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FLOOD SUSCEPTIBILITY AND SPATIAL ANALYSIS OF PANGKALPINANG CITY, BANGKA BELITUNG, INDONESIA

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Abstract

The city of Pangkalpinang has a history of frequent floods. The purposes of this study are to determine the distribution of locations of flood points, mapping of flood driving factors, and spatial analysis of flood susceptibility of Pangkalpinang city. The method of this study was observing the incidents and locations from various data sources. Then the data obtained was mapped to make the distribution of the flood location points. The determination of flood susceptibility based on geographic information systems used several variables with an overlay technique. These variables were slope, geological structure, annual rainfall, soil type, land use, and distance to the river. The class of susceptibility of flooding determines by the weighting method and ground checking. The incidence of flood in Pangkalpinang city found in several districts with a water level of 1-2 meters. Flood point locations distributed in all the city was 24 points. Rangkui as one from seven sub-districts has six points of the flood. Flood susceptibility classes consist of low, moderate, and high susceptibility. Based on the flood susceptibility map, there were 19% of the total area with high susceptibility, 35% of the area with moderate susceptibility, and 45% of the region with low flood susceptibility. Land use as a settlement was the largest area or 43% of the total high flood susceptibility and 34% of the area with moderate flood susceptibility. The results of this study could be used as a recommendation in flood disaster mitigation planning by considering community behaviour and the condition of the urban drainage system.

Keywords**:** Flood, Flood susceptibility, Geographic information system, Land use.

1. Introduction

Among natural disasters that often cause damage throughout the world, floods have the highest intensity of events, which have negative impacts on humans and create the most significant economic losses. The current general understanding is that waters will not decrease shortly; they will increase the intensity and frequency due to global warming [1].

Every rainy season the city of Pangkalpinang faces a flood problem. The topography of the region, drainage system, and the land structure are driving factors of the flooding problem. Efforts need to be made to estimate the potential for floods or flood-prone areas; it is also necessary to know the causes of flooding, one method for analysing flood-prone areas is Geographic Information System (GIS). By using this method, identification and mapping of the flood-prone regions in Pangkalpinang city can be carried out.

Pangkalpinang city is an autonomous region located in the eastern part of the island of Bangka. Administratively on February 9, 2001, the city of Pangkalpinang was designated as the Capital of the Bangka Belitung Islands Province, based on law number 27 of 2000 and is the 31st Province of the Republic of Indonesia. The city of Pangkalpinang is a strategic area in terms of its geography, especially with the development of national and Bangka Belitung Islands Province. The main function of Pangkalpinang as the capital city of the province is a regional development centre.

The Pangkalpinang city Spatial Plan in the flood control system plan states that it will build a Retention Pool in several areas. The existence of tin mining in the river flow triggers the flood because it causes the siltation of the river so that floods occur, which inundate several areas in the city of Pangkalpinang [2].

Flood incidents are relatively high surface water that cannot be accommodated by drainage channels or rivers, thus, causing inundation/flow in amounts exceeding normal and causing losses. Amri et al. [3] mentioned that flood disasters could occur due to natural factors or the influence of people's behaviour on nature and the environment. Physical elements are erosion and sedimentation, drainage capacity, tides, and watersheds, while the non-natural factor is the construction of housing or other facilities.

Long periods of inundation due to the overflow of river water, excess rainfall, and rising sea levels cause a flood. However, generally, the causes of flooding are caused by natural factors and actions or human behaviour [4]. Factors that cause flooding are rain catchment area, rain duration and intensity, land use, topographic conditions, and drainage network capacity [5]. There are three types of flood classification, namely: (a) Floods as a result of river overflows (runoff); This occurs because the channel/river capacity seems cannot accommodate the existing discharge so that the water overflows through the river embankment. In the urban areas, it caused by drainage capacity/waterways unable to provide rainwater; (b) Local flood or the inundation generally occurs because of the high intensity of rain in a certain period, which can inundate relatively low areas and the unavailability of adequate drainage facilities; (c) Floods caused by tides of the sea (flood tides); This flood occurs due to rising seawater in the coastal alluvial plain area where it is located lower or in the form of a basin, and there is a river estuary with its tributaries. If a tide occurs, seawater or river water will inundate the area. This flood can happen in the rainy and dry season [6, 7].

In flood risk management, several terms are often used, such as vulnerability and susceptibility. The concept of vulnerability is a combination of three factors, namely, exposure, susceptibility, and resilience. Exposure is tangible and intangible valuable goods and services in the area with the flood, while susceptibility is the extent of flood events whereas resilience is an adaptation capacity of flood-affected areas [8-11]. Research on flood risk management in Indonesia has been carried out with various methods and approaches. Neolaka [12] proposed that flood research projects in Jakarta have conducted an emphasis on environmental aspects and impacts on society, and spatial patterns [13, 14]. Flood impact mapping and its perception study in Kalimantan had been conducted with the result for environmental recommendation [15]. Besides, there is a study that emphasizes the management strategies for floods in Indonesia [16]. There are regional, and city planning approaches integrated with flood mitigation. The results are models for anticipation before its occurrence, management at the time of the flood event, and after the incident [6, 7].

