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Flood Mapping using HEC-RAS and GIS: A Case Study of Palembang Watersheds

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ABSTRACT

Flooding is a significant issue in Palembang City, affecting areas such as Gandus, Lambidaro, Boang, Sekanak, Bendung, Kidul, Buah, Juaro, Selinca, Nyiur, Aur, Sriguna, Kedukan, Keramasan, Kertapati and Jakabaring watershed. This research contributes to flood control measures by providing flood mapping and modelling for decision-makers and local authorities. The main objective of this paper is to perform a steady flow analysis to study the hydraulic characteristics of flow; velocity and water surface profile of the adjacent research areas. There are three processes involved in the data analysis: hydrological, hydraulic and spatial. The calculation of average rainfall is performed using the Isohyet method with the assistance of the IDW 3D Analyst tool in ArcGIS and the design discharge is calculated using the HSS Nakayasu method. The hydraulic analyses involve river morphology extraction using RAS Mapper tools in HEC-RAS. Steady flow simulations are conducted for normal water depth conditions and the highest tidal conditions. The simulation result is then reclassified and the flood location points are verified with observed data. For normal water depth conditions, the maximum water level in the Lambidaro watershed reaches 2,09 meters, which covers a flood area of 721,53 ha. Meanwhile, based on the highest tidal simulations, the maximum water level in the Selinca watershed reaches 3,21 meters, covering a flood area of 209,36 ha.

Keywords:
Urban flood; steady flow; spatial analysis; flood mapping

1. Introduction

Indonesia is prone to natural disasters due to its geographical conditions and location. Based on data from the National Disaster Management Agency (BNPB) until 2021, flooding is the most common natural disaster event, with as many as 1,794 events throughout Indonesia. Floods can be triggered naturally because of heavy rains, frequent intense storms, melting snow or ice and human-made caused by urbanization, settlements near rivers and other water bodies [1]. Land use changes

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and natural and anthropogenic transformations are likewise responsible for substantial influence on watershed hydrology [2]. According to The United Nations Development Programme, the world has lost 70 percent of its natural wetlands over the last century [3]. Urban development leads to more impervious surfaces, lowering water absorption and raising flood risk [4]. The increasing area of impervious surfaces exhibits faster hydrological responses than natural pervious areas even for low rainfall intensity. Increased runoff can create significant flood risk with even moderate rainfall and the situation is only expected to worsen due to climate change [5]. Research in some countries confirmed this warming effect intensifies extreme rainfall events resulting in more frequent and severe short-duration floods in urban areas [5,6]. According to IPCC (Intergovernmental Panel on Climate Change) reports, regions and people exposed to water-related risks will face more significant risks with every degree of global warming [7].

Flood mapping and modelling are necessary flood control measures [8]. Mapping flood hazards is considered one of the real-time solutions to estimate the potential consequences of flood events which is extremely valuable for confronting emergency responses and mitigating the impact of those events [9]. Effective flood mitigation strategies are crucial given the projected increase in the frequency and intensity of flood events happening globally [10]. Accurate assessment of the flood susceptibility mapping is crucial for sustainable development by helping respective authorities to prevent irreversible consequences [11]. Flood modelling is one of the technical measures to design an integrated flood control system that aims to reduce the upcoming risk and number of flood events. Identification of flood susceptibility areas has been performed by applying advanced machine learning [12]. It can also use as a combination of the analytical hierarchy process and geographic information system and HMA (Hierarchical Multi-criterion Analysis), offering a low-cost methodology to produce vulnerability maps [13,14]. Analysis results, including location, depth, area, duration and other evaluation parameters, can serve as the foundation for flood control planning since the factors that make communities vulnerable vary across disaster stages and countries [15].

This research contributes to flood control measures by providing flood mapping and modelling for decision-makers and local authorities that covers major river basins in Palembang City. The main objective of this paper is to perform a steady flow analysis to study the hydraulic characteristics of flow; velocity and water surface profile of the adjacent research areas. There are three processes involved in the data analysis: hydrological, hydraulic and spatial. The calculation of average rainfall is performed using the Isohyet method with the assistance of the IDW 3D Analyst tool in ArcGIS and the design discharge is calculated using the HSS Nakayasu method. Flood mapping and modelling simulations were conducted using RAS Mapper tools for channel geometry extraction and HEC-RAS for flood water level profile simulation and spatial analysis with GIS (Geographical Information System).

2. Methodology

2.1 General Description

Palembang is the capital city of South Sumatera Province, Indonesia. The city covers 352.51 square kilometres on both banks of the Musi River. The research locations selected are the watersheds bordering the Musi River. They are significantly impacted by tides, namely Gandus, Lambidaro, Boang, Sekanak, Bendung, Kidul, Buah, Juaro, Selinca, Nyiur, Aur, Sriguna, Kedukan, Keramasan, Kertapati and Jakabaring watersheds, as in the following Figure 1.

