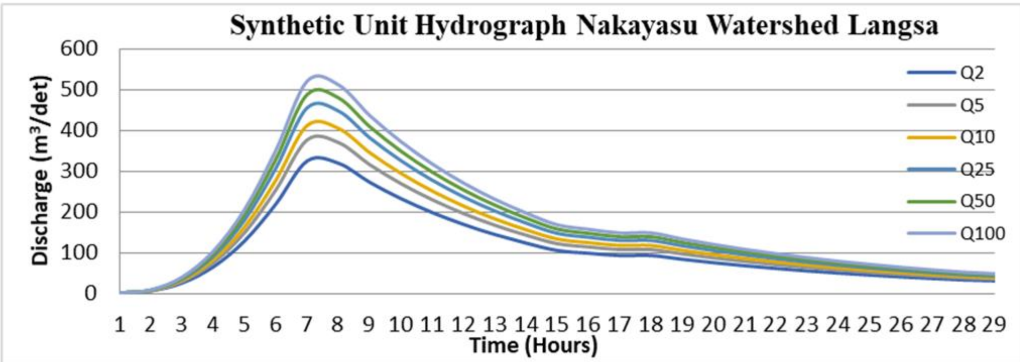

Fig. 4. Takayasu Synthetic Unit Hydrograph (HSS) Flood Discharge.

Figure 4 explains that the peak time of 5.89 hours with a hydrograph unit of 3.567 m3 / second produces an annual peak discharge of Q2 of 286.80 m3 / second, Q5 of 361.21 m3 / second, Q10 of 410.45 m3 / second, Q25. Amounting to 472.68 m3 / second, Q50 at 518.84 m3 / second, Q100 at 564.65 m3 / second. The time required from peak conditions to bottom flow conditions for 24.75 hours with a hydrograph unit of 0.321 m3 / second produces a Q2 base discharge of 27.24 m3 / second, Q5 of 33.94 m3 / second, Q10 of 38.37 m3 / second, Q25 of 43.98 m3 / second, Q50 of 48.13 m3 / second, Q100 of 52.26 m3 / second. 7.

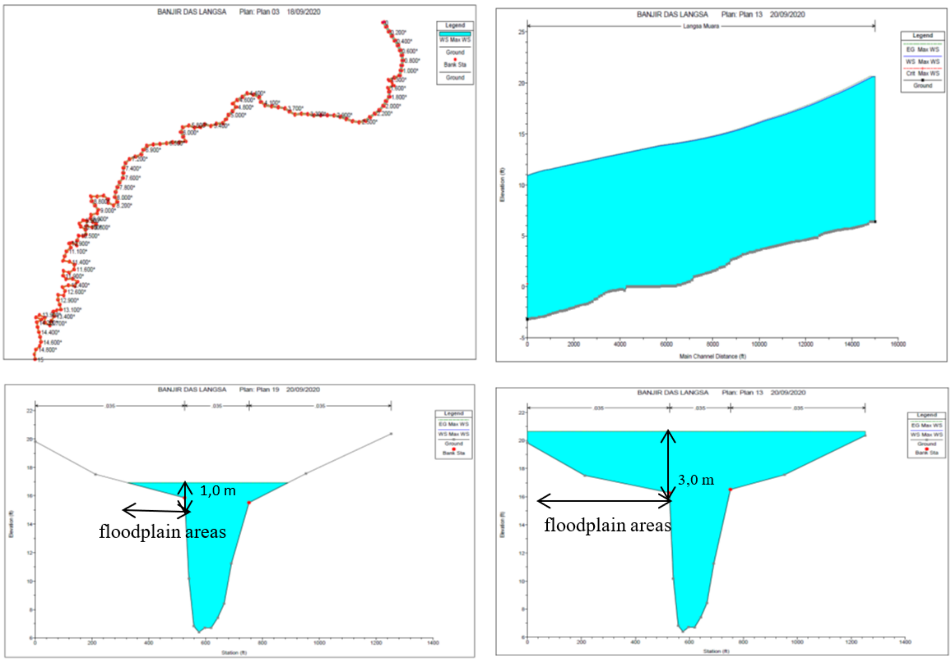

Fig. 5. Flood water level due to the annual Q5 and Q100 discharge.

