GIS Analysis for Flood Problem in the Big City: A Case Study in Pekanbaru City, Riau Province, Indonesia

Husnul Kausarian[a,*], Adi Suryadi[a], Susilo[a], Josaphat Tetuko Sri Sumantyo[b], Batara[a]

[a] Geological Engineering Program, Universitas Islam Riau, Jl. Kaharuddin Nasution 113, Pekanbaru 28284, Indonesia
[b]Center for Environmental Remote Sensing, Advance Integration Science, Chiba University, 1-33 Yayoi-Inage, Chiba 263-8522, Japan
Corresponding author: husnulkausarian@eng.uir.ac.id

Abstract— **Pekanbaru City, Riau Province, Indonesia located at 0°25'29.20"- 0°39'15.22" N and 101°20'43.39"- 101°34'25.60" E. This research aims to study the common causes of flooding in Pekanbaru city with a good geological condition. Research in the flood area of the city of Pekanbaru using primary and secondary data; geological, geomorphological, rainfall, and land use data. Information about this earth system combined with geographic information system (GIS) analysis using a small unmanned aerial vehicle (UAV) / drones including Geographic Positioning Systems (GPS) combined with online coordinate systems that can help spatial analysis to determine the level of vulnerability of flood disasters by producing a visual mapping model. The study shows that 4 locations were found vulnerable to being affected by flooding when it rained. The flood impact in those areas happened because those locations are in a geomorphological system with a low topographic area, the natural river system that controls the water to the main river, and a poor water escape-system / drainage. The geomorphological analysis showed two geomorphological units, i.e., lowland denudational and lowland structural with river flow-pattern that is dendritic, sub-dendritic, and parallel. Rainfall is quite high in 2018 with 2621.5 mm and caused flood-prone areas, which are divided into three categories: Non-vulnerable area (64.575%), Medium Vulnerable area (23,386%), and Vulnerable area (12,039%) from the entire of the research area.**

Keywords— **Pekanbaru City; flood; GIS; geomorphology; geological mapping.**

I. INTRODUCTION

Pekanbaru is the capital city of Riau Province, with a large population on the island of Sumatra, Indonesia, located in the center of Sumatra Island with an area of 632.34 km^2 [1], [2], [3]. The total population is 1.6 million people, with an average population of 2000 people per kilometer [4], [5]. It is undoubtedly a problem in urban areas. One of them is the problem of flooding for the area surrounding Pekanbaru City [6], [7], [8].

The problem of flooding in this city has become a severe thought to officials and spatial experts of Pekanbaru City. Almost every month, particular floods routinely happen in Pekanbaru City, especially when heavy rainfalls Lately, rainfall is quite high in December with a value of 16,954 [9] mm accompanied by unusual discharge, so that Pekanbaru is not ready to collect rain. As a result, the high rainfall inundated the road/street and residential areas—geological Condition.

Geologically, Pekanbaru City is in the Central Sumatra Basin, a back-arc basin that develops along the west and south coast of the Sunda Exposure in Southwestern Southeast Asia. This study built on the formation of Minas, old alluvium, and young alluvium. The Geological Map of Pekanbaru Sheet in the study area is in three formations [10]. These formations are Minas formation, old alluvium, and young alluvium. This alluvial unit consists of river sediment (sand, gravel, limestone, and claystone) and beach sediment, i.e., sand to mud; the alluvial unit's thickness estimated at 20 meters.

II. MATERIAL AND METHOD

The flooding effect in an urban area [11], [12], [13], [14] is an essential concern in this study to determine the cause, such as the influence of general geological conditions, the effect of watershed relations and rainfall on the problem of flooding, and the influence of land use on floods [15], [16], [17], [18]. These data (Figure 1) become a reference to measure and obtain the values of the geological impact on floods that occur

101°21'0"E   101°24'0"E   101°27'0"E   101°30'0"E   101°33'0"E   101°36'0"E

0°39'0"N   0°36'0"N   0°33'0"N   0°30'0"N   0°27'0"N   0°24'0"N

B

A

St11
St7
St3
St2
St1
St9
St8
St4
St10
St6
St5

Symbol	geomorphology unit	morphography			morphometry			morphogenetic	
		pattern	ele-vation	land form	relief	slope		original land form	lithology
						%	degree		
(green)	Denudational lowland	parallel, subdendritic	6.25 - 18.75m	lowland	flat	0-2	0-1.15	denudational	gravel, sand, silt, peat
(yellow)	Structural lowland	parallel, sub & dendritic	18.75-68.75m	structural lowland	sloping	7-15	4-8.5	structural	gravel, sand, silt, organic