The flood susceptibility study was conducted in Kelantan with data on the probability of occurrence to determine the risk of flooding [17]. The flood susceptibility study in the continental Portuguese territory produced spatial data on the susceptibility index. Low indexes are found in mountainous regions. The weakness of the research results is that it cannot describe the dynamics of the flood and over a very wide area [18]. In China for susceptibility index research for flash floods used GIS and radio frequencies. The rainfall factor used is short term heavy rain. For the construction of the model, researchers surveyed 85 flash flood locations [19]. Land use is one of the important factors in flood susceptibility research, as has been done in Papua New Guinea [20], and densely populated urban areas in Italy [21].

Changes in land use are one of the factors causing flooding. The increasing land demand for settlements will follow the growing population. Changes in land use from vacant land to built-up areas cause water catchment areas to decrease so that it can increase the amount of runoff and increase the inundation [4]. Land-use change into the area of buildings and infrastructure increases flooding [22]. Therefore, inappropriate land use planning has an impact on flooding [23].

According to Nugroho et al. [24], changes in land use will increase the surface flow coefficient. Changes in land use have an impact on increasing surface runoff. For example, in the forest area, it only transfers 10-40% of rainwater so that it can absorb rainwater by 60-90%. The residential area will provide around 40-75% of rain and absorb 25-60% of rainwater. The denser the settlements, the greater the rainwater runoff that occurs; hence, the higher the level of flood susceptibility in the region [25, 26].

The purpose of this study is to identify flood-prone areas in the city of Pangkalpinang, by: (a) Identifying the events and characteristics of flood-prone regions; (b) Identifying the distribution of flood locations, and (c) Determine the susceptibility map of floods in Pangkalpinang city. This study used the application of geographic information systems (GIS). GIS application used to determine the distribution of flood locations that occur, calculate the class of flood susceptibility, and determine most affected urban land use.

2. Research Method

The first research stage was identifying the events and characteristics of floods; then determine the distribution of flood location points; then assessed the level of flood susceptibility based on six parameters. Six parameters that determined the level of flood susceptibility were land use, slope, geological formation, soil type, rainfall, and watershed. Geographic Information System (GIS) was applied in this study.

In implementing the Geographic Information System (GIS), aerial photographs and thematic maps were data for mapping flood-prone areas. Different thematic maps, both those obtained from remote sensing analysis and other methods could be combined to produce derivative maps. The collected data were processed to obtain new information through the weighting method. Susceptibility flood mapping was by overlap thematic maps of slope, altitude, soil type, and land cover or land use maps. The process of overlapping sheets was to associate attribute data through data manipulation and analysis. The processing and summation of the value of each parameter would produce a new number in the form of a potential level prone to flooding.

The study used variables, namely: (a) Land use included its classification and intensity such as settlements, plantations, forests, open land, mining, pond, water bodies, and dry farmland; and (b) The physical condition of the area included slope, geological structure, soil type, annual rainfall, and rivers. There were two parts analyses, namely spatial and attribute analysis. These analyses had particular functions in flood susceptibility mapping.

This study used two analyses, namely, spatial analysis and attributes analysis. The spatial analysis consists of (1) reclassification and classification; (2) map overlay; (3) buffering.

2.1. Spatial analysis

Reclassification/classification to describe the condition of the physical conditions found in the research area [27]. This activity was for physical aspects, including slope, soil type, rainfall, and rivers. Land use was classified to describe and find out how the relationship between flood characteristics and land use conditions (classification and intensity of land use) in the study area.

Based on studies by Caplan and Moreto [28], for overlaying technique, ArcGIS Geographic Information System (GIS) software was applied. The overlay was used to determine flood susceptibility. This overlay process was carried out in stages based on several essential physical aspects, namely slope, geological structure, annual rainfall, land use, soil type, and river buffers in the research area.

Buffer analysis is to identify a region with a certain width around a point, line, or polygon with a certain distance. The buffer analysis process will produce coverage areas around geographical features.

2.2. Attribute analysis

The crucial processes to determine the analysis of flood susceptibility, namely scoring and weighting. The assessment is intended to give scores and weights to each class in each parameter determining flood susceptibility. The scoring was based on the influence of the class on flooding. The higher the effect on flooding, the higher the score given. This step was to determine the susceptibility area, which included the category of low susceptibility, moderate susceptibility, and high susceptibility.

The results of editing attribute data result in the sum of the scores for flood susceptibility classes. Thematic maps are according to flood hazard parameters. Classification of flood susceptibility based on total score.