Figure 5 describes the prediction of flood water level due to the annual discharge of Q5 and Q100 increasing the flood water level of 1.0 m and 3.0 m, resulting in a flood bank area as shown in Figure 7 (a) and (b), which illustrates the conditions of flood inundation in Langsa City. As a result of the Q5 discharge, 10 flood-affected villages will experience an increase if the annual Q100 discharge occurs in the Langsa river, causing 12 villages to have an estimated flood risk according to the area of flood inundation affected by the number of residents, and damage to residents' houses where the flood risk value refers to the Ministry of Planning National Development of the Republic of Indonesia [19] where the estimated flood impact and flood risk costs are shown in Table 3.

TABLE III. IMPACT OF FLOOD INUNDATION AND FLOOD RISK IN LANGSA CITY

No	**Village**	**Districts**	**Area (km^2)**	**Inundation Area (km^2)**		**Number of Affected Population (Soul)**		**Number of Houses Affected (Soul)**		**Estimated Cost (Million/Rp)**	
				Q5	***Q100***	***Q5***	***Q100***	***Q5***	***Q100***	***Q5***	***Q100***
1	Seulalah	Langsa Lama	0,436	0,278	0,381	1.454	1.991	386	529	1.931	2.644
2	Siderejo		0,313	0,289	0,281	3.230	3.142	486	681	2.430	3.406
3	Seulalah Baru		0,206	0,070	0,181	913	2.354	183	471	913	2.354
4	Sidodadi		0,315	0,167	0,313	1.781	3.335	371	694	1.854	3.472
5	Meurandeh Dayah		1,161	0,048	0,823	49	852	11	194	56,08	968
6	Pondok Pabrik		1,334	0,096	1,292	157	2.117	38	510	188	2.550
7	Pondok Kemuning		9,134	0,036	2,359	10	630	3	191	14,75	955
8	Suka Jadi Kebun Ireng		10,668	-	2,143	-	150	-	41	-	203
9	Teungoh	Langsa Kota	1,045	0,151	0,152	853	857	172	173	862	866
10	Jawa		1,325	0,014	0,006	91	40	27	12	133	58,48
11	Geudubang Jawa	Langsa Baro	0,563	0,016	0,017	99	103	20	21	100	103
12	Geudubang Aceh		1,651	-	0,077	-	156	-	31	-	153
Total			**33,856**	1,164	8,152						

Table 3 states that there will be an impact of flood inundation due to Q5 and Q100 annually on 3 sub-districts in Langsa city, namely Langsa lama there are 8 villages, Langsa Kota there are 2 villages. Langsa Baro, there are 2 villages, it is stated that the flood incident due to Q5 causes the widest flood inundation to occur In the village of Siderejo, Langsa Lama Subdistrict, an area of 0.289 km2, resulted in a loss of 486 houses affected by floods in the range of IDR 2,430,000,000, - there will be an increase in the area of flood inundation by 85.54% due to Q100 with a flood inundation area of 8,152 km2 were the most extensive village affected by flood Seulalah village covering an area of 0.381 km2 causes 1,991 people to be affected by flood inundation. There are 529 residential units at risk of flooding, with an estimated loss due to flooding of Rp. 2,644,000,000, but the risk of loss due to flooding occurs in Sidodadi village of IDR 3,472,000,000, - to 694 housing units and 3,335 residents with a flood inundation area of 0.313 km2 in where the distribution of flood inundation in Langsa City due to Q5 and Q100 discharge is shown in Figure 6.

