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Hourly Rainfall Distribution Pattern in the Northern Coast of Bolaang Mongondow

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Abstract. The data for this research is compiled from the records of hourly rainfall between 1993 to 2014 which was generated from several. Automatic Rainfall Stations namely; Ayong-Bumbung Climatology Station, Sangkub-Huntuk climatology station, and Sangkub-Pangkusa Climatology Station. The data was then analyzed using statistical methods. Rainfall distribution pattern is based on heavy rainfall recorded by automatic rainfall measuring device. The rainfall data used here are the ones with rainfall depth of more than 50mm. All the data are then analyzed to obtain the frequency of occurrence of each of the rainfall duration. From the result of frequency analysis, it is then determined that certain rainfall duration represents the general rainfall condition in the research area. Research will show that rainfall pattern on the Northern Coast of Bolaang Mongondow, for heavy storm have a tendency of 7 hour duration, with 22% distribution for the first hour, 28% distribution for the second hour, 19% distribution for the third hour, 15% for the fourth hour, 7% for the fifth hour, 6% for the sixth hour, and 3% for the seventh hour.

1. Introduction

In the analysis of design flood for ungauged catchment, the rainfall input at the river basin is transformed into output which constitutes the design flood of the river. The daily design rainfall value must be converted into hourly rainfall value for the purpose of analyzing design flood. One method of converting daily rainfall into hourly rainfall is by distributing them in accordance to the rainfall distribution pattern of the local region. Currently, however, no research on the rainfall distribution pattern for the region of the northern coast of Bolaang Mongondow has ever been conducted. The analysis of rainfall distribution patterns still using results of analysis from the region of Java which is at risk at being inaccurate. It is therefore necessary to determine the rainfall pattern for the Northern Coast of Bolaang Mongondow, so that the rainfall pattern of the region can be used in the analysis of transforming daily rainfall pattern in to hourly rainfall pattern.

The current problem is the unavailability of rainfall pattern for the Northern Coast of Bolaang Mongondow region, analysis is therefore still using the rainfall pattern of Java which is not necessarily accurate hence the result may not be suitable.

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Figure 1. Area of research

2. Literature Review

In the flood flow calculation, the input required is design flood which is distributed into hourly rainfall depth (hyetograph). In order to convert design flood into hourly rainfall value, a pattern of hourly distribution is required. Several methods can be used to obtain the pattern such as: when only daily rainfall data is available, rainfall distribution model can be used to obtain hourly rainfall depth from the design flood. Rainfall distribution model which has been developed to convert daily rainfall to hourly rainfall pattern is, for instance, uniformed rainfall distribution, triangle, and Alternating Block Method (ABN) (Chow et.al 1988).

If rainfall data from automatic rainfall post is available then hourly rainfall distribution pattern can be obtained through observation on heavy rainfall occurrences. Rainfall distribution pattern is then spread evenly to obtain the average rainfall distribution pattern which is then assumed to represent the general rainfall condition and then used as pattern to distribute design flood into hourly rainfall value. Tadashi Tanimoto (1969) developed hourly rainfall distribution used on Java island as shown in Table 1 and Figure 2.

Table 1: Rainfall distribution on Java island according to Tanimoto (1969)

Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
% of Distribution	26	24	17	13	7	5.5	4	3.5
% of Cum. Distribution	26	50	67	80	87	92.5	96.5	100

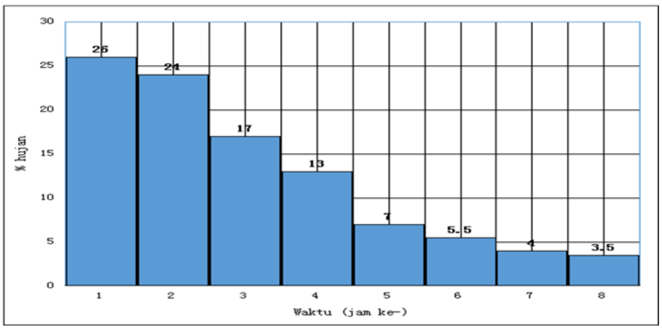

Figure 2. Tadashi Tanimoto (1969) rainfall distribution

By analyzing data from measured rainfall occurrences, typical time of rainfall recurrence can be obtained. Huff (1967) found correlation between time and distribution for heavy rainfall on an area the size of 400 mi2 on Illinois. Time distribution pattern is divided into four groups of probability, from the

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driest in the first group, to the dampest in the fourth group. Figure 3 displays selected histograms of the first group for 10, 50, 90 % cumulative occurrence probability, each of which illustrate percentage of total for every 10 % rise from the entire rainfall duration. Histogram 50 % represents cumulative rainfall pattern which occurred in more than half of rainfall occurrences. This histogram 50% has been used in the ILLUDAS storm drainage simulation model by Terstriep and Stall (1974).