This tabular analysis is an analysis of the attributes of the theme of the final overlay. This step is to determine the susceptibility area, which includes the category of low susceptibility, moderate susceptibility, and high susceptibility.

The total weight value generated from the sum of the multiplication results between variable scores and the weight of each factor determines the level of flood susceptibility [17, 21, 29]. Three categories of flood-prone are classifications defined by the equation:

$$X = \sum(Wi \times Xi) \tag{1}$$

where:

X = Class of flood susceptibility
Wi = weight factor for i parameter
Xi = class score for *i* parameter
The details of the formula for determining flood susceptibility are as follows:

$$X = Xi(S) \times 0.3 + Xi(AR) \times 0.20 + Xi(LU) \times 0.15 + Xi(GS) \times 0.10 + Xi(ST) \times 0.05 + Xi(DR) \times 0.20 \tag{2}$$

where *X* = flood susceptibility level, *S*: Slope, AR: Annual Rainfall, LU: Land Use, GS: Geological Structure, ST: Soil Type, DR: Distance to the River.

Table 1. Flood susceptibility.

No.	Class of flood susceptibility	Scores
1.	Low	< 3
2.	Moderate	3 - < 3.4
3.	High	> 3.4

3. Results and Discussion

3.1. Flood location distribution in Pangkalpinang city

Based on field surveys and interviews at each Pangkalpinang city Sub-district Agency, which has an area of 14,503 hectares, the results of flood inundation plots were obtained using Global Positioning System (GPS) and interviews with informants at each Sub-District institution who know the area well where flood incident in Pangkalpinang city (see Fig. 1).

Based on a map of the distribution of flood locations, all districts experienced flooding. The area with the most extensive flooding was Girimaya. The highest number of flood locations is in Rangkui sub-district with six flood locations. The highest level of flooding was in Tamansari sub-district (Fig. 1 and Table 1).

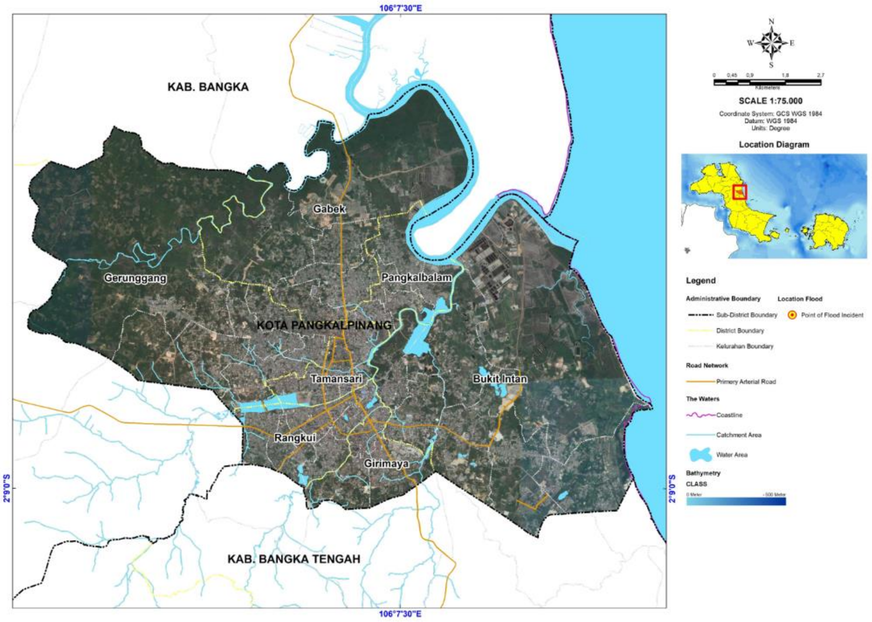

Fig. 1. Location distribution of flood in Pangkalpinang city.

Table 1. Distribution of flood in Pangkalpinang city.

District	Sub-district	Flood characteristics	Area (hectares)	Height (cm)	Flood duration (hours)
Gerunggang	Taman Bunga	Spread to roads and houses	-	20	2-4
Bukit Intan	• Bacang • Semabung Lama • Pasir Putih Air Itam	Spread to settlements, trade and services, roads	5	30-60	5-6
Girimaya	• Sriwijaya • Bukit Besar • Semabung Baru • Batu Intan Pasar Padi	Spread to settlements, trade and services, roads	10	30-60	1-2 hours in 1 day
Taman Sari	• Kejaksaan • Rawa Bangun • Gedung Nasional Opas Indah	Spread to trade centres, residential settlements and roads	-	100-200	3-6 hours in 4 days
Gabek	Selindung Baru	Spread to settlements and roads	1-2	30	5 hours
Rangkui	• Keramat • Pintu Air • Masjid Jamik • Kp. Bintang • Parit Lalang Kp. Melintang	Spread to open land, commercial areas, residential areas	4-5	60	1 day
Pangkalbalam	• Lontong Pancur • Ketapang Ampui	Spread to open land, industry, trade and services, housing	6	20-40	12 hours

3.3. Mapping of flooding factors

In determining the level of flood susceptibility in the city of Pangkalpinang, variables should be considered. The parameters that affect the flood were slope, annual rainfall, land use, geological structure, soil types, and distance to the rivers (buffer).

