Spatial and statistical analysis on the cause of flooding in Northwest Jakarta floodplain (Kapuk and Penjaringan Districts)

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Abstract. Jakarta, as the capital city of Indonesia, is one of the most flooded areas in Indonesia. The floods occurred annually and heavy floods usually occurred once in a few years. This paper address the geographic distribution of floods and statistical analysis of the floods causes by using rain intensity, tidal height, elevation, and floods occurrence as the parameters. This research was conducted in Angke (Kapuk) and Penjaringan Districts, located in Northern Jakarta where the floods usually occur. The result shows that rainfall intensity, remaining water inundation from the previous flood, and land runoff coefficient as the key factors of flooding in these areas.

1 Introduction

Flooding has been an annual natural disaster in Jakarta every year [1]. The increase of population, intensively building construction and climate change cause the flood factors become more complex, therefore, it requires more comprehensive analysis [2].

This research investigates the main cause of flooding in Kapuk District and Penjaringan District, which are the most flooded areas in Jakarta. The results are considered as the solution in mitigating of the flood disaster in Jakarta.

2 Flooding in Muara Angke Basin

The area of interest of this study is Angke District and Penjaringan district located in West Jakarta, as shown in Fig. 1. Angke District has 16 RWs (community groups) with 700 hectares of land and Penjaringan District has 17 RWs with 500 hectares of land.

In this study, the available floods data from the Jakarta Disaster Mitigation Agency (BPBD Jakarta) from January 2013 to December 2016 was used as references. The floods are defined as an overflow of water that submerges dry land areas above 30 cm.

3 Types of flood

Geomorphologically, Jakarta is a low-land area where thirteen (13) rivers flow within the region. The rivers are Cakung river, Jatikramat river, Buaran river, Sunter river, Cipinang river, Ciliwung river, Cideng river, Krukut river, Grogol river, Angke river, and Mookervert river, as shown in Fig. 2.

Fig. 1. Boundary map of study area. Red dots are the district's boundary, blue are rivers, and cyan is the coastal boundary

Fig.2. Rivers in Jakarta Region

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The average annual rainfall intensity in Jakarta is high, about 2000-3000 mm [3]. The area also directly affected by a tidal wave is about 40% (24,000 hectares) of total area (64,000 hectares). Both parameters increase the risk factor of flooding in Jakarta.

According to National Meteorology, Climatology, and Geophysics Bureau (BMKG) data based on 10-year analysis using 20 independent rain gauges [4], the heaviest rainfall occurs on January and February, which is about 365 mm – 329 mm / month and in some cases it is >400 mm at Rorotan and Tanjung Priok sub-districts.

3.1 Heavy rainfall floods

When rain falls for a long time, the soil that serves as a water absorbent medium can become saturated. If the water is unable to infiltrate the already saturated soil, it causes the water to flow above the soil, increasing the runoff and consequently, the existing rivers are unable to accommodate excessive rainwater. This makes the water will overflow to the banks of their neighboring lands.

3.2 Coastal floods

Coastal flood is when the coast is flooded by the sea. It occurs when normally dry, the low-lying land is flooded by seawater.

Coastal floods have some characteristics:

1. Occurs when the tide is high
2. Watercolor is not too cloudy
3. Not always occurs in the rainy season (sometimes it occurs during the dry season)
4. Usually occurs in areas that have a lower elevation than the ocean

3.3 Surface / Pluvial floods

Pluvial floods is a condition in where there is a high flood in an area with a low level of soil absorption, causing a slow disposal of water and absorption to the soil that results in inundation of the land area more than one (1) day although on that day there is no rain or rain occurs with low intensity. There are several factors that can cause a Pluvial flood, namely:

1) Low soil elevation

A condition where the elevation of an area is lower or equal to seawater, resulting in a slow flow of drainage into the sea.

2) Conversion of land

Conversion of land is the conditions where the function of the land change that causes the surface layer of soil that previously can absorb water easily become hard to absorb water properly.

3) Blockage of water flow

The condition where there is a blockage of the flow of drainage into the sea that caused by various things such as

piles of garbage, siltation of the river due to mud, or the overbuilt river banks.

