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Frequency Analysis for Rainfall Design in Medan North Sumatra Indonesia

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Abstract
Rainfall is an essential component of climatology that should be consistently analyzed over extended periods. Availability of complete rainfall data is one of the most important parts in relation to Hydrology and Water Resources. The ideal data is that in accordance with what is needed. However, in practice, incomplete records are often encountered, this can be caused by several things, including equipment damage, employee negligence, equipment replacement, and natural disaster. This situation causes certain parts of the time series data to contain empty data, it is necessary to pay attention to the pattern of the distribution of rain and the surrounding stations. In this paper, there are three rainfall stations analyzed, these are BBMKG Region I, Sampali station, and Belawan station. Unfortunately, there are two missing rainfall data in 2001 and 2006 in Belawan station. Therefore, this paper uses the Normal Ratio Method and the Inversed Square Distance Method to complete the rainfall data and compare the two methods. From the result, there are different values from the two methods, the value is smaller using the Normal Ratio Method. It can be caused by the influence of distance factors on inversed square distance.

1. Introduction

Medan is one of the cities often hit by floods. Thus, recording rainfall data in Medan is crucial to analyze the effect of rainfall on the flood disaster. Due to variations in the monsoon climate, drought and flood disasters are natural phenomena that alternately always hit several places in Indonesia. However, the mechanism of drought and flood disasters is still very limited in understanding due to limited climate data and limited meteorological research in Indonesia. From the number of floods and landslides, it can be seen that the main cause is meteorological factors, elements of rainfall, especially rain intensity, distribution, and duration. Frequent urban flooding in Medan, exacerbated by climate variability and infrastructure limitations, presents a major challenge for urban planning. Rainfall frequency analysis provides essential data for designing flood mitigation systems and predicting flood risks. This study addresses the challenges in incomplete rainfall data and applies hydrological analysis techniques to establish reliable design parameters for flood-prone areas in Medan, using data from three stations over a 20-year period.

2. Method

This study analyzed maximum daily rainfall data from three stations in Medan—BBMKG Region I, Sampali, and Belawan. Missing data at Belawan station (2001 and 2006) were estimated using the Normal Ratio Method (NRM) and Inverse Square Distance (ISD) Method. In both methods, rainfall data from neighboring stations were incorporated to obtain interpolated values. The data consistency was verified using double mass curve analysis, and various frequency distributions (e.g., Gumbel, Log-Pearson III) were applied to estimate rainfall intensity for multiple return periods.

2.1. Normal Ratio Method

The Normal Ratio method is one of the methods used to find loss rainfall data. The calculation method used is quite simple, namely by takes into account rainfall data at adjacent rain stations to look up the data rainfall loss at the station. The variables that are taken into account in this method are daily rainfall at other stations and the amount of 1 year's rainfall at other stations

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Linsley, Kohler and Paulhus (1958) suggest a method called the "Normal Ratio Method" as follows:

$$Dx = \frac{1}{n}\sum_{i=1}^{n} d_i \frac{An_x}{An_i} \qquad (2.1)$$

Dx = Maximum daily rainfall at x station

N = Number of stations around x to search for data in x

Di = Maximum daily rainfall at i station

Anx= Annual mean rainfall at x station

Ani= The average annual rainfall at the station around x

2.2. Inversed Square Distance

The Inversed Square Distance method is one of the methods used to find missing data. The calculation method used is almost the same as the Rational Method, namely takes into account adjacent stations to look for missing rainfall data on the station. If the Rational Method used is the amount of rainfall in 1 year, in this method the variable used is the distance from the closest station to the station, which will look for missing rainfall data.

The equation used in the "Inverse Square Distance" method is as follows:

$$Px = \frac{\frac{1}{(dXA)^2} P_A + \frac{1}{(dXB)^2} P_B + \frac{1}{(dXC)^2} P_C}{\frac{1}{(dXA)^2} + \frac{1}{(dXB)^2} + \frac{1}{(dXC)^2}} \qquad (2.2)$$

Px = The height of the rain in question

PA, PB, Pc = Rainfall height at nearby stations

dXA, dXB, dXC = Distance from station X to each station A, B, C

2.3. Algebraic Average

This algebraic average is used when the lack of data is less than 10% (<10%). For example, it is known: For example, the annual mean rain at station A = x mm = XA, the annual mean rain at B = x mm = XB.