The slope is a factor that influences surface runoff, surface drainage, land use, and erosion. The slope map of Pangkalpinang city is classified into five classes: 0-8% flat, 8-15% ramps, slightly steep 15-25%, 25-40% steep, very steep> 40%.

From the results of the analysis, the slope in Pangkalpinang city was dominated by flat slope 0-8% with an area of 5168.40 hectares with an area of 35.64% (Fig. 2).

Rainfall in Pangkalpinang city is relatively high with an average of 2500 - 3500 mm per year. Based on the amount of annual rainfall, the map is classified into two classes, namely rainfall 2000-3000 mm and 3000 - 3500 mm (Fig. 3).

Land use in the city of Pangkalpinang is classified into nine classes: shrubs, water bodies, mixed forests, plantations, ponds, mining, settlements, dry farmland, and open land.

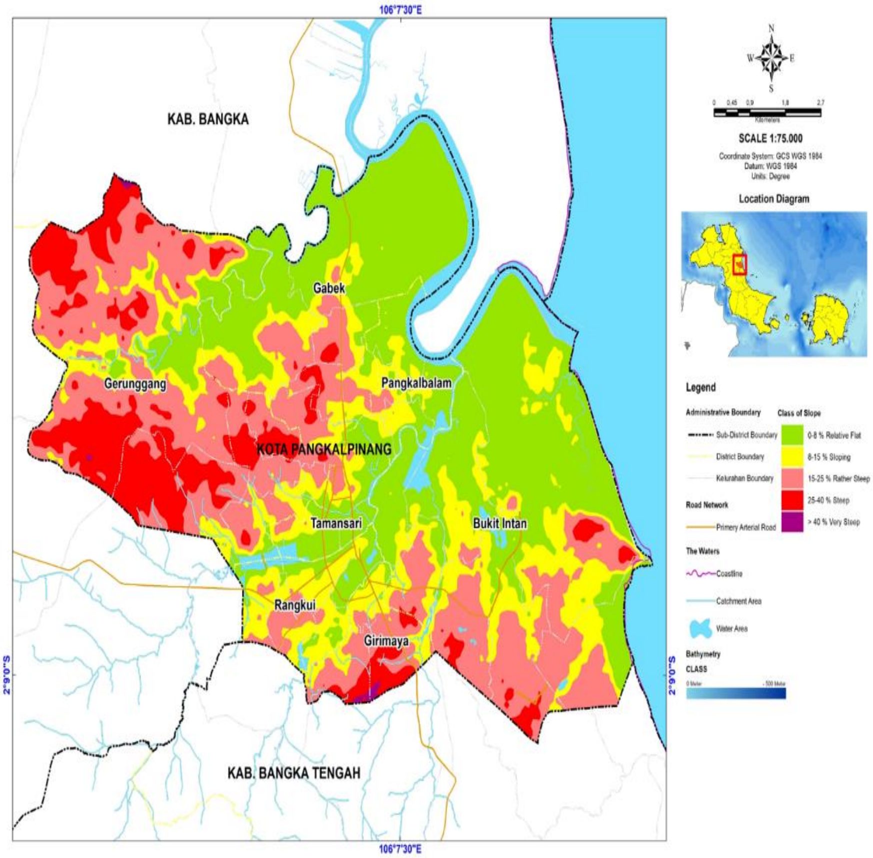

Fig. 2. Slope map of Pangkalpinang city.