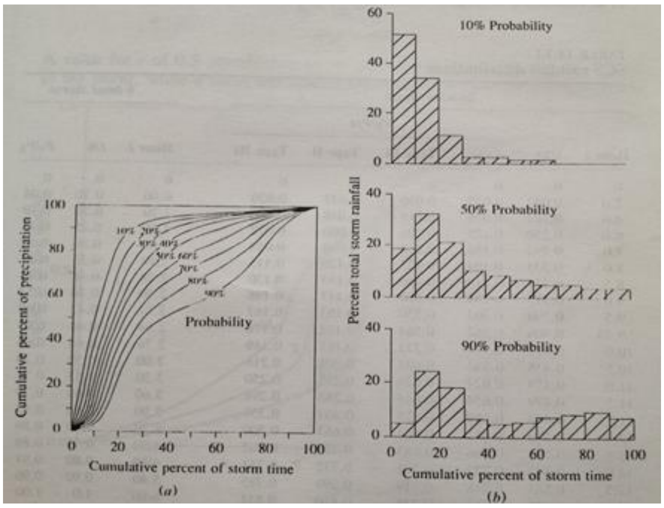

Figure 3. Huff's distribution pattern

US Department of Agriculture, SCS 1986 built a synthetic rainfall hyetographs to be used in America from rainfall occurrences with the durations of 6 and 24 hours. Pilgrim and Cordery 1975 developed hyetograph analysis method based on ranking of time interval in every rainfall occurrences with the rainfall depth of the occurrence. Repeated analysis was conducted on many rainfall occurrences on the research area. Typical form of hyetograph was then acquired by adding up the ranking of each intervals. This approach is a standard method at the Australian hydrologic design (The Institution of Engineers Australia, 1987).

Prayoga (2004) conducted a research on rainfall pattern at the river basin of Cimanuk West Java. Rainfall distribution pattern was based on heavy rainfall recorded by automatic rainfall measuring device. Rainfall data used was the ones above 50 mm in depth which was considered equivalent to a one year repetition period. All the data were then analyzed to obtain occurrence frequency of each of the rainfall duration. From the frequency analysis result it is then established that certain rainfall duration is the duration that represents general rainfall condition in the area of research. This hourly rainfall data is then presented in the form of cumulative percentage of rainfall depth, and described in the form of rainfall profile curve and its rainfall profile determined as shown in Figure 4. This average rainfall profile is the rainfall distribution pattern of the research area, which can be stated in the average graphic.

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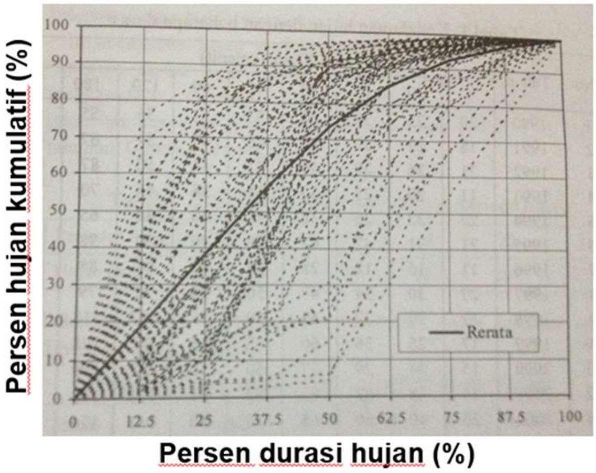

Figure 4. Rainfall distribution profile of Cimanuk river basin

3. Research Methodology

This research is projected to take place for one year, by analyzing rainfall pattern of the Northen Coast of Bolaang Mongondow. Automatic rainfall stations selected were: Ayong-Bumbung climatology station, Sangkub-Huntuk climatology station, and Sangkub-Pangkusa climatology station.