Asked: how to fill in the rain data in a certain year, if in the same year in B the amount of rain = x mm. The solution is:

$$XA = \frac{\bar{X}A}{\bar{X}B} . XB \qquad (2.3)$$

2.4. Data Consistency Test Theory

A rain data may be inconsistent. Data like this cannot be directly used for analysis, so before the rain data, if used as material for further analysis, a consistency test must be carried out.

In this case, a double mass curve will be used, namely the intermediate false test none rain station with the cumulative of the surrounding stations. Steps to calculate the double mass curve as follows:

Calculate the annual rainfall for each station.

Calculate the average annual rainfall for the reference station.

Calculate the cumulative average of the reference rain stations.

Calculate the cumulative for the rain station to be tested.

Make a description in the form of the X axis and the station to be tested on the Y axis.

Then perform an analysis of the data by making a line straight on the diagram, is there any slant. If there is a mishap then it is necessary to make corrections to the recording of rain data by means of multiplying the coefficient (K) calculated based on the comparison slope before experiencing change (S1) and after change (S2) or K = S2/S1.

Several ways to check the quality of rainfall data include:

(a) carrying out field checks,

(b) carrying out checks at the data processing office,

(c) comparing rainfall data with climate data for the same location,

(d) analysis of multiple mass curves (curves double period), and

(e) statistical analysis.

This consistency test can be investigated by comparing the cumulative annual rainfall of the station with the cumulative average rainfall value of a network of corresponding base stations. In general, this method is arranged in backward chronological order and starts from the last year or the most recent data to the last data.

If the rainfall data is inconsistent, it can be corrected using the formula:

Yz = Fk x ……………………………………………………..………………….(2.4)

$$Fk = \frac{\tan \alpha}{\tan \alpha_0}$$

Yz : Repaired rainfall data, mm

Y : Rainfall data from observations, mm

Tgα : The slope before the change

Tg c : The slope after the change

3. Result and Discussion

The Normal Ratio and Inverse Square Distance methods yielded different results for estimating missing data in 2001 and 2006 at Belawan station, with ISD values consistently higher due to the influence of distance between stations. Consistency tests confirmed the reliability of interpolated data. Rainfall intensities for return periods up to 50 years were calculated, revealing significant variation across periods and the necessity for adaptive.

3.1. Hydrological Data Series

Hydrological data is a collection of information or facts about phenomena hydrology (hydrologic phenomena). Hydrological data is information material very important in carrying out an inventory of potential water sources, appropriate use and management of water sources and rehabilitation of natural resources such as water, soil and forests that have been damaged. Such hydrological phenomena magnitude: rainfall, temperature, evaporation, length of sunlight, wind speed, river discharge, river water level, flow velocity and sediment concentration the river will always change according to time. Thus a value of a Hydrological data can only occur again at different times according to phenomenon when the value measurement is carried out. Hydrological data sets can be arranged in the form of lists or tables. Often also the list or table is accompanied by pictures that are commonly referred to diagrams or graphs, and can be presented in the form of thematic maps, such as bulk maps rainfall and water level maps with the intention of being able to explain more about studied issues, flood planning, GIS-based flood maps were developed, indicating critical inundation areas in Medan, which are essential for urban planners.

Table 3.1 Yearly Rainfall Data in the North Sumatra in three rainfall stations

Year	Yearly Rainfall (cm)		
	BBMKG Region I Medan	Sampali	Belawan
2001	136	177	X
2002	47	99	99
2003	140	151	118
2004	91	123	236
2005	143	116	190
2006	396	112	X
2007	103	135	112
2008	190	90	66
2009	96	103	85
2010	101	401	85
2011	62	98	97
2012	59	83	100
2013	114	111	98
2014	100	165	112
2015	81	90	107
2016	109	84	159
2017	110	135	201
2018	93	147	160
2019	89	159	127
2020	159	146	131

3.2. Rainfall Analysis

The analysis of rainfall intensity for various return periods, an analysis must first be carried out on the maximum rainfall data from the stations in Medan, there are three rainfall stations in this study, namely:
1. BBMKG Region I station
2. Sampali station
3. Belawan station

The data, which is used in this research, is the maximum daily rainfall data from 2001 to 2020, which is obtained from BBMKG Region I station.