4 Analysis of floods causes

To analyze the cause of floods in Jakarta, Table 1 shows the list of the variables that will be used in the statistical analysis using multiple linear regression method.

Table 1. Cause of floods variables

No	Variables	Definition	Unit
1	Tide	The height of the tides (tides) of seawater during the observation hour recorded at the tidal station	Centimeter (cm)
2	Rain intensity	The amount of rainfall in one day per square meter (m ²)	Millimeter (mm)/day
3	Soil Type	Type of soil in the study area	-
4	Land Use Classification	Types of land use based on the land use classification	-
5	Elevation	Ground level altitude based Mean Sea Level (MSL)	Meter (m)
6	Floods Frequency	Number of flood events per Rukun Warga (RW) for four (4) years from 2013-2016	-

Water Runoff coefficients are used to calculate the runoff volume that may occur in the event of rain, which can be calculated by using the Rational method.

$$Q = 0.278.C.I.A \quad (1)$$

Where:

Q = Runoff volume (m³/s)

C = Runoff coefficient

I = Rain intensity (mm/h)

A = Surface area (hectares)

4.2 Tidal wave calculation

Typically, the method used to calculate tidal wave is the Admiralty method to obtain harmonic constants on through tidal equations.

$$A_{(t)} = S_n + A_{n=1}^{n=k} \cdot \cos(W - G_n) \quad \dots\dots\dots(2)$$

Where,

A(t) = Amplitude

So = Mean Sea Level(MSL)

An = Amplitude of tidal harmonic components.

Gn = Phase of tidal components

n = constants obtained from astronomical calculations

t = time

4.3 Rain intensity

Rain intensity is the amount of rain expressed in rainfall or rainfall volume per unit time. Rain intensity for short durations of time can be estimated using the Mononobe formula.

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

Where,

- I = Rain intensity (mm/h)
- T = Rain fall period (h)
- R₂₄ = Maximum rainfall in 24 hours (mm)

4.4 Linear regression

Multiple linear regression analysis is a linear relationship between two or more independent variables (X₁, X₂, ... X_n) with the dependent variable of (Y). This analysis is commonly used to determine the relationship between independent variables with dependent variables whether each independent variable is positive or negative and to predict the value of the dependent variable if the value of the independent variable increases or decreases. The data used are usually scaled in intervals or ratios.

$$Y' = a + b_1X_1 + b_2X_2 + \dots + b_nX_n \quad (4)$$

Where:

- Y' = Dependent variable (predicted value)
- X₁, X₂ = Independent variables
- a = Constants
- b = Regression's coefficient

5 Flood occurrences and tidal height in Kapuk and Penjaringan District at flood's time

Table 2 shows the occurrences of floods in Kapuk and Penjaringan District. The maps of floods geographical distribution in the area between 2013 and 2016 are shown in Figs. 3-6.

Table 2. Date of flood occurrences

No	Date	Location	Affected RW	Depth (cm)
1	14-Jan-13	Kapuk	16	160
2	16-Jan-13	Kapuk	16	160
3	17-Jan-13	Kapuk	16	160
4	18-Jan-13	Kapuk	16	160
5	19-Jan-13	Kapuk	16	160
6	20-Jan-13	Kapuk	16	160
7	21-Jan-13	Kapuk	16	160
8	22-Jan-13	Kapuk	16	160
9	23-Jan-13	Kapuk	16	160
10	24-Jan-13	Kapuk	16	160
11	25-Jan-13	Kapuk	16	160
12	14-Jan-13	Penjaringan	17	100