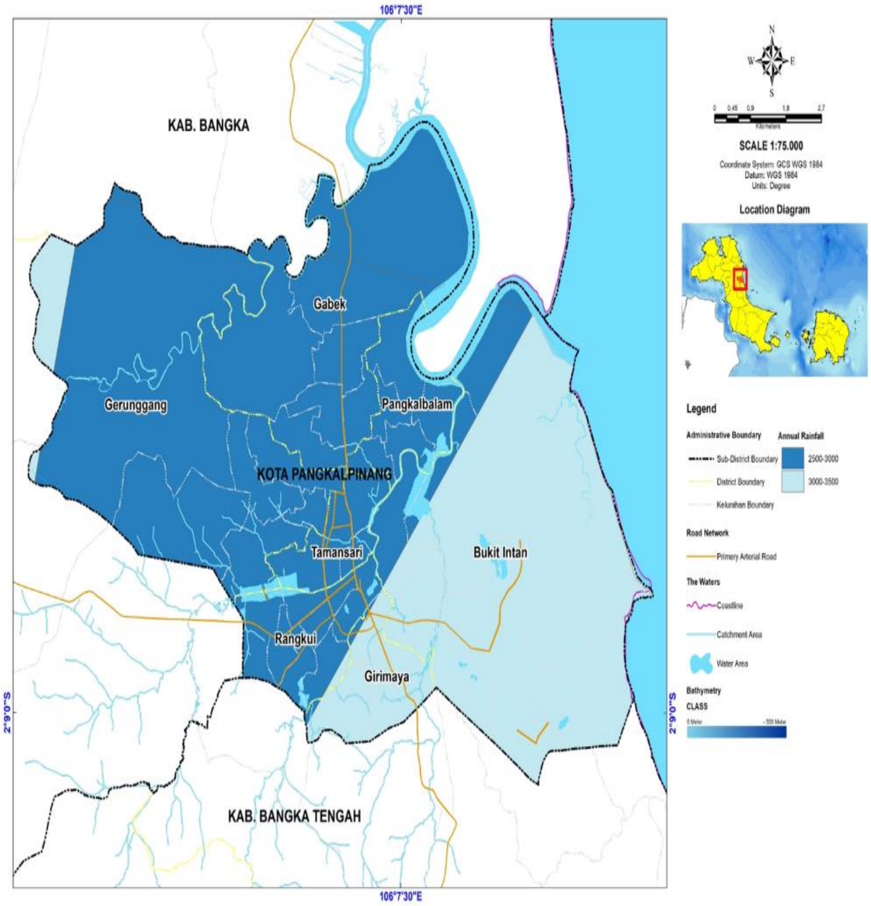

Fig. 3. Annual rainfall map of Pangkalpinang city.

The use of land as a settlement has an area of 3935.84 hectares or 27.14% while the land use, which has the largest area is plantations with an area of 4792.81 or 33.55%; while the lowest area of land use is mining with an area of 26.90 hectares or 0.19% (Fig. 4 and Table 2).

The geological structure of Pangkalpinang city is a depression of geoanticline folds, which consists of alluvium rocks, which are sediments; Tanjunggenting Formation is a sedimentary rock formed from the results of separation; Pemali Formation Complex in the form of metamorphosis, which is formed due to the influence of strong pressure and high temperature [30]. On the map, the structure of the geological formation is made into three classes, namely Sediment: clastic: alluvium; Sediment: clastic: alluvium and Sediment: clastic: sandstone (Fig. 5).

Soil type plays an important role in the occurrence of floods. The types of soil in the city of Pangkalpinang are classified into three types of soil orders, namely Entisols, Inceptisols and Ultisols (Fig. 6). The three types of soil can drain water, and absorbing water into the soil by the nature of the soil can slow the flow of water and can also accelerate the flow that occurs.

The Baturusa watershed on the map is in the form of lines. To create a river buffer map to obtain an area directly adjacent to the river, where the closer an area is to the river, the greater the chance that an area will occur flooding. River buffer areas in Pangkalpinang city are classified into three buffer classes, namely the distance between rivers 0 - 50 meters, the distance between rivers 100 meters, and the distance between rivers 300 meters (Fig. 7).

Table 2. Land use of Pangkalpinang city.

Use of land	Area (hectares)	Percentage (%)
Forest	781.09	5.39%
Open land	243.71	1.68%
Plantation	4 792.81	33.05%
Settlement	3 935.84	27.14%
Mining	26.90	0.19%
Shrub	2 521.83	17.39%
Pond	106.38	0.73%
Dry farmland	1 825.94	12.59%
Water bodies	268.90	1.85%
Total	14 503.40	100.00%