Table 3.2 Maximum rainfall data in BBMKG Region I station

No	Maximum rainfall data	Month Occurrence
1	136	June
2	47	October
3	140	July
4	91	October

5	143	August
6	396	December
7	103	November
8	190	December
9	96	November
10	101	December
11	62	June
12	59	February
13	114	April
14	100	September
15	81	May
16	109	October
17	110	September
18	93	October
19	89	January
20	159	December

Source: Meteorological and Geophysics Region I Medan

Table 3.3 Maximum rainfall data in Sampali station

No	Maximum rainfall data	Month Occurrence
1	177	December
2	99	October
3	151	April
4	123	March
5	116	July
6	112	December
7	135	October
8	90	October
9	103	January
10	401	March
11	98	August
12	83	May
13	111	December
14	165	December
15	90	November
16	84	September
17	135	December
18	147	October
19	159	May
20	146	March

Source: Meteorological and Geophysics Region I Medan

Table 1.4 Maximum rainfall data in Belawan station

No	Maximum rainfall data	Month Occurrence
1	X	X
2	99	September
3	118	February
4	236	August
5	190	January
6	X	X
7	112	December
8	66	April
9	85	January
10	85	March
11	97	October
12	100	December
13	98	December
14	112	November
15	107	September
16	159	December
17	201	July
18	160	May
19	127	May
20	131	August

Source: Meteorological and Geophysics Region I Medan

The rainfall stations are located around Medan City. There are Belawan station located on the north side, BBMKG Region 1 station on the south side, and Sampali station on the northeast side of Medan.

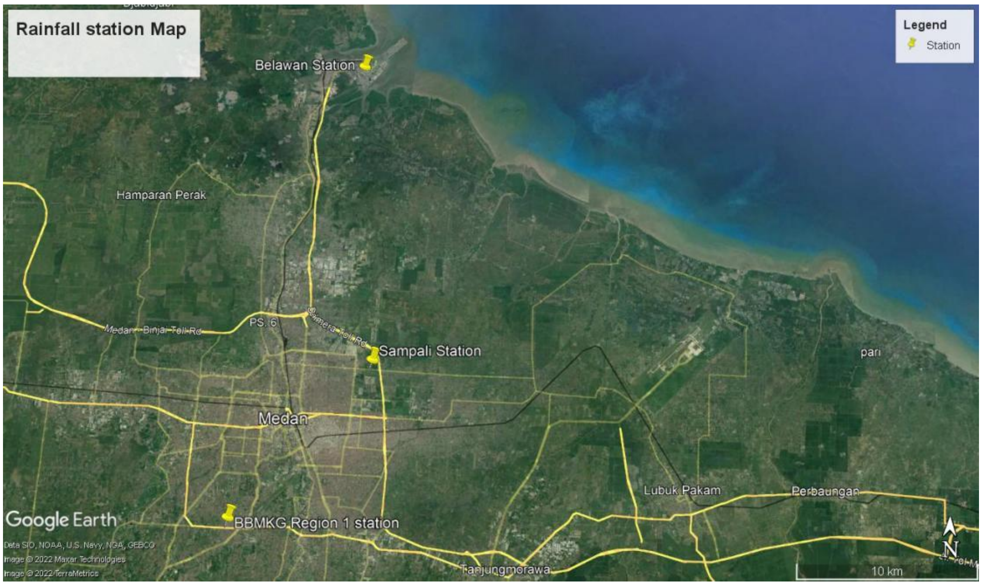

Figure 3.1 Rainfall Stations

In some cases, the rainfall data can be blank due to some reasons such as flood disaster and lack of maintenance. However, this problem can be solved with the analysis of Normal Ratio and Inversed Square Distance Method. From the rainfall data in table 4.2 above, there are two maximum rainfall data in the Belawan station that we need to solve.