~ Countour   A____B Cross Section   ~ Main River   Research location

60 m
40 m
20 m
0 m

Siak River

5 km   10 km   15 km   20 km   26,6 km

A   B

N
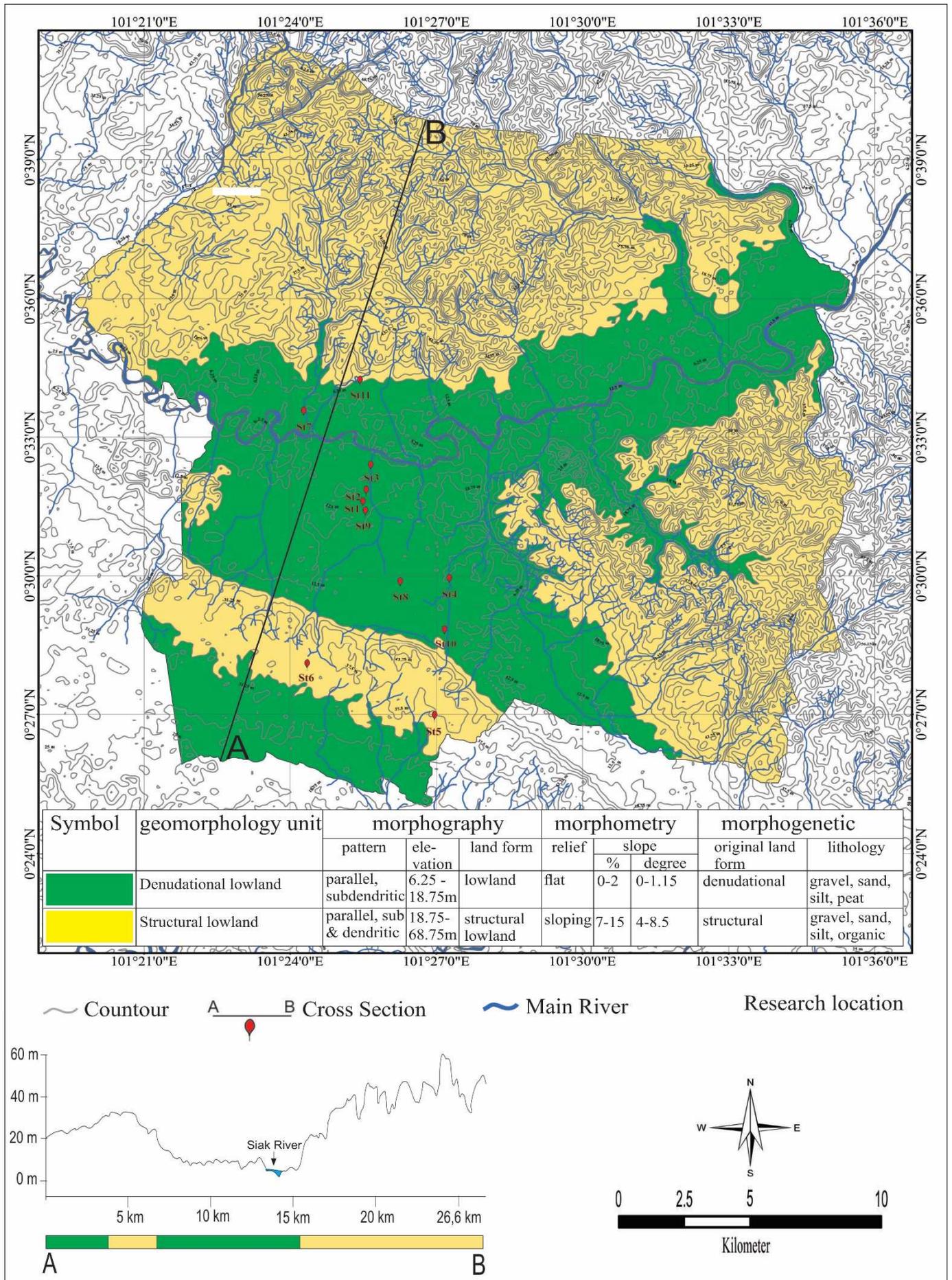W   E
S

0   2.5   5   10
Kilometer

Fig. 1 Geomorphological Map of Pekanbaru City for the Flood Distribution Area based on the Geological Condition Analysis.

in Pekanbaru City. With sufficient equipment, primary data collection in the field did not experience significant obstacles.

The equipment used is GPS, topographic maps, compass, camera, and drone or Unmanned Aerial Vehicle (UAV) [19], [20], [21], [22], [23]. While secondary data used are geological map data containing lithological and structural information [24], [25], land use data, rainfall data [9], and information about flood events from affected residents.

A. Primary Data

Primary data collection through direct surveys to the field to obtain information or data needed, such as flood events, in the form of visits to flood locations and interviews with local communities. For collecting primary data, methods for collecting data are needed, including mapping of flood-affected areas, aerial photographs using UAV DJI Phantom 3 [26], [27], [28], [29], [30] with overlapping photo-taking techniques (Figure 2).
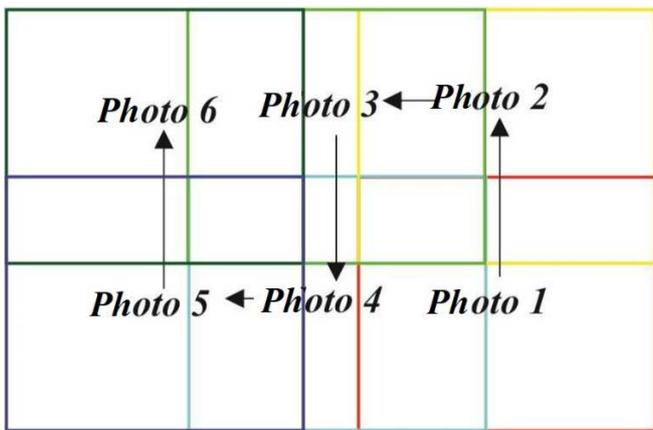

Fig. 2 Data Retrieval Route uses a Drone / small Unmanned Aerial Vehicle (UAV) with overlapping photo capture techniques.

B. Secondary Data

Secondary data is supporting data that already exists, so that only needs to find and collect data. The data can be obtained or secondary data supporting data that already exists, so that only need to find and collect data. The data can be obtained or collected by visiting the place or agency related to the research. This secondary data can be in the form of literature, documents, and reports relating to the research. This secondary data consists of the geological map containing information on the lithology, regional geological structures in Pekanbaru, land use data, rainfall data, and flood events from affected residents.