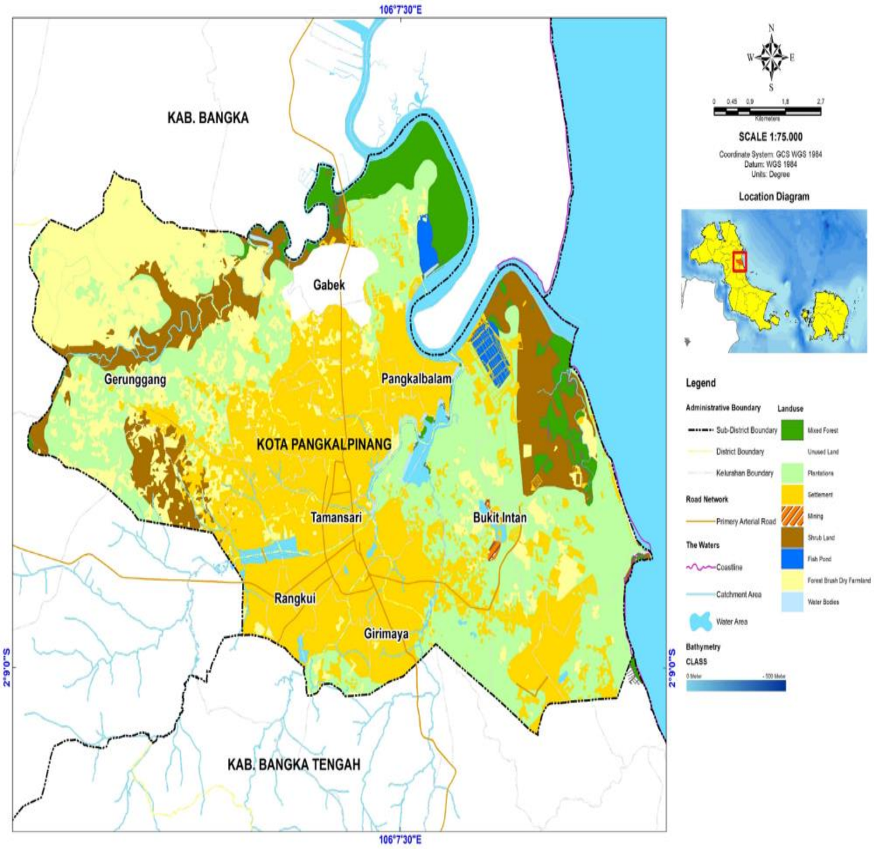

Fig. 4. Land use map of Pangkalpinang city.

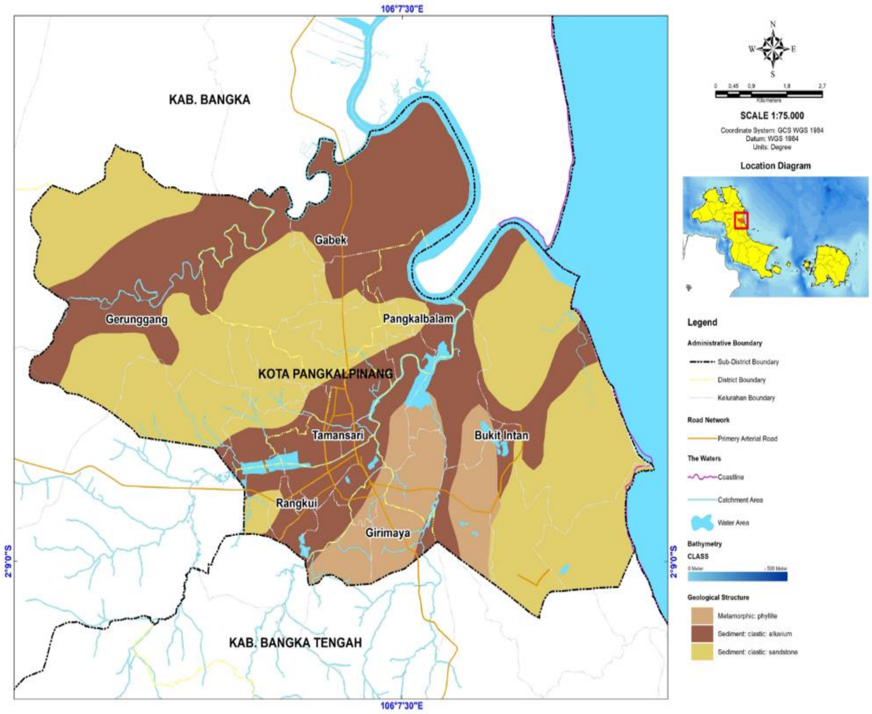

Fig. 5. Geological structure map of Pangkalpinang city.