1. Normal Ratio Method (NRM)

Table 3.5 NRM Analysis of rainfall data in station Belawan in 2001

Year	Yearly Rainfall (mm)		
	St BBMKG Wil I Medan (A)	St Sampali (B)	St Belawan (C)
2001	136	177	X
2002	47	99	99
2003	140	151	118
2004	91	123	236
2005	143	116	190
Total	**557**	**666**	**643**

$$Dx = \frac{1}{n}\sum_{i=1}^{n} d_i \frac{An_x}{An_i}$$

$$\text{Dx} = \frac{1}{2}\left[\left(\frac{643}{557} \times 136\right) + (\frac{643}{666} \times 177)\right]$$

$$= \frac{328}{2}$$

$$= 164 \text{ mm}$$

Table 3.6 NRM Analysis of rainfall data in station Belawan in 2006

Year	Yearly Rainfall (mm)		
	St BBMKG Wil I Medan (A)	St Sampali (B)	St Belawan (C)
2006	396	112	X
2007	103	135	112
2008	190	90	66
2009	96	103	85
2010	101	401	85
Total	**886**	**841**	**348**

$$Dx = \frac{1}{n}\sum_{i=1}^{n} d_i \frac{An_x}{An_i}$$

$$\text{Dx} = \frac{1}{2}\left[\left(\frac{348}{886} \times 396\right) + (\frac{348}{841} \times 112)\right]$$

$$= \frac{202}{2}$$

$$= 101 \text{ mm}$$

Thus, the loss of rainfall data in Belawan station in 2001 and 2006 are 164mm and 101mm.

2. Inversed Square Distance Method

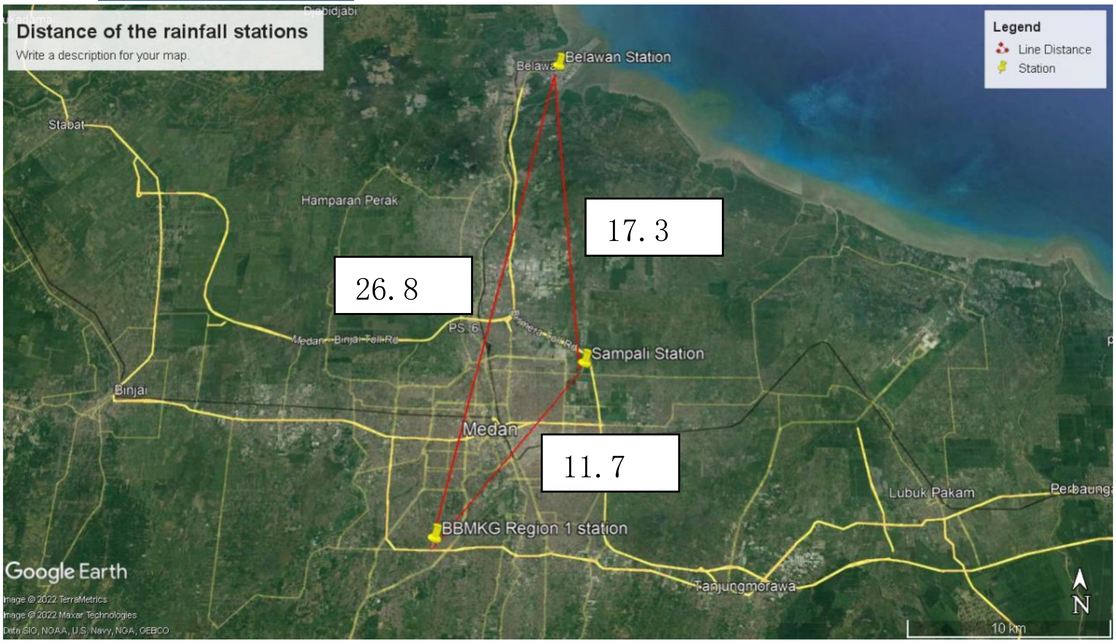

Figure 3.2 Rainfall stations distance

Table 3.7 ISD Analysis of rainfall data in station Belawan in 2001

Year	Yearly Rainfall (mm)		
	St BBMKG Wil I Medan (A)	St Sampali (B)	St Belawan (C)
2001	136	177	X
Distance to Belawan (C)	26.8	17.3	0

$$Pc = \frac{\frac{1}{(dXB)^2}P_B + \frac{1}{(dXC)^2}P_C}{\frac{1}{(dXB)^2} + \frac{1}{(dXC)^2}}$$

$$Pc = \frac{\left(\frac{1}{26.8^2} \times 136\right) + \left(\frac{1}{17.3^2} \times 177\right)}{\left(\frac{1}{26.8^2}\right) + \left(\frac{1}{17.3^2}\right)}$$

$$Pc = \frac{\left(\frac{1}{718.2} \times 136\right) + \left(\frac{1}{299.3} \times 177\right)}{\left(\frac{1}{718.2}\right) + \left(\frac{1}{299.3}\right)}$$