13	15-Jan-13	Penjaringan	17	100
14	17-Jan-13	Penjaringan	17	100
15	18-Jan-13	Penjaringan	17	100
16	19-Jan-13	Penjaringan	17	100
17	20-Jan-13	Penjaringan	17	100
18	21-Jan-13	Penjaringan	17	100
19	22-Jan-13	Penjaringan	17	100
20	23-Jan-13	Penjaringan	17	100
21	24-Jan-13	Penjaringan	17	100
22	25-Jan-13	Penjaringan	17	100
23	26-Jan-13	Penjaringan	17	100
24	27-Jan-13	Penjaringan	17	100
25	28-Jan-13	Penjaringan	17	100
26	29-Jan-13	Penjaringan	17	100
27	14-Jan-14	Kapuk	16	70
28	15-Jan-14	Kapuk	16	70
29	16-Jan-14	Kapuk	16	70
30	17-Jan-14	Kapuk	16	70
31	18-Jan-14	Kapuk	16	70
32	19-Jan-14	Kapuk	16	70
33	20-Jan-14	Kapuk	16	70
34	21-Jan-14	Kapuk	16	70
35	22-Jan-14	Kapuk	16	70
36	23-Jan-14	Kapuk	16	70
37	24-Jan-14	Kapuk	16	70
38	25-Jan-14	Kapuk	16	70
39	26-Jan-14	Kapuk	16	70
40	27-Jan-14	Kapuk	16	70
41	18-Jan-14	Penjaringan	4	50
42	19-Jan-14	Penjaringan	4	50
43	20-Jan-14	Penjaringan	4	50
44	21-Jan-14	Penjaringan	4	50
45	22-Jan-14	Penjaringan	4	50
46	23-Jan-14	Penjaringan	4	50
47	24-Jan-14	Penjaringan	4	50
48	29-Jan-14	Penjaringan	4	50
49	30-Jan-14	Penjaringan	4	50
50	31-Jan-14	Penjaringan	4	50
51	22-Feb-14	Kapuk	7	80
52	23-Feb-14	Kapuk	7	80
53	24-Feb-14	Kapuk	7	80
54	25-Feb-14	Kapuk	7	80
55	26-Feb-14	Kapuk	7	80
56	27-Feb-14	Kapuk	7	80
57	28-Feb-14	Kapuk	7	80
58	23-Jan-15	Kapuk	4	40

59	24-Jan-15	Kapuk	4	40
60	02-Feb-15	Kapuk	14	100
61	09-Feb-15	Kapuk	14	100
62	10-Feb-15	Kapuk	14	100
63	11-Feb-15	Kapuk	14	100
64	12-Feb-15	Kapuk	14	100
65	13-Feb-15	Kapuk	14	100
66	14-Feb-15	Kapuk	14	100
67	09-Feb-15	Penjaringan	6	60
68	10-Feb-15	Penjaringan	6	60
69	11-Feb-15	Penjaringan	6	60
70	12-Feb-15	Penjaringan	6	60
71	13-Feb-15	Penjaringan	6	60
72	26-Feb-16	Kapuk	14	30
73	27-Feb-16	Kapuk	14	30
74	29-Feb-16	Kapuk	14	30
75	01-Mar-16	Kapuk	3	15
76	05-Jun-16	Penjaringan	1	30
77	07-Jun-16	Penjaringan	1	30

The table above contains the date of floods, the area affected by the floods, and flood depth as reported by local officials

Fig. 3. Flood occurrences in 2013

Fig.4. Flood occurrences in 2014

Fig. 5. Flood occurrences in 2015

Fig. 6. Flood occurrences in 2016

For better flood analysis, we also include tides as one of the floods cause factor. Fig.7 shows the maximum daily tide height from the nearest tide station during the floods.

Fig.7. Maximum tide height

Table 3. Highest tidal wave at floods time

No	Date	Max Height (cm)
1	09-Jan-13	158
2	10-Jan-13	140
3	11-Jan-13	167
4	12-Jan-13	175
5	13-Jan-13	180
6	14-Jan-13	175
7	16-Jan-13	154
8	17-Jan-13	137
9	18-Jan-13	150
10	19-Jan-13	143
11	20-Jan-13	141
12	21-Jan-13	149
13	22-Jan-13	155
14	23-Jan-13	157
15	24-Jan-13	146
16	25-Jan-13	160
17	26-Jan-13	159
18	27-Jan-13	155
19	28-Jan-13	154
20	29-Jan-13	167
21	30-Jan-13	162
22	09-Jan-13	158
23	10-Jan-13	140
24	11-Jan-13	167
25	12-Jan-13	175
26	13-Jan-13	180
27	14-Jan-13	175
28	15-Jan-13	180
29	17-Jan-13	138
30	18-Jan-13	150
31	19-Jan-13	143
32	20-Jan-13	141
33	21-Jan-13	149
34	22-Jan-13	155
35	23-Jan-13	157
36	24-Jan-13	146
37	25-Jan-13	160
38	26-Jan-13	154
39	27-Jan-13	155
40	28-Jan-13	154
41	29-Jan-13	167