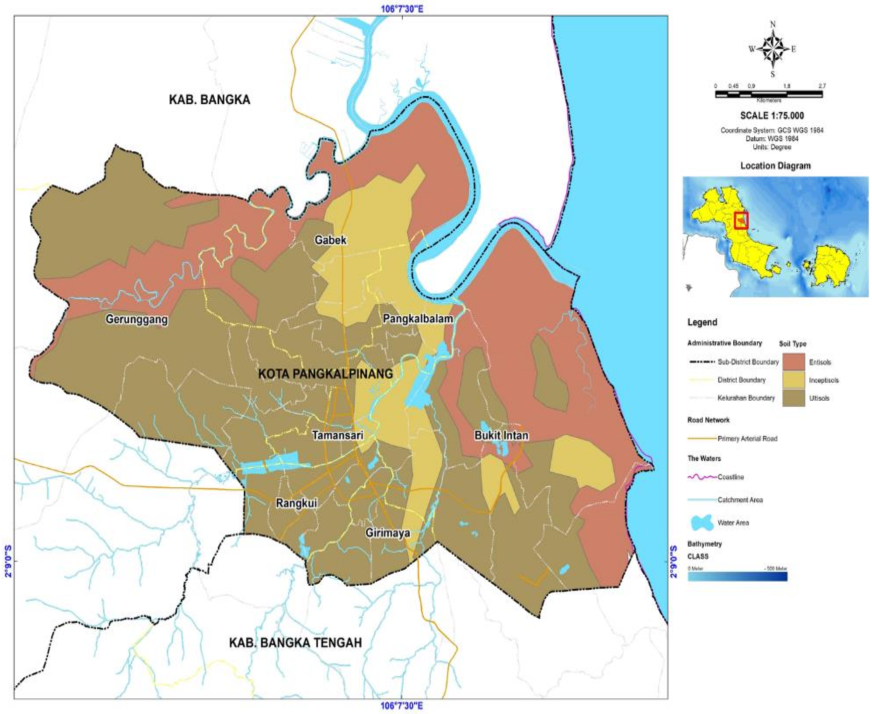

Fig. 6. Soil type map of Pangkalpinang city.

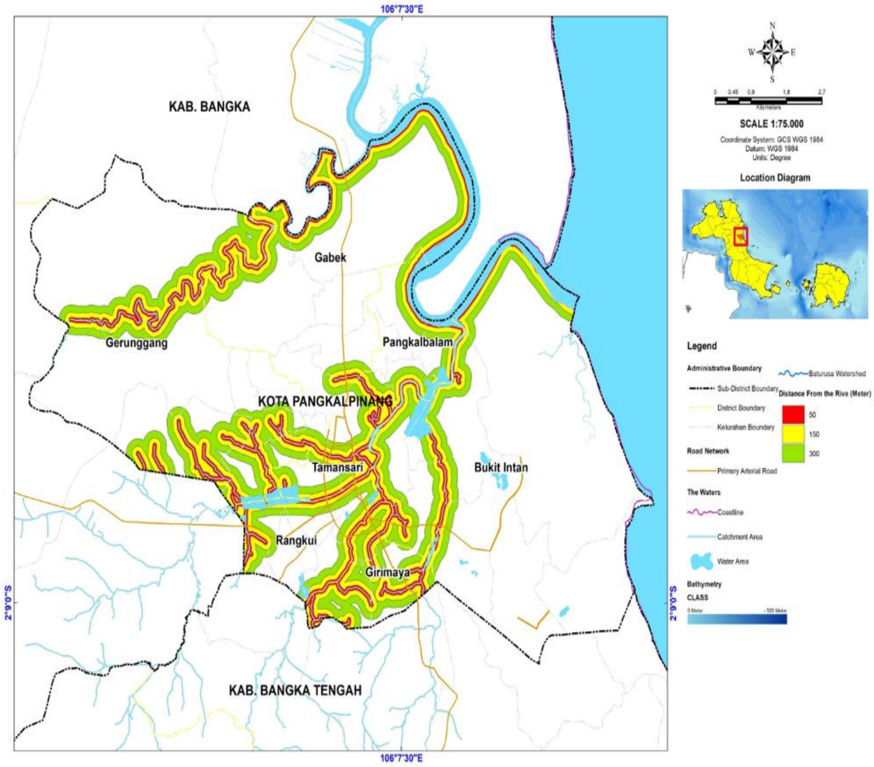

Fig. 7. Distance to river of Pangkalpinang city.

3.4. Spatial analysis of flood susceptibility and urban land use in Pangkalpinang city

The level of flood susceptibility used statistical classification with the distribution criteria based on the normal distribution method by considering the minimum, maximum, and average frequency of distribution. The results of reclassification obtained flood susceptibility map. The classes are low, moderate, and high susceptibility (Fig. 8).

The flood susceptibility classification is explained based on the subdistrict administration in the city of Pangkalpinang (Table 3). The level of flood susceptibility is explained based on the type of land use (Table 4). Impact of the geology must be also considered [31].

Table 3 explains the distribution of flood susceptibility classes by region. Areas with low susceptibility had an area of around 19%; areas with moderate flood susceptibility by 35% and areas with low flood susceptibility by 45%. The results of this research need to be integrated with the urban drainage system so that it can be used for flood disaster mitigation planning [32].

Table 4 shows the type of land use and the level of flood susceptibility. Land-use type of settlement that was a built-up area was the highest percentage area with high and moderate susceptibility. This information is very important in land use planning by reviewing aspects of flood disaster mitigation as has been done in the United States, which has observed community adaptation to flooding based on land use planning [33]. The change of land use into a developed area in Pangkalpinang can be suspected as an important factor causing the high level of flood vulnerability. The same situation occurs in Africa, where the loss of forest vegetation results in an increased surface run-off. This increased surface flow can cause flooding [25].