Data analysis begins with selection of rainfall data, conducting data analysis to generating histogram of hourly rainfall distribution pattern. Rainfall occurrence is the time when the rainfall occurs in hour or minute. The following is an example of rainfall selection.

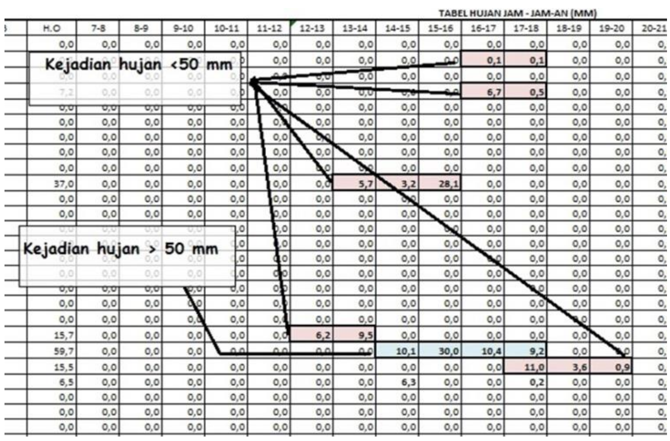

Figure 5. Example of rainfall data

The exhibit above illustrates rainfall coloured in red as the one with < 50 mm in depth, while the rainfall occurrence in blue as > 50 mm. Therefore in the selection period only the blue coloured data is used, and this also applies on data of other occurrences, thereafter these occurrence data are listed into one. The list of rainfall with depth of > 50 mm can be seen in Table 2.

Table 2: Resume Example of Selected Rainfall – Analysis Result

No.	Tanggal	Waktu	JAM KE-									
			1	2	3	4	5	6	7	8	9	10
Pos Hujan Ayong - Bumbung												
1	12-Mar-11	22:00 - 7:00	2.5	2.7	8.0	8.0	7.0	6.0	6.0	5.0	9.0	
2	4-Dec-11	21:00 - 6:00	0.8	9.0	24.0	0.3	1.3	10.6	4.5	6.0	5.5	
3	7-Aug-13	19:00 - 21:00	51.9	2.4								
Pos Hujan Sangkub - Huntuk												
4	23-Nov-08	8:00 - 18:00	0.3	0.5	20.7	11.7	14.4	5.7	4.6	2.5	0.4	0.5
5	25-Nov-09	18:00 - 23:00	10	20	9.7	9.6	19.2					
Pos Hujan Sangkub - Pangkusa												
6	10-Jan-94	14:00 - 19:00	20	29.7	19.8	19.7	25					
7	27-Jan-94	16:00 - 22:00	31.6	24.4	3	1	10.8	3.3				
8	17-Mar-94	14:00 - 19:00	12.2	39.2	49	96	1					
9	5-Feb-95	21:00 - 3:00	30	20	3.7	7.7	4	1.8				
10	8-Jul-95	10:00 - 16:00	40.6	24.8	4	2.8	1.1	0.2				
11	1-ags-95	14:00 -18:00	8	30	20	6.2						
12	3-ags-95	8:00 - 12:00	2.7	20.2	10	20						
13	14-Nov-95	12:00 -17:00	3.8	114	1.5	0.5	1.1					
14	20-Jan-96	9:00 - 12:00	40	11	16.1							
15	26-Jan-96	21:00 - 6:00	10	27.5	4.4	5.5	5	4.9	2	0.9	0.6	
16	5-Mar-96	18:00 - 1:00	18.7	12.8	17.5	15	2	8.5	2.3			
17	18-Mar-96	17:00 - 19:00	46	26.6								
18	19-Mar-96	20:00 - 24:00	2.6	30	20	4.5						
19	18-Ags-96	16:00 - 19:00	40	12.7	0.8							
20	4-Des-96	7:00 - 10:00	53	10	1.5							
21	11-Des-96	4:00 - 6:00	38	25.8								
22	16-Jan-97	8:00 - 9:00	59.5									
23	1-Mar-97	12:00 - 15:00	54	0.2	3.4							
24	9-mei-97	20:00 - 23:00	10	50	16							
25	19-mei-97	16:00 - 23:00	5	70	14.5	13.5	2	13	3.9			

Accumulation of rainfall depth is conducted based on the resume of selected rainfall from Table 2. Selected rainfall occurrences are then accumulated by its rainfall depth per occurrence until the occurrence has the total hour similar to the total hour of the occurrence with the longest hour. In this research the occurrence with the longest hour came from ARR Sangkub-Huntuk on November 23, 2008 with the total hour of 10 hours, therefore all selected rainfall occurrences will be accumulated into 10 hours.