42	11-Feb-13	171
43	12-Feb-13	160
44	13-Feb-13	149
45	14-Feb-13	153
46	15-Feb-13	133
47	09-Jan-14	164
48	10-Jan-14	167
49	11-Jan-14	185
50	12-Jan-14	183
51	13-Jan-14	181
52	14-Jan-14	167
53	15-Jan-14	164
54	16-Jan-14	157
55	17-Jan-14	165
56	18-Jan-14	159
57	19-Jan-14	169
58	20-Jan-14	148
59	21-Jan-14	144
60	22-Jan-14	137
61	23-Jan-14	142
62	24-Jan-14	141
63	25-Jan-14	154
64	26-Jan-14	163
65	27-Jan-14	175
66	28-Jan-14	183
67	29-Jan-14	184
68	30-Jan-14	176
69	31-Jan-14	179
70	13-Jan-14	181
71	14-Jan-14	167
72	15-Jan-14	164
73	16-Jan-14	157
74	17-Jan-14	165
75	18-Jan-14	159
76	19-Jan-14	169
77	20-Jan-14	148
78	21-Jan-14	144
79	22-Jan-14	137
80	23-Jan-14	142
81	24-Jan-14	141
82	29-Jan-14	184
83	30-Jan-14	176
84	31-Jan-14	179
85	01-Feb-14	160
86	02-Feb-14	164
87	03-Feb-14	155

88	04-Feb-14	154
89	05-Feb-14	163
90	17-Feb-14	156
91	18-Feb-14	148
92	19-Feb-14	141
93	20-Feb-14	168
94	21-Feb-14	153
95	22-Feb-14	141
96	23-Feb-14	139
97	24-Feb-14	155
98	25-Feb-14	170
99	26-Feb-14	168
100	27-Feb-14	174
101	28-Feb-14	169
102	01-Mar-14	168
103	02-Mar-14	157
104	03-Mar-14	148
105	04-Mar-14	159
106	05-Mar-14	154
107	18-Jan-15	192
108	19-Jan-15	195
109	20-Jan-15	196
110	21-Jan-15	204
111	22-Jan-15	202
112	23-Jan-15	184
113	24-Jan-15	181
114	02-Feb-15	172
115	09-Feb-15	157
116	10-Feb-15	165
117	11-Feb-15	143
118	12-Feb-15	140
119	13-Feb-15	168
120	14-Feb-15	168
121	15-Feb-15	184
122	16-Feb-15	186
123	17-Feb-15	187
124	18-Feb-15	188
125	19-Feb-15	177
126	04-Feb-15	173
127	05-Feb-15	172
128	06-Feb-15	168
129	07-Feb-15	163
130	08-Feb-15	156
131	09-Feb-15	157
132	10-Feb-15	165
133	11-Feb-15	143

134	12-Feb-15	140
135	13-Feb-15	168
136	14-Feb-15	178
137	15-Feb-15	184
138	16-Feb-15	186
139	17-Feb-15	187
140	18-Feb-15	188
141	13-Feb-16	179
142	14-Feb-16	197
143	15-Feb-16	203
144	16-Feb-16	209
145	17-Feb-16	196

6 Statistical analysis

6.1 Statistical analysis of relationship between rain intensity, tides, elevation and floods occurrence

By using Linear Regression method using data from January 2013 to December 2016 as a dependent variable and daily rainfall data and tidal data (tide) of seawater as an independent variable, the obtained result is shown in Table. 4.

Table 4. Model summary of linear regression analysis

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.769 ^a	.592	.577	.326

a. predictors : (constant), Runoff, Rainfall, Tide height, previous flood, Lidar elevation

The Summary Model explains how much independent factors can explain the occurrence of bound variables / R-squared and adjusted R-square values are indicators of how much free variables are able to explain the changes that occur in the dependent variable. From the summary model, the value of Adjusted R Square value of .592 indicates that the factors/variables that formed can explain the flood incidence as much as 59.2%, with other factors that have the chance of causing flood event of 32.6%.