III. RESULT AND DISCUSSION

A. Geomorphology and Topography Analysis

Pekanbaru is around 5-20 meters above sea level (masl). In geological structure, Pekanbaru is a fold (anticline) area with the lower wing at each end of the left and right side, a large river, namely Siak River and Kampar Kiri River, so logically, Pekanbaru will not experience flooding. However, this is the opposite when heavy rains occur, even if only for a short time. The geomorphological analysis results showed that the morphography, morphometry, and morphogenetics of Pekanbaru are divided into denudational lowland

geomorphological and structural lowland geomorphological unit (Figure 3, also see Figure 1 as reference).

Symbol		
geomorphology unit	Denudational lowland	Structural lowland
morphography - Pattern - Elevation - Landform	Parallel, subdendritic 6.25 - 18.75m lowland	Parallel, Sub & Dendritic 18.75- 68.75m Structural Lowland

morphometry
- Relief
- Slope
  * Percentage (%)
  * Degree
	Flat
	
	0 - 2
	0 - 1.15
		Sloping
		
		7 - 15
		4 - 8.5

morphogenetic - Original Landform - Lithology	Denudational Gravel, Sand, Silt, Peat	Structural Gravel, Sand, Silt, Organic

Fig. 3 Geomorphology Explanation of the Research Area.

The Denudational lowland unit elevates 6.25 - 18.75 meters above sea level with relatively flat relief (slope range 00-1,150). The geological process predominates in forming a geomorphological unit is a denudational process in which almost all fields have been broken down into loose sedimentary material and soil. This geomorphological unit covers 45% of the city of Pekanbaru. In this unit, the predominant flow patterns are dendritic and sub-dendritic. Other geomorphology units are structural lowland geomorphology, which covers 55% of Pekanbaru. This geomorphology unit is characterized by an elevation of 18.75 - 68.75 meters above sea level.

The slope of the morphometric calculation results in this unit is 40 - 8.50 with gentle relief. This landform was formed because of fold structure, so the heights and valleys are created even though the slope is relatively sloping. The process shows that the dominant geological process developing this land is structural. In this unit, the dominant flow pattern is parallel because there are valleys between high elevations. Thus, there will be a relationship between geomorphology and flooding if the high intensity of rainfall at the low geomorphological area. The water flows to flat topography, i.e., in denudational lowland geomorphological unit with a slope of $0-1.50^0$ (See Figure 1 and Figure 3).

The mapping analysis results using drone or UAV show that flood events that occurred on Jalan Umban Sari, Rumbai District (Figure 2), showed that flooding was caused by heavy rainfall that occurred at 2 to 6 am. The overflow of water from the drainage around the road was due to sand sediment thickness in the drainage, or shallow siltation made drainage in awful condition. The flood height in this area reaches 30 cm.

Rainfall data in Pekanbaru (Meteorological, Climatological, and Geophysical Agency of The Republic of Indonesia (BMKG) 2018) shown the lowest rainfall is in April with an average of 3.47 mm, and the highest rainfall occurred in December with an average of 16,954 mm. From October to December, the rainfall range is 9,432-16,954 mm, and the highest number of rainy days is along 17-25 days throughout the year of 2018. Overall, Pekanbaru City, throughout 2018, had experienced 176 days with a total rainfall of 2621.5 mm.

B. Drone / Small Unmanned Aerial Vehicle (UAV) Analysis

Discussion of Aerial Photo Analysis using drones and Small UAVs includes taking photos at the flood site area to see the conditions of flood-prone areas to see the conditions around. Several points affected and flood-prone can be seen through this analysis from Station 1 (Figure 4) to Station 4.
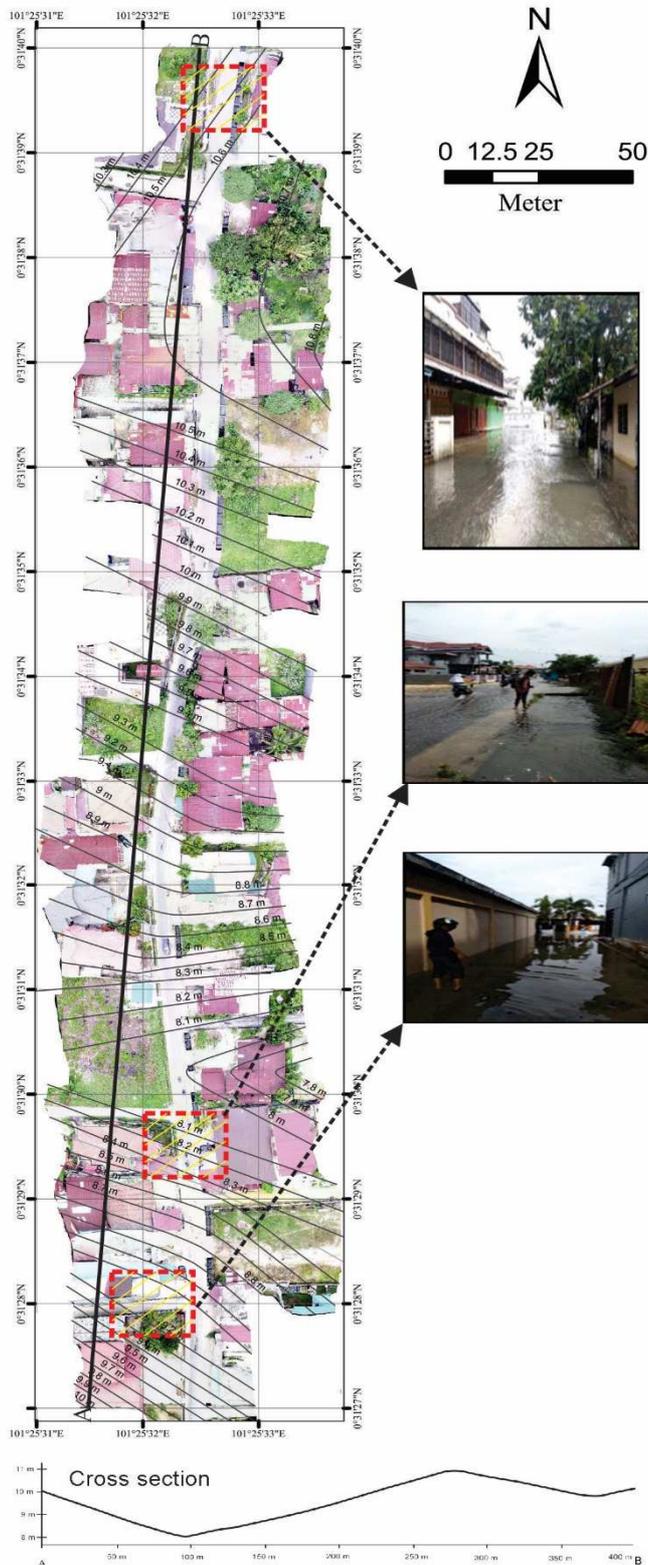