Pc = 169 mm

Table 3.8 ISD Analysis of rainfall data in station Belawan in 2006

Year	Yearly Rainfall (mm)		
	St BBMKG Wil I Medan (A)	St Sampali (B)	St Belawan (C)
2006	396	112	X
Distance to Belawan (C)	26.8	17.3	0

$$Pc = \frac{\frac{1}{(dXB)^2}P_B + \frac{1}{(dXC)^2}P_C}{\frac{1}{(dXB)^2} + \frac{1}{(dXC)^2}}$$

$$Pc = \frac{\left(\frac{1}{26.8^2} \times 396\right) + \left(\frac{1}{17.3^2} \times 112\right)}{\left(\frac{1}{26.8^2}\right) + \left(\frac{1}{17.3^2}\right)}$$

$$Pc = \frac{\left(\frac{1}{718.2} \times 396\right) + \left(\frac{1}{299.3} \times 112\right)}{\left(\frac{1}{718.2}\right) + \left(\frac{1}{299.3}\right)}$$

Pc = 185 mm

Thus, the loss of rainfall data in Belawan station in 2001 and 2006 are 169mm and 185mm.

3. Comparison of two different methods

Table 3.9 Result comparison between NRM and ISD in 2001 and 2006

Year	**Normal ratio**	**ISD**
2001	164	169
2006	101	185

Different values are obtained between the "Normal Ratio" and "Inversed Square Distance" method. The results obtained in the normal ratio method are smaller than those using the ISD method, this is because there is a distance factor affected. From the analysis can be concluded that in the analysis of rainfall loss data, not only the height of rainfall data considered but the distance between the station questioned to the other stations also need to be considered. Thus, the complete rainfall data is shown in the table below.

Table 3.10 Rainfall data in three stations

Year	St BBMKG Wil I Medan	St Sampali	St Belawan
2001	136	177	164
2002	47	99	99
2003	140	151	118
2004	91	123	236
2005	143	116	190
2006	396	112	101
2007	103	135	112
2008	190	90	66
2009	96	103	85
2010	101	401	85
2011	62	98	97
2012	59	83	100
2013	114	111	98
2014	100	165	112
2015	81	90	107
2016	109	84	159
2017	110	135	201
2018	93	147	160
2019	89	159	127

2020	159	146	131

3.3. Analysis of Data Consistency Test

The data used in the consistency test is data based on the "Normal Ratio Method" analysis. Because the data is based on analysis without assumption.

Table 3.11 Data consistency test in BBMKG towards Sampali and Belawan stations

No.	Year	Rainfal Station (A)	Cumulative (A)	Average (B,C)	Average Cumulative (B,C)
1	2020	159	159	159	159
2	2019	89	248	168,5	327,5
3	2018	93	341	217	544,5
4	2017	110	451	280,5	825
5	2016	109	560	334,5	1159,5
6	2015	81	641	361	1520,5
7	2014	100	741	420,5	1941
8	2013	114	855	484,5	2425,5
9	2012	59	914	486,5	2912
10	2011	62	976	519	3431
11	2010	101	1077	589	4020
12	2009	96	1173	634,5	4654,5
13	2008	190	1363	776,5	5431
14	2007	103	1466	784,5	6215,5
15	2006	396	1862	1129	7344,5
16	2005	143	2005	1074	8418,5
17	2004	91	2096	1093,5	9512
18	2003	140	2236	1188	10700
19	2002	47	2283	1165	11865
20	2001	136	2419	1277,5	13142,5