The following is an example of calculation for accumulating rainfall depth in one occurrence. Taken for a sample is a record of occurrence in January 6, 2015 from meteorological station of Sam Ratulangi with rainfall depth as follow.

Table 3: Rainfall Depth Sample

Hour	Depth (mm)
1	9.6
2	9.2
3	0.3
4	97
5	97
6	97
7	3.8
8	1.4

After rainfall depth data in Table 3 is accumulated, result is shown in Table 4.

Table 4: Cummulative Depth Sample

Hour	Depth (mm)	Cum. Depth (mm)
1	9.6	9.6
2	9.2	18.8
3	0.3	19.1
4	97	116.1
5	97	213.1
6	97	310.1

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Hour	Depth (mm)	Cum. Depth (mm)
7	3.8	313.9
8	1.4	315.3

This formula of calculation is run on the entire selected rainfall occurrences, the accumulated result of which can be seen in Table 5. The average of rainfall depth in this research is average value of the entire rainfall depth of the selected rainfall depth, which is calculated by averaging rainfall depth of every hour of the entire selected rainfall occurrences. In this research 10 measure of rainfall depth is set for every available rainfall occurrences, producing 10 data of rainfall depth average. The rainfall depth average can be obtained using the formula of:

$$\overline{X_t} = \frac{1}{n}\sum X_t$$

Where: $\overline{X}_t$ = rainfall depth average on the-t hour; n = quantity of rainfall occurrence; X_t = rainfall depth on the-t hour.

The result of overall average rainfall depth calculation using the formula is enclosed in Table 6.

Mass and weight calculation is a calculation to find the value of the weight of rainfall depth on the t-hour. Mass weight can be obtained by finding the difference between rainfall depth average on the t-hour, and rainfall depth of previous hour. Mass weight is calculated by the following formula:

$$BM_t = \bar{X}_t - \bar{X}_{t-1}$$

Where: BM_t = mass weight of t-hour; X_t = rainfall depth average of t-hour; X_{t-1} = rainfall depth average of previous t-hour.

The result of the entire calculation of average rainfall depth mass weight using the above formula is enclosed in Table 7.

Table 5: Accumulation of selected rainfall occurences – analysis result

No	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
1	2.5	5.2	13.2	21.2	28.2	34.2	40.2	45.2	54.2	54.2
2	0.8	9.8	33.8	34.1	35.4	46.0	50.5	56.5	62.0	62.0
3	51.9	54.3	54.3	54.3	54.3	54.3	54.3	54.3	54.3	54.3
4	0.3	0.8	21.5	33.2	47.6	53.3	57.9	60.4	60.8	61.3
5	10	30	39.7	49.3	68.5	68.5	68.5	68.5	68.5	68.5
6	20	49.7	69.5	89.2	114.2	114.2	114.2	114.2	114.2	114.2
7	31.6	56	59	60	70.8	74.1	74.1	74.1	74.1	74.1
8	12.2	51.4	100.4	196.4	197.4	197.4	197.4	197.4	197.4	197.4
9	30	50	53.7	61.4	65.4	67.2	67.2	67.2	67.2	67.2
10	40.6	65.4	69.4	72.2	73.3	73.5	73.5	73.5	73.5	73.5
11	8	38	58	64.2	64.2	64.2	64.2	64.2	64.2	64.2
12	2.7	22.9	32.9	52.9	52.9	52.9	52.9	52.9	52.9	52.9
13	3.8	117.8	119.3	119.8	120.9	120.9	120.9	120.9	120.9	120.9
14	40	51	67.1	67.1	67.1	67.1	67.1	67.1	67.1	67.1
15	10	37.5	41.9	47.4	52.4	57.3	59.3	60.2	60.8	60.8
16	18.7	31.5	49	64	66	74.5	76.8	76.8	76.8	76.8
17	46	72.6	72.6	72.6	72.6	72.6	72.6	72.6	72.6	72.6
18	2.6	32.6	52.6	57.1	57.1	57.1	57.1	57.1	57.1	57.1
19	40	52.7	53.5	53.5	53.5	53.5	53.5	53.5	53.5	53.5
20	53	63	64.5	64.5	64.5	64.5	64.5	64.5	64.5	64.5
21	38	63.8	63.8	63.8	63.8	63.8	63.8	63.8	63.8	63.8
22	59.5	59.5	59.5	59.5	59.5	59.5	59.5	59.5	59.5	59.5
23	54	54.2	57.6	57.6	57.6	57.6	57.6	57.6	57.6	57.6
24	10	60	76	76	76	76	76	76	76	76
25	5	75	89.5	103	105	118	121.9	121.9	121.9	121.9
26	6.5	23.5	28.5	33.5	36.5	54.5	58.5	61	61	61
27	2.4	4.4	8.4	38.4	58.4	87.4	94.4	100.4	100.4	100.4
28	1.4	6	16	25.6	35.2	44.7	54.1	56.2	56.2	56.2
29	9.6	18.8	19.1	116.1	213.1	310.1	313.9	315.3	315.3	315.3