Fig. 4 Aerial Photography from Drone / Small UAV at Station 1.

Flood at station 1 with coordinates N 00 ° 31'27.03 "/ E101 ° 25'32" located on Jalan Bintara, Payung Sekaki sub-district topographic height of 18 meters above sea level. At this station, flooding occurred along the street and impacted residential areas (Figure 4). Floods happen in the southern part of the street and the northern part of the map. It occurs because the south and north parts of the topography tend to be lower than the middle part of the map, which tends to be higher. As a result, the flow of water from the south overflowed because it was blocked by hilly areas, resulting in water overflow; in addition to the topography, drainage at this location is also inadequate because of the thick sediment (rich in sand), causing siltation of the drainage.

Flood at station 2 with coordinates N 00 ° 31 '41.66 "/ E101 ° 25' 33.69" located on Jalan Lili, Payung Sekaki district with a topographic height 18 meters above sea level. At this station, the flood occurred and inundated the street. The resulted map from drone / small UAV analysis (Figure 5) shows the water flow is from West to East towards more significant drainage. The flood occurs because the principal (greater) drainage has an abundant amount of water from the small block-drainage. The topography from upstream to downstream is very flat or does not show any significant topographic changes. This flood also occurs due to the thickness of sediment in the drainage (rich in sand), causing siltation in the drainage and unable to accommodate the massive water flow and cause overflow of water from the drainage.

Station 3 with coordinates N 00°27'51"/ E101°24'19"occurred at HR. Subrantas street, Tampan sub-district with a topographic height of 35 meters above sea level. At this station, the flood occurred on the street (approximately 100 meters). The resulted map from drone / small UAV analysis (Figure 6) shows the topography forms a basin so that the flow of water from east to west is abundant due to the lower topography. Besides that, the area is also lacking in water catchment areas. Based on observations at the time of the incident, flooding occurred due to heavy rainfall at 22:00. The height of the flood reaches above the ankle of an adult (about 30 cm), one of the triggers caused by the lack of water infiltration in the area and drainage that is unable to accommodate the amount of water so that abundant water overflows from the drainage, drainage flow quite smoothly. However, there is still some drainage that needs cleaning.

Flood at station 4 with coordinates N 00°34'8"/ E 101°25'26" occurred on Jalan Umban Sari, Rumbai Pesisir District, with the topographic altitude of 11 meters above sea level. The flood occurred on the street section and affected residents at this station, based on the map from drone / Small UAV analysis (Figure 7) shows the topography forms a basin. The south (downstream area) has a slightly rising topography, so that water coming from upstream or the north was blocked by the topography and caused water to overflow in the basin area. Based on observations at the time of the incident, flooding is caused by heavy rainfall from 2 am until 6 am. The height of standing water in this area reaches above the ankles of adults. This flood trigger is caused by heavy rainfall and water overflow from drainage around the road due to thick sand sediments in the drainage or shallow drainage. Moreover, the drainage in the area is not good.