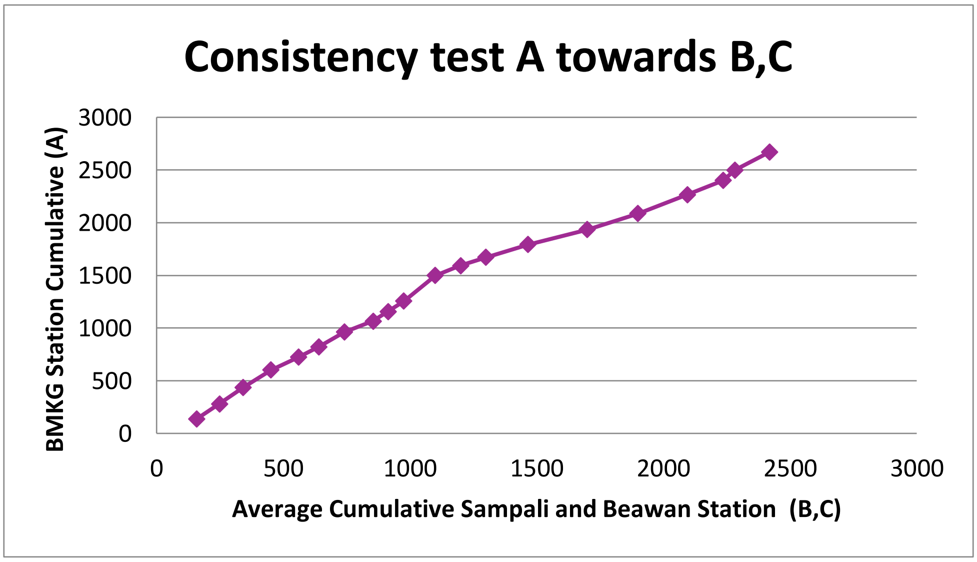

Figure 3.3 Graph of consistency test in BBMKG towards Sampali and Belawan stations

Table 3.12 Data consistency test in Sampali towards BBMKG and Belawan stations

No.	Year	Rainfal Station (B)	Cumulative (B)	Average (A,C)	Average Cumulative (A,C)
1	2020	146	146	145	145
2	2019	159	305	108	253
3	2018	147	452	126,5	379,5
4	2017	135	587	155,5	535
5	2016	84	671	134	669
6	2015	90	761	94	763
7	2014	165	926	106	869
8	2013	111	1037	106	975
9	2012	83	1120	79,5	1054,5
10	2011	98	1218	79,5	1150
11	2010	401	1619	93	1300
12	2009	103	1722	90,5	1350
13	2008	90	1812	128	1445,5
14	2007	135	1947	107,5	1700
15	2006	112	2059	282,5	1890
16	2005	116	2175	166,5	2002
17	2004	123	2298	163,5	2165,5
18	2003	151	2449	129	2294,5
19	2002	99	2548	73	2367,5
20	2001	177	2725	150	2517,5

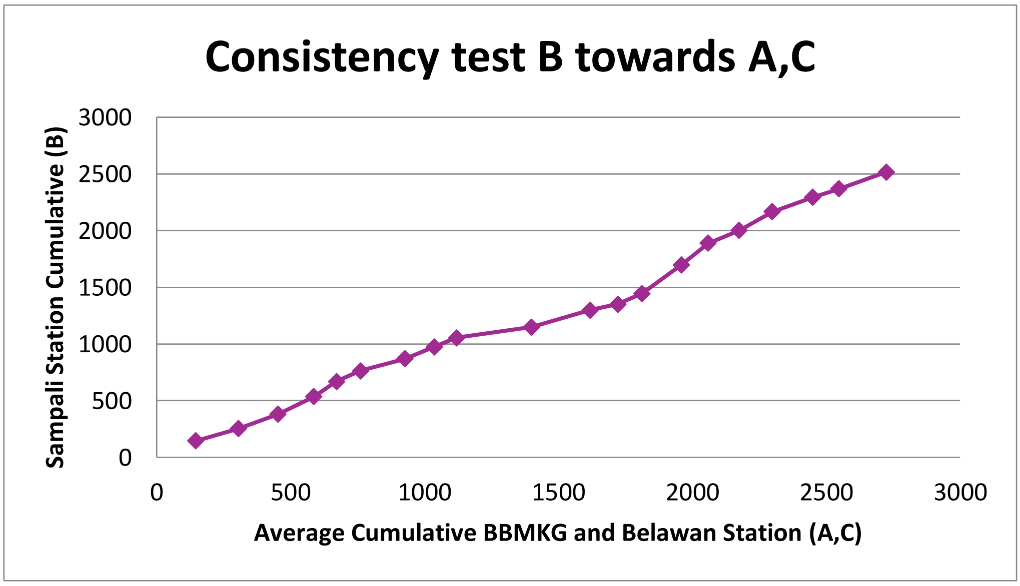

Figure 3.4 Graph of consistency test in Sampali towards BBMKG and Belawan station