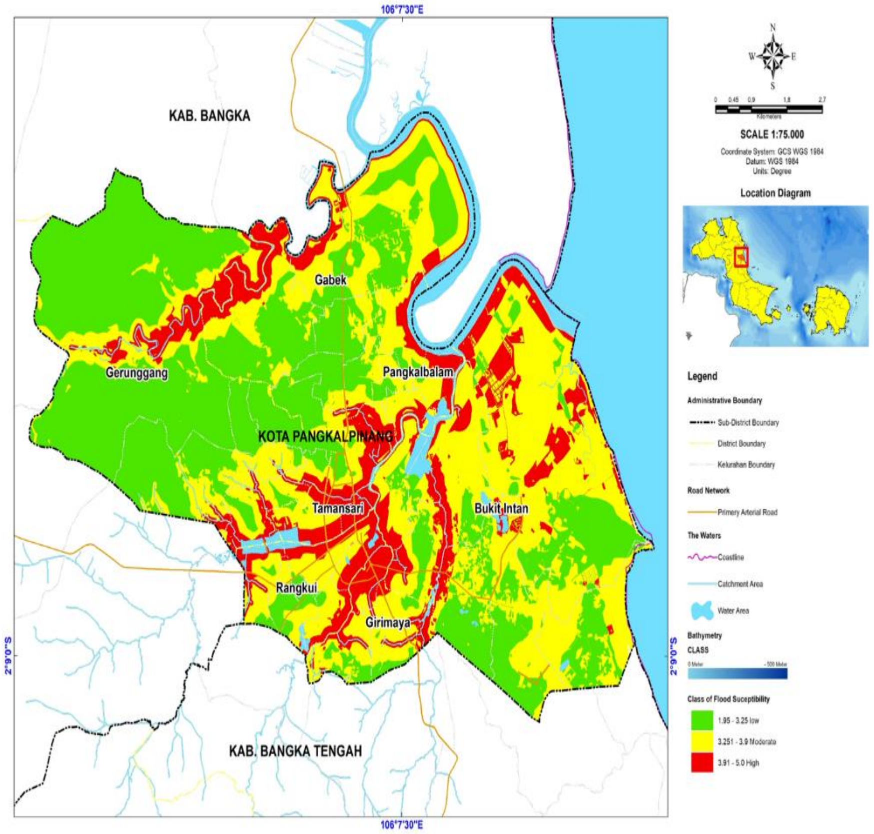

Fig. 8. Map of flood susceptibility of Pangkalpinang city.

Table 3. Area of susceptibility class based on sub-district in Pangkalpinang city.

Sub-district	Area with high susceptibility (hectares)	Area with moderate susceptibility (hectares)	Area with low susceptibility (hectares)	Total area of sub-district (hectares)
Bukit Intan	916.62	2650.96	1455.07	5022.65
Gabek	492.07	1106.39	1219.45	2817.91
Gerunggang	442.82	675.78	3615.21	4733.80
Girimaya	256.78	209.21	81.70	547.69
Pangkalbalam	234.12	215.70	71.71	521.54
Rangkui	226.64	202.00	92.09	520.73
Tamansari	225.78	86.61	26.70	339.09
Total area (hectares)	2794.83	5146.64	6561.93	14503.40
Total percentage (%)	19.27%	35.49%	45.24%	100.00%

Table 4. Area and percentage of susceptibility class based on land use in Pangkalpinang city.

Land use	High susceptibility		Moderate susceptibility		Low susceptibility	
	Area (hectares)	(%)	Area (hectares)	(%)	Area (hectares)	(%)
Forest	89.31	3.20%	392.44	7.63%	299.34	4.56%
Open land	19.40	0.69%	141.57	2.75%	82.74	1.26%
Plantation	201.17	7.20%	1297.25	25.21%	3294.39	**50.20%**
Settlement	1196.35	**42.81%**	1751.92	**34.04%**	987.58	15.05%
Mining	14.71	0.53%	12.19	0.24%	0.00	0.00%
Shrub	870.72	31.15%	1124.62	21.85%	526.49	8.02%
Pond	45.18	1.62%	61.20	1.19%	0.00	0.00%
Dry farmland	99.47	3.56%	355.07	6.90%	1371.39	20.90%
Water bodies	258.52	9.25%	10.38	0.20%	0.00	0.00%
Total	2794.83	100.00%	5146.64	100.00%	6561.93	100.00%

4. Conclusions

Pangkalpinang city is an area that often occurs floods; therefore flood susceptibility maps and spatial analysis was important to research results. The distribution of flood points was in every sub-district in Pangkalpinang city, although the number and condition of flood points differ in each sub-district. Rangkui sub-district had the highest number of points, while Taman Sari sub-district had the highest flood level. The classes of flood susceptibility were classified into three groups, namely low, medium and high. The total area with high flood hazard was 19%; moderate vulnerability 35% and low vulnerability 45%. Land use of settlement is the most extensive area of high and moderate flood susceptibility. Information obtained for areas with flood susceptibility levels can be used as input or recommendations for flood disaster mitigation planning. In compiling this flood disaster mitigation plan, planners must consider aspects of land use, community behaviour, and the condition of the urban drainage system.

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