For the final result, the flood hazard map of Pekanbaru city resulted from the research that has been carried out (Figure 8).
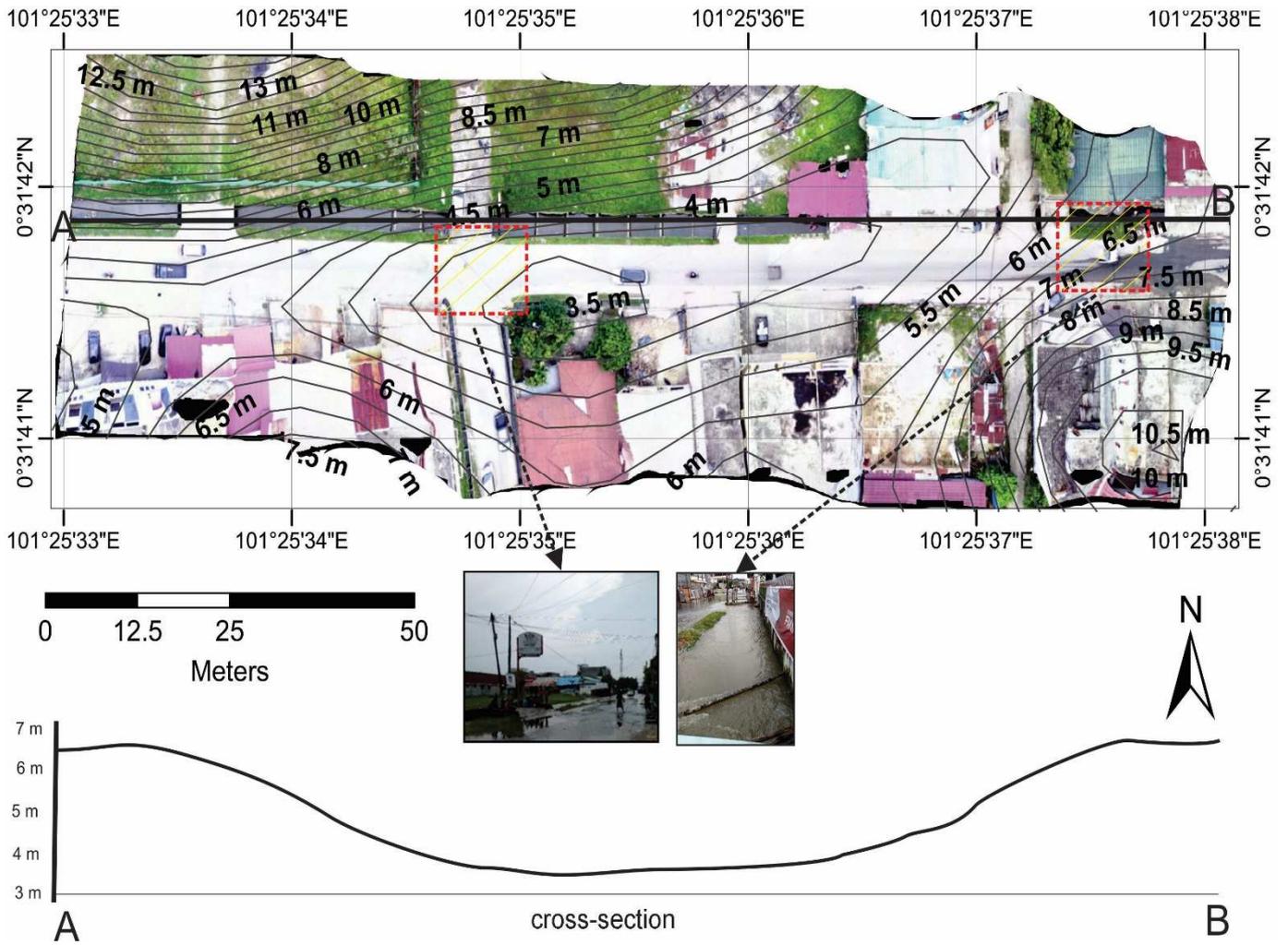
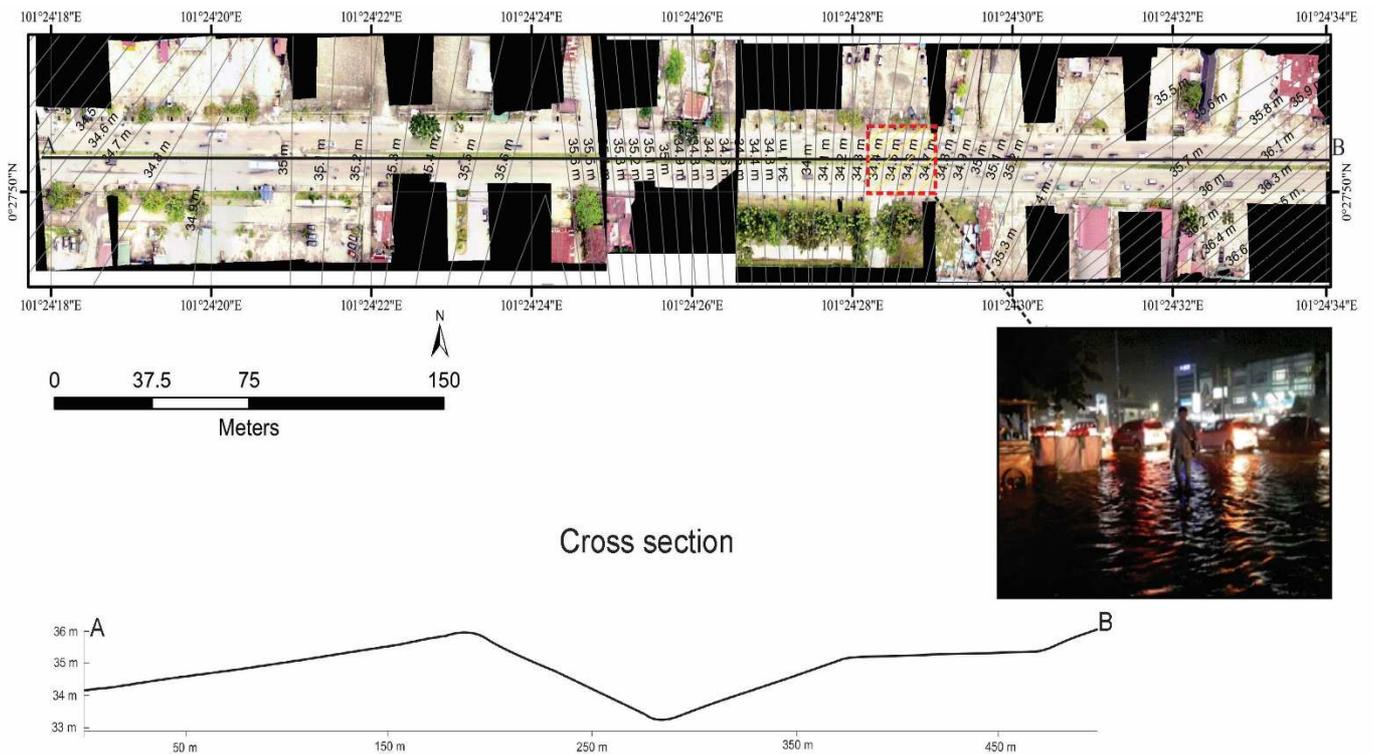Fig. 5 Aerial Photography from Drone / Small UAV at Station 2.