6.2. F-Significance test

F-significance test is performed to test the model simultaneously or in a bundle. The test is called the simultaneous test (F-Test) aims to see whether together independent variables affect the dependent variable or not.

The test is statistically written as follows :

Hypothesis:

H0: $\beta_0 = \beta_1 = \beta_2 = \beta_3 = \beta_4 = 0$

H1: there is at least one non-zero β_i

Significance level : $\alpha = 0.001 / 99.9\%$

Critical value: Reject H0 if significance value more than ' α '

If significance value = 0.000, reject H0. Or we can compare the F value in the result table with the F value in the standard F table. To determine whether the inserted free variable meets the tolerance requirement or not, the calculated F value must be greater than the F table value (F arithmetic > F table). F table value can be searched by first determining the degree of freedom (degree of freedom/df) from data, which is:

$$df1 = k - 1$$

$$df2 = n - k$$

Where,

k = number of independent variables + independent variable

$$df1 = \text{degree of freedom 1 (N1)}$$

$$df2 = \text{degree of freedom 2 (N2)}$$

Then,

$$df1 = 5 - 1$$

$$= 4$$

$$df2 = 145 - 4$$

$$= 141$$

Table 5. ANOVA table

ANOVA ^b						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	21.446	5	4.289	40.317	.000 ^a
	Residual	14.788	139	.106		
	Total	36.234	144			

a. predictors : (constant), Runoff, Rainfall, Tide height, previous flood, Lidar elevation

b. dependent variable : flood event

From F test result with a probability of 99.9% (0.001), it shows that the model formed has a high significance value (Sig. <0.000) with the value of F count (40.317) larger than F table (3.46) which means these variables influence the chance level of the flood disaster convincingly.

6.3. Regression's Coefficient

Table 6 shows the results of the analysis of each independent variable relative to the independent variables (probability of flood occurrence) which are obtained from SPSS analysis. Column 'B' is the multiplier factor of each independent variable (coefficient).

Table 6. Coefficient Table

coefficient (a)					
Model	Unstandardized coefficients		Standardize Coefficients	1	Sig.
	B	std. Error	Beta		
1 (constant)	-4,240	0,858		-4,941	0,000
Rainfall	-0,002	0,001	0,219	3,773	0,000
Tide height	-0,004	0,002	-0,135	-2,169	0,032
Previous flood	0,653	0,073	0,568	8,965	0,000
Lidar elevation	-0,549	0,089	-0,848	-6,148	0,000
Runoff	12,569	1,938	0,886	6,487	0,000

b. dependent variable : flood event

From the above results, then we can see the magnitude of the coefficient of each independent variable to the dependent variable, along with the level of significance. Based on the above results, Rainfall variables, Previous Flood Events, Elevation, and Water Runoff Coefficients have a very high

significance which greater than 99.9% (<0.000) and elevation has a low level of significance of 96.8% (0.032).

The value of regression equation calculation result is :

$$Y = 0.936 + 0.003 X1 - 0.004 X2 + 0.676 X3 - 0,18 X4$$

Where,

Y = Probability of flood occurrence

X1 = Rain intensity (mm)

X2 = Tides maximum height

X3 = Floods from a day before (0=No, 1=Yes)

X4 = Elevation

6.4 Normal distribution table plot

Fig.8 shows a plot of normal distribution for the flood event, equations with free variables in the form of daily rainfall, highest tide, elevation, and previous flood events. From the figure, it can be seen that distribution pattern most likely increase when a certain value/quantity is input into the regression equation.

Fig. 8. Normal distribution plot of flood's probability

7 Conclusions

Based on the statistical analysis, it can be concluded that the highest contributor of flooding in Angke and Penjaringan areas are rainfall intensity, lands elevation, runoff coefficient, and the excess of the flood (Pluvial or surface flood) from the previous day which hasn't recede.

This excessive flood is directly correlated with water runoff coefficient, where the higher coefficient indicates that a large amount of water can't be absorbed into the soil because the surface is covered by hard materials such as asphalt and buildings.

The slow drainage of floods water also caused by blockage of water drainage which can be caused by several factors such as a heap of wastes at the housing water drainage, a deposit of soils at the riverbanks, insufficient water in catchment area caused by the land conversion, and the low elevation of Northern part of Jakarta itself.

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