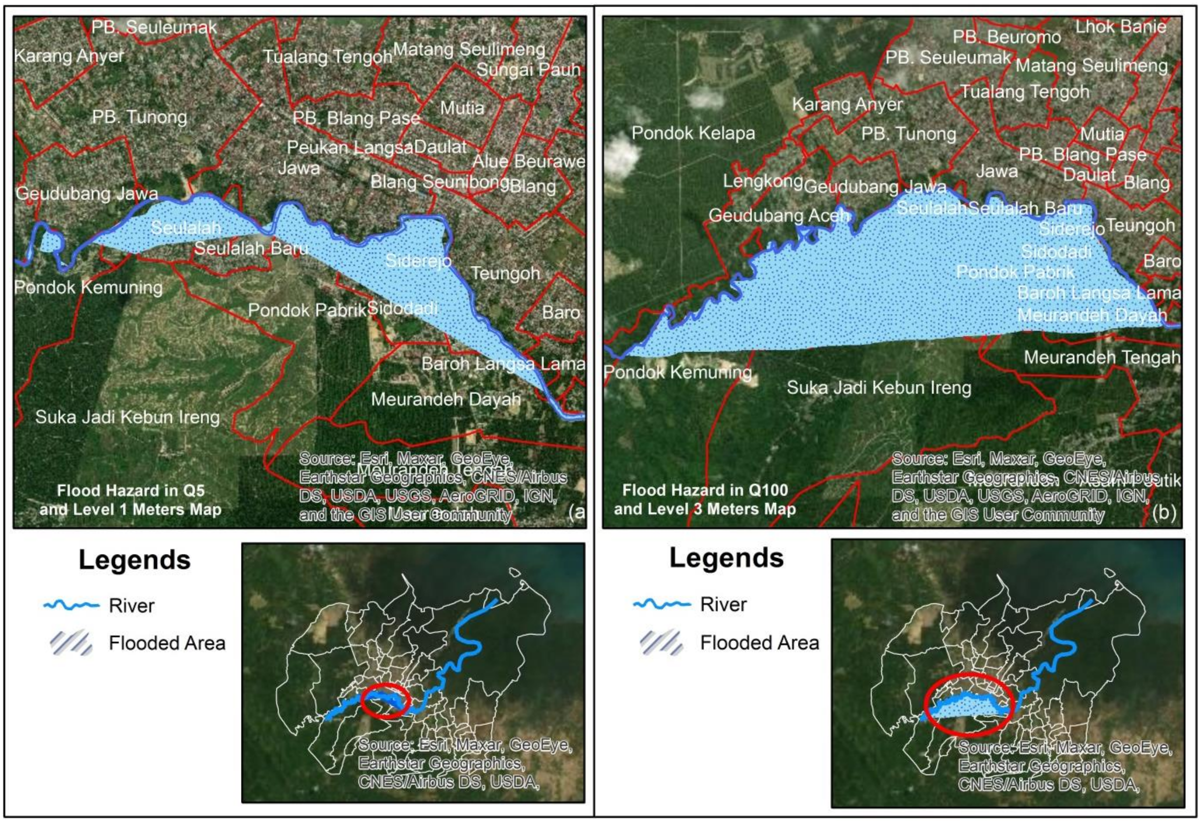

Fig. 6. Flood inundation due to flood discharge planned for the return period.

Figure 6 states that the integration between the flood inundation from the results of HEC-RAS 5.01 and the Geographical Information System (GIS) will provide information on the prediction of flood banks due to the peak discharge during the Q5 and Q100 times with the overlay process of the flood inundation map on the map of population distribution and urban infrastructure so that Obtained the distribution of the impact of flood risk in Langsa City, the estimated flood events due to this annual Q100 can be used as a reference in mitigating flood disasters in Langsa City by implementing flood prevention infrastructure that can divert the volume of floodwater in the event of a repeat peak discharge in the Langsa River. The procedure for estimating the return flood discharge using HSS Nakayashu in the Langsa watershed can be applied in the same way to other watershed conditions, especially around Aceh province - Indonesia predicting flood events in a watershed.

IV. Conclusion

The estimation of the peak flood discharge for the return period from the main river in Langsa city based on the maximum daily rainfall data in the selected language city, the analysis of the appropriate Gumbel frequency distribution was applied in the Langsa watershed. It was found that the peak discharge of the language river with HSS Nakayashu obtained a Q5 debit of 361, 21 m3 / second and Q100 of 564.65 m3 / second resulted in an increase in the average flood water level of the Langsa river of 1.0 meter and 3.0 meters resulting in a flood inundation area due to Q5 of 1,164 km^2, an increase of 85.54% due to Q100 an annual area of 8,152 km2 with a coverage area of the impact of flooding through the integration of HEC-RAS and SIG, a flood distribution map is obtained which can estimate the risk of flooding to the affected population and houses so that they can identify losses due to the flood risk.

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