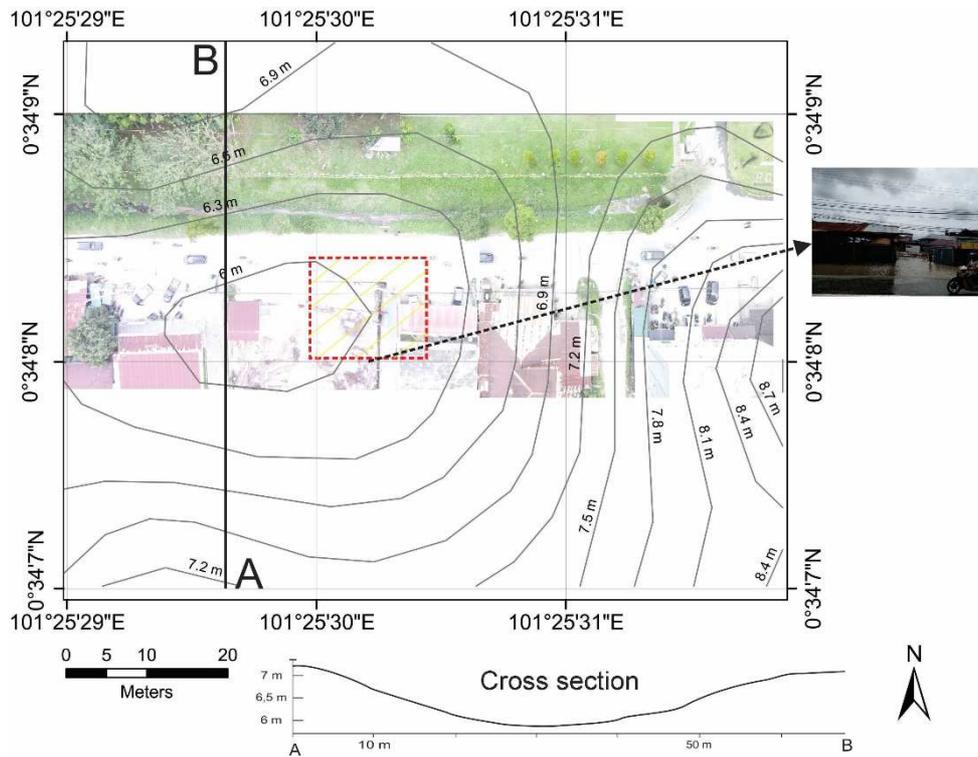Fig. 6 Aerial Photography from Drone / Small UAV at Station 3.

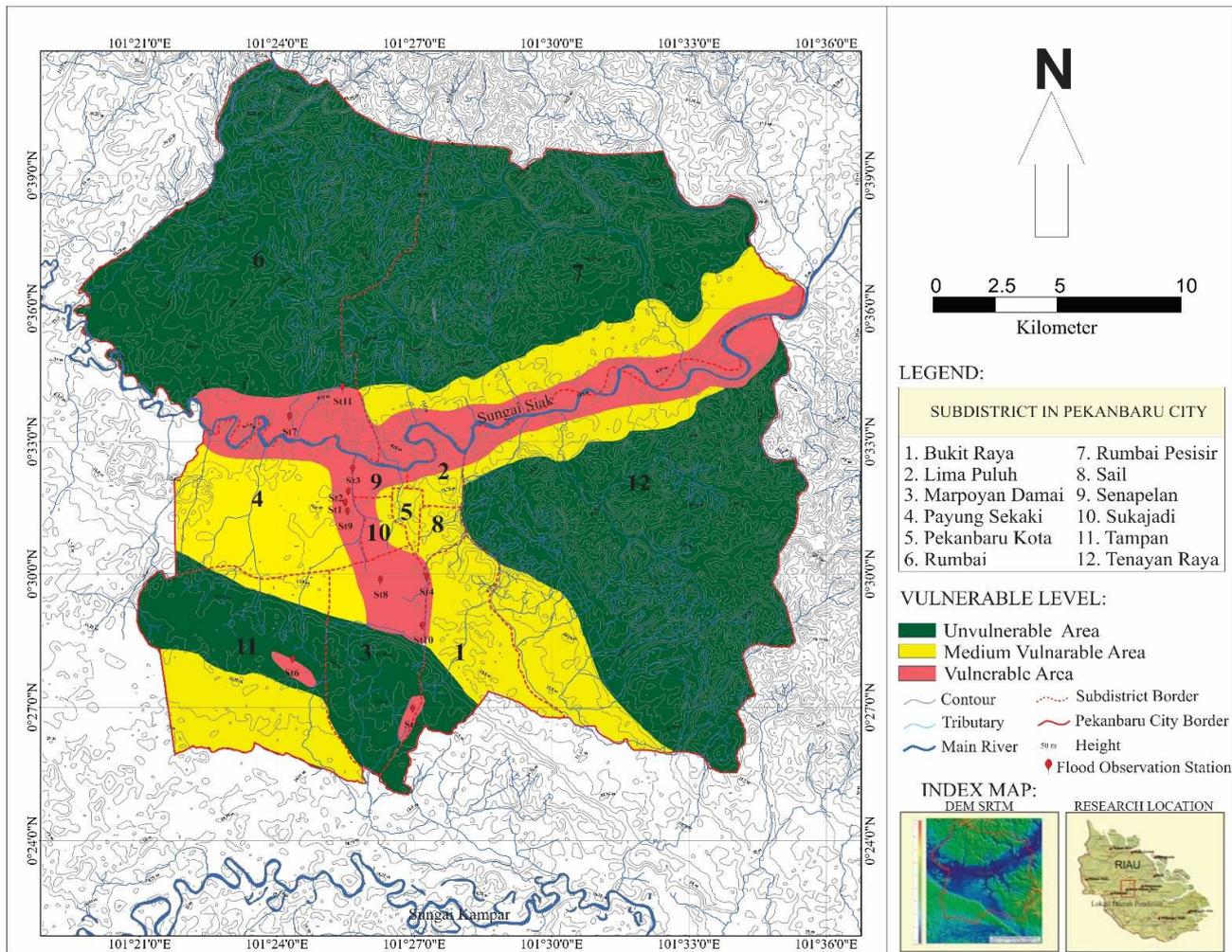Fig. 7 Aerial Photography from Drone / Small UAV at Station 4.