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Table 6: Average Rainfall Depth – Analysis Result

No	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
1	2.5	5.2	13.2	21.2	28.2	34.2	40.2	45.2	54.2	54.2
2	0.8	9.8	33.8	34.1	35.4	46.0	50.5	56.5	62.0	62.0
3	51.9	54.3	54.3	54.3	54.3	54.3	54.3	54.3	54.3	54.3
4	0.3	0.8	21.5	33.2	47.6	53.3	57.9	60.4	60.8	61.3
5	10	30	39.7	49.3	68.5	68.5	68.5	68.5	68.5	68.5
6	20	49.7	69.5	89.2	114.2	114.2	114.2	114.2	114.2	114.2
7	31.6	56	59	60	70.8	74.1	74.1	74.1	74.1	74.1
8	12.2	51.4	100.4	196.4	197.4	197.4	197.4	197.4	197.4	197.4
9	30	50	53.7	61.4	65.4	67.2	67.2	67.2	67.2	67.2
10	40.6	65.4	69.4	72.2	73.3	73.5	73.5	73.5	73.5	73.5
28	1.4	6	16	25.6	35.2	44.7	54.1	56.2	56.2	56.2
29	9.6	18.8	19.1	116.1	213.1	310.1	313.9	315.3	315.3	315.3
30	0.4	20.4	30.4	50.4	60.4	60.4	60.4	60.4	60.4	60.4
31	11	24	51	51	51	51	51	51	51	51
32	40	70	75	75	75	75	75	75	75	75
33	2.5	10	40	59	59	59	59	59	59	59
34	7	10	19.5	28.5	37.5	46.5	55.5	58.2	58.9	58.9
35	20.4	60.4	70.4	136.4	136.4	136.4	136.4	136.4	136.4	136.4
36	1.3	11.3	141.2	149.4	149.4	149.4	149.4	149.4	149.4	149.4
37	4.4	10.2	50.2	53.6	53.6	53.6	53.6	53.6	53.6	53.6
38	20	50	60	70.2	73.6	73.6	73.6	73.6	73.6	73.6
39	21	52	53	54.2	55	57.3	57.4	58.2	58.2	58.2
40	8.5	9.1	99.1	102.4	102.4	102.4	102.4	102.4	102.4	102.4
41	5.7	95.9	95.9	95.9	95.9	95.9	95.9	95.9	95.9	95.9
42	3.8	63.8	69.9	76	85.2	92.8	93.7	93.7	93.7	93.7
∑	757.1	1,744.5	2,399.9	2,909.9	3,165.8	3,392.2	3,449.7	3,479.6	3,495.8	3,496.3

The percentage of rainfall depth is percentage value of rainfall depth mass weight. Rainfall depth percentage can be calculated with the following formula:

$$P_t(\%) = \frac{BM_t}{BM_{TOTAL}}.100\%$$

Where: $P_t(\%)$ = rainfall depth percentage of t-hour; BM_t = mass weight of t-hour; BM_{TOTAL} = mass weight total of the entire hour. The result of the entire calculation of depth percentage is enclosed I Table 8.