Table 3.13 Data consistency test in Belawan towards BBMKG and Sampali stations

No.	Year	Rainfal Station (C)	Cumulative (C)	Average (A,B)	Average Cumulative (A,B)
1	2020	131	131	152,5	152,5
2	2019	127	258	124	276,5
3	2018	160	418	120	396,5
4	2017	201	619	122,5	519
5	2016	159	778	96,5	615,5
6	2015	107	885	85,5	701
7	2014	112	997	132,5	833,5
8	2013	98	1095	112,5	946
9	2012	100	1195	71	1017
10	2011	97	1292	80	1097
11	2010	85	1377	251	1348
12	2009	85	1462	99,5	1447,5
13	2008	66	1528	140	1587,5
14	2007	112	1640	119	1706,5
15	2006	169	1809	254	1960,5
16	2005	190	1999	129,5	2090
17	2004	236	2235	107	2197
18	2003	118	2353	145,5	2342,5
19	2002	99	2452	73	2415,5
20	2001	164	2616	156,5	2572

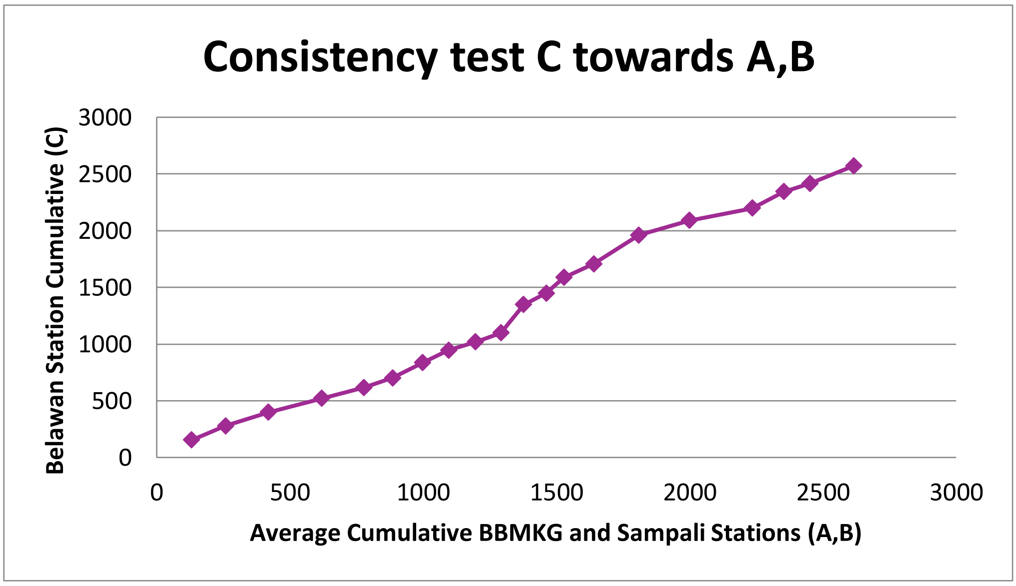

Figure 3.5 Graph of consistency test in Belawan towards BBMKG and Sampali stations

Based on the consistency test graph of stations A towards B, C. It can be concluded that the rainfall data is consistent because the graph is a straight line. Likewise, what happened to the consistency test chart for station B towards A, and C, and the consistency test chart for station C towards A, and B.

4. Conclusion

This study presents an approach for rainfall data estimation and flood risk mapping for Medan. Addressing missing data through Normal Ratio and Inverse Square Distance methods, it improves the accuracy of rainfall intensity estimation for design purposes. The methodology and findings are valuable for urban flood management and can be applied to other cities facing similar hydrological challenges. The results obtained in the normal ratio method are smaller than those using the Inverse Square Distance (ISD) method, this is because there is a distance factor affected. From the analysis can be concluded that in the analysis of rainfall loss data, not only the height of rainfall data considered but the distance between the station questioned to the other stations also needs to be considered. The data used in the consistency test is data based on the “Normal Ratio Method” analysis. Because the data is based on analysis without assumption. The loss of rainfall data in Belawan station in 2001 and 2006 are 164mm and 101mm.

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