Fig. 8 Flood Vulnerable Map of Pekanbaru City.

IV. CONCLUSION

The study shows the flood problem in Pekanbaru city caused by the rainfall, which is affected by human interruptions such as the drainage system and the population. This problem should be handled by the design that can be applied, which matches the geomorphological condition. The general problem of causes of flooding observed at the observation station is low topography with a slope of 0 ° -1.5 ° that forms a basin. In general, the cause of the flooding is caused by poor drainage, thick sediment, and garbage. Simultaneously, the other common problem lies in the position of the flood, which is very close to the main river so that the flood is affected by the overflowing river water level.

Flood observation stations are generally located above the Old Alluvium Formation, which has a reasonably excellent or moderate absorption rate, but this condition does not affect flooding much. Still, the problem of flooding is influenced by land cover areas densely populated, resulting in a lack of catchment areas. In this study, the authors recommend three issues as follows:

- The need to socialize to the public about awareness in caring for and cleaning drainage.
- The need to build infiltration wells, especially in densely populated areas, infiltration wells are made to increase rainwater absorption capacity into the soil and reduce surface runoff.
- We need to reorganize some unsystematic drainage lines leading to large rivers.

ACKNOWLEDGMENT

REFERENCES

[1] H. Kausarian, J. T. Sri Sumantyo, D. B. E. Putra, A. Suryadi, and Gevisioner, "Image processing of alos palsar satellite data, small unmanned aerial vehicle (UAV), and field measurement of land deformation," Int. J. Adv. Intell. Informatics, vol. 4, no. 2, pp. 132–141, 2018, doi: 10.26555/ijain.v4i2.221.

[2] K. Sari, "Management strategy of sustainable urban drainage in Pekanbaru City," IOP Conf. Ser. Earth Environ. Sci., vol. 361, no. 1, 2019, doi: 10.1088/1755-1315/361/1/012007.

[3] A. Ardiansah and S. Fahmi, "The Implementation of the Law on Spatial Planning in Pekanbaru, Indonesia," IOP Conf. Ser. Earth Environ. Sci., vol. 175, no. 1, 2018, doi: 10.1088/1755-1315/175/1/012079.

[4] Y. Qiang, "Disparities of population exposed to flood hazards in the United States," J. Environ. Manage., vol. 232, no. November 2018, pp. 295–304, 2019, doi: 10.1016/j.jenvman.2018.11.039.

[5] BPS Pekanbaru, "Badan Pusat Statistik Kota Pekanbaru." BPS, pekanbaru, p. 1, 2018, [Online]. Available: https://pekanbarukota.bps.go.id/.

[6] N. Sugiartha, K. Ogawara, T. Tanaka, and M. S. Mahendra, "Application of GSMaP Product and Rain Gauge Data for Monitoring Rainfall Condition of Flood Events in Indonesia," Int. J. Environ. Geosci., vol. 1, no. 1, pp. 36–47, 2017, doi: 10.24843/ijeg.2017.v01.i01.p05.

[7] A. Junaidi, N. Nurhamidah, and D. Daoed, "Future flood management strategies in Indonesia," MATEC Web Conf., vol. 229, pp. 1–7, 2018, doi: 10.1051/matecconf/201822901014.

[8] Nurhamidah, B. Rusman, B. Istijono, T. Ophyandri, and A. Junaidi, "Social, economic and environmental perspectives of flood assessment on delta lowland," Int. J. Civ. Eng. Technol., vol. 8, no. 10, pp. 966–978, 2017.

[9] BMKG, "9 Prakiraan Cuaca Pekanbaru - Provinsi Riau _ BMKG." BMKG, pekanbaru, [Online]. Available: https://www.bmkg.go.id/cuaca/prakiraan-cuaca.bmkg?Kota=Pekanbaru&AreaID=501478&Prov=35.

[10] M. Clarke, M.C.G., Kartawa, W., Djunuddin, A., Suganda, E. and Bagdja, "Peta Geologi Lembar Pekanbaru." bandung, p. 1, 1982.

[11] A. Palla, M. Colli, A. Candela, G. T. Aronica, and L. G. Lanza, "Pluvial flooding in urban areas: the role of surface drainage efficiency," J. Flood Risk Manag., vol. 11, pp. S663–S676, 2018, doi: 10.1111/jfr3.12246.

[12] V. Pappalardo, D. La Rosa, A. Campisano, and P. La Greca, "The potential of green infrastructure application in urban runoff control for land use planning: A preliminary evaluation from a southern Italy case study," Ecosyst. Serv., vol. 26, no. June 2016, pp. 345–354, 2017, doi: 10.1016/j.ecoser.2017.04.015.