Table 7: Average Rainfall Depth Mass Weight – Analysis Result

No	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
1	2.5	5.2	13.2	21.2	28.2	34.2	40.2	45.2	54.2	54.2
2	0.8	9.8	33.8	34.1	35.4	46.0	50.5	56.5	62.0	62.0
3	51.9	54.3	54.3	54.3	54.3	54.3	54.3	54.3	54.3	54.3
4	0.3	0.8	21.5	33.2	47.6	53.3	57.9	60.4	60.8	61.3
5	10	30	39.7	49.3	68.5	68.5	68.5	68.5	68.5	68.5
6	20	49.7	69.5	89.2	114.2	114.2	114.2	114.2	114.2	114.2
7	31.6	56	59	60	70.8	74.1	74.1	74.1	74.1	74.1
8	12.2	51.4	100.4	196.4	197.4	197.4	197.4	197.4	197.4	197.4
9	30	50	53.7	61.4	65.4	67.2	67.2	67.2	67.2	67.2
10	40.6	65.4	69.4	72.2	73.3	73.5	73.5	73.5	73.5	73.5
28	1.4	6	16	25.6	35.2	44.7	54.1	56.2	56.2	56.2
29	9.6	18.8	19.1	116.1	213.1	310.1	313.9	315.3	315.3	315.3
30	0.4	20.4	30.4	50.4	60.4	60.4	60.4	60.4	60.4	60.4
31	11	24	51	51	51	51	51	51	51	51
32	40	70	75	75	75	75	75	75	75	75
33	2.5	10	40	59	59	59	59	59	59	59
34	7	10	19.5	28.5	37.5	46.5	55.5	58.2	58.9	58.9
35	20.4	60.4	70.4	136.4	136.4	136.4	136.4	136.4	136.4	136.4
36	1.3	11.3	141.2	149.4	149.4	149.4	149.4	149.4	149.4	149.4
37	4.4	10.2	50.2	53.6	53.6	53.6	53.6	53.6	53.6	53.6
38	20	50	60	70.2	73.6	73.6	73.6	73.6	73.6	73.6
39	21	52	53	54.2	55	57.3	57.4	58.2	58.2	58.2
40	8.5	9.1	99.1	102.4	102.4	102.4	102.4	102.4	102.4	102.4
41	5.7	95.9	95.9	95.9	95.9	95.9	95.9	95.9	95.9	95.9
42	3.8	63.8	69.9	76	85.2	92.8	93.7	93.7	93.7	93.7
∑	757.1	1,744.5	2,399.9	2,909.9	3,165.8	3,392.2	3,449.7	3,479.6	3,495.8	3,496.3
x	18.0262	41.5357	57.1405	69.2833	75.3762	80.7667	82.1357	82.8476	83.2333	83.2452
Bobot Massa	18.0262	23.5095	15.6048	12.1429	6.09286	5.39048	1.36905	0.7119	0.38571	0.0119

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Table 8: Percentage of Rainfall Depth – Analysis Result