[13] Y. T. Chang, Y. C. Lee, and S. L. Huang, "Integrated spatial ecosystem model for simulating land use change and assessing vulnerability to flooding," Ecol. Modell., vol. 362, pp. 87–100, 2017, doi: 10.1016/j.ecolmodel.2017.08.013.

[14] Z. Zhu and X. Chen, "Evaluating the effects of low impact development practices on urban flooding under different rainfall intensities," Water (Switzerland), vol. 9, no. 7, 2017, doi: 10.3390/w9070548.

[15] H. Kausarian, B. Batara, and D. B. E. Putra, "The Phenomena of Flood Caused by the Seawater Tidal and its Solution for the Rapid-growth City: A case study in Dumai City, Riau Province, Indonesia," J. Geosci. Eng. Environ. Technol., vol. 3, no. 1l, p. 39, 2018, doi: 10.24273/jgeet.2018.3.01.1221.

[16] J. Liu and Z. wu Shi, "Quantifying land-use change impacts on the dynamic evolution of flood vulnerability," Land use policy, vol. 65, no. October 2016, pp. 198–210, 2017, doi: 10.1016/j.landusepol.2017.04.012.

[17] J. Hounkpè, B. Diekkrüger, A. A. Afouda, and L. O. C. Sintondji, "Land use change increases flood hazard: a multi-modelling approach to assess change in flood characteristics driven by socio-economic land use change scenarios," Nat. Hazards, vol. 98, no. 3, pp. 1021–1050, 2019, doi: 10.1007/s11069-018-3557-8.

[18] Z. Liu, V. Merwade, and K. Jafarzadegan, "Investigating the role of model structure and surface roughness in generating flood inundation extents using one- and two-dimensional hydraulic models," J. Flood Risk Manag., vol. 12, no. 1, 2019, doi: 10.1111/jfr3.12347.

[19] D. Popescu, L. Ichim, and F. Stoican, "Unmanned aerial vehicle systems for remote estimation of flooded areas based on complex image processing," Sensors (Switzerland), vol. 17, no. 3, 2017, doi: 10.3390/s17030446.

[20] S. Coveney and K. Roberts, "Lightweight UAV digital elevation models and orthoimagery for environmental applications: data accuracy evaluation and potential for river flood risk modelling," Int. J. Remote Sens., vol. 38, no. 8–10, pp. 3159–3180, 2017, doi: 10.1080/01431161.2017.1292074.

[21] Z. Li, C. Wang, C. T. Emrich, and D. Guo, "A novel approach to leveraging social media for rapid flood mapping: a case study of the 2015 South Carolina floods," Cartogr. Geogr. Inf. Sci., vol. 45, no. 2, pp. 97–110, 2018, doi: 10.1080/15230406.2016.1271356.

[22] L. Hashemi-Beni, J. Jones, G. Thompson, C. Johnson, and A. Gebrehiwot, "Challenges and opportunities for UAV-based digital elevation model generation for flood-risk management: A case of princeville, north carolina," Sensors (Switzerland), vol. 18, no. 11, 2018, doi: 10.3390/s18113843.

[23] J. Langhammer and T. Vacková, "Detection and Mapping of the Geomorphic Effects of Flooding Using UAV Photogrammetry," Pure Appl. Geophys., vol. 175, no. 9, pp. 3223–3245, 2018, doi: 10.1007/s00024-018-1874-1.

[24] H. Kausarian, J. T. Sri Sumantyo, H. Kuze, J. Aminuddin, and M. M. Waqar, "Analysis of Polarimetric Decomposition, Backscattering Coefficient, and Sample Properties for Identification and Layer Thickness Estimation of Silica Sand Distribution Using L-Band Synthetic Aperture Radar," Can. J. Remote Sens., vol. 43, no. 2, pp. 95–108, 2017, doi: 10.1080/07038992.2017.1286935.

[25] M. Z. Lubis, W. Anurogo, A. Hanafi, H. Kausarian, H. M. Taki, and S. Antoni, "Distribution of benthic habitat using Landsat-7 Imagery in shallow waters of Sekupang, Batam Island, Indonesia," Biodiversitas, vol. 19, no. 3, pp. 1117–1122, 2018, doi: 10.13057/biodiv/d190346.

[26] A. Roder, K. K. R. Choo, and N. A. Le-Khac, "Unmanned aerial vehicle forensic investigation process: Dji phantom 3 drone as a case study," arXiv, pp. 1–14, 2018.

[27] D. R. Clark, C. Meffert, I. Baggili, and F. Breitinger, "DROP (DRone open source parser) your drone: Forensic analysis of the DJI phantom III," DFRWS 2017 USA - Proc. 17th Annu. DFRWS USA, vol. 22, pp. S3–S14, 2017, doi: 10.1016/j.diin.2017.06.013.

[28] P. Sedlak, J. Komarkova, O. Masin, and J. Jech, "The procedure for processing images from a low-cost UAV," Iber. Conf. Inf. Syst. Technol. Cist., vol. 2019-June, no. June, pp. 19–22, 2019, doi: 10.23919/CISTI.2019.8760952.

[29] S. Manfreda et al., "On the use of unmanned aerial systems for environmental monitoring," Remote Sens., vol. 10, no. 4, 2018, doi: 10.3390/rs10040641.

[30] K. Ondara, R. Dhiauddin, U. J. Wisha, "Hydrodynamics Features and Coastal Vulnerability of Sayung Sub-District, Demak, Central Java, Indonesia," J. Geosci. Eng. Environ. Technol., vol. 5, no. 1, pp. 32–39, 2020, doi: https://doi.org/10.25299/jgeet.2020.5.1.3996.