No	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
1	2.5	5.2	13.2	21.2	28.2	34.2	40.2	45.2	54.2	54.2
2	0.8	9.8	33.8	34.1	35.4	46.0	50.5	56.5	62.0	62.0
3	51.9	54.3	54.3	54.3	54.3	54.3	54.3	54.3	54.3	54.3
4	0.3	0.8	21.5	33.2	47.6	53.3	57.9	60.4	60.8	61.3
5	10	30	39.7	49.3	68.5	68.5	68.5	68.5	68.5	68.5
6	20	49.7	69.5	89.2	114.2	114.2	114.2	114.2	114.2	114.2
7	31.6	56	59	60	70.8	74.1	74.1	74.1	74.1	74.1
8	12.2	51.4	100.4	196.4	197.4	197.4	197.4	197.4	197.4	197.4
9	30	50	53.7	61.4	65.4	67.2	67.2	67.2	67.2	67.2
10	40.6	65.4	69.4	72.2	73.3	73.5	73.5	73.5	73.5	73.5
28	1.4	6	16	25.6	35.2	44.7	54.1	56.2	56.2	56.2
29	9.6	18.8	19.1	116.1	213.1	310.1	313.9	315.3	315.3	315.3
30	0.4	20.4	30.4	50.4	60.4	60.4	60.4	60.4	60.4	60.4
31	11	24	51	51	51	51	51	51	51	51
32	40	70	75	75	75	75	75	75	75	75
33	2.5	10	40	59	59	59	59	59	59	59
34	7	10	19.5	28.5	37.5	46.5	55.5	58.2	58.9	58.9
35	20.4	60.4	70.4	136.4	136.4	136.4	136.4	136.4	136.4	136.4
36	1.3	11.3	141.2	149.4	149.4	149.4	149.4	149.4	149.4	149.4
37	4.4	10.2	50.2	53.6	53.6	53.6	53.6	53.6	53.6	53.6
38	20	50	60	70.2	73.6	73.6	73.6	73.6	73.6	73.6
39	21	52	53	54.2	55	57.3	57.4	58.2	58.2	58.2
40	8.5	9.1	99.1	102.4	102.4	102.4	102.4	102.4	102.4	102.4
41	5.7	95.9	95.9	95.9	95.9	95.9	95.9	95.9	95.9	95.9
42	3.8	63.8	69.9	76	85.2	92.8	93.7	93.7	93.7	93.7
∑	757.1	1,744.5	2,399.9	2,909.9	3,165.8	3,392.2	3,449.7	3,479.6	3,495.8	3,496.3
x	18.0262	41.5357	57.1405	69.2833	75.3762	80.7667	82.1357	82.8476	83.2333	83.2452
Bobot Massa	18.0262	23.5095	15.6048	12.1429	6.09286	5.39048	1.36905	0.7119	0.38571	0.0119
Presentase (%)	21.6543	28.2413	18.7455	14.5868	7.31917	6.47542	1.6446	0.85519	0.46335	0.0143

Hourly rainfall distribution pattern is the aimed result of this research, hourly rainfall distribution is obtained by analysis result conducted previously. From the analysis, rainfall depth percentage has been obtained. Said percentage will then be described in a histogram and its rainfall distribution table be made.

The following is hourly rainfall distribution table obtained for analysis result conducted using hourly rainfall data from the three automatic rainfall gauge station on the Northern Coast of Bolaang Mongondow.

Table 9: Rainfall Distribution – Analysis Result

Hour	Rainfall Distribution (%)	Cum. Rainfall Distribution (%)
1	22	22
2	28	50
3	19	69
4	15	84
5	7	91
6	6	97
7	3	100

Based on the rainfall distribution percentage in Table 9, a histogram of rainfall distribution percentage can be constructed, as the following figure shows:

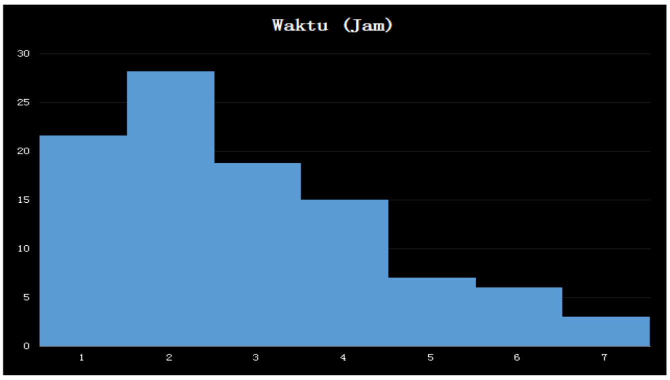

Figure 6: Percentage of rainfall distribution pattern based on result of analysis

Based on Figure 6, rainfall distribution pattern on the Northern Coast of Bolaang Mongondow can be seen as occurring in 7 hour, with its hourly rainfall distribution as follows:

Table 10: Rainfall Distribution of Northern Coast of Bolaang Mongondow – Analysis Result

Hour	Rainfall Distribution (%)
1	22
2	28
3	19
4	15
5	7
6	6
7	3

4. Conclusion

Hourly rainfall pattern of the Northern Coast of Bolaang Mongondow, for stormy rainfall has a tendency of 7 hour duration. Distribution per hour is shown in Table 10. It is suggested to conduct hourly distribution pattern analysis for the region of Northern Coast of Bolaang Mongondow, so that in analyzing flood flow for the rivers in the region of Bolaang Mongondow, local hourly distribution pattern can be used to promote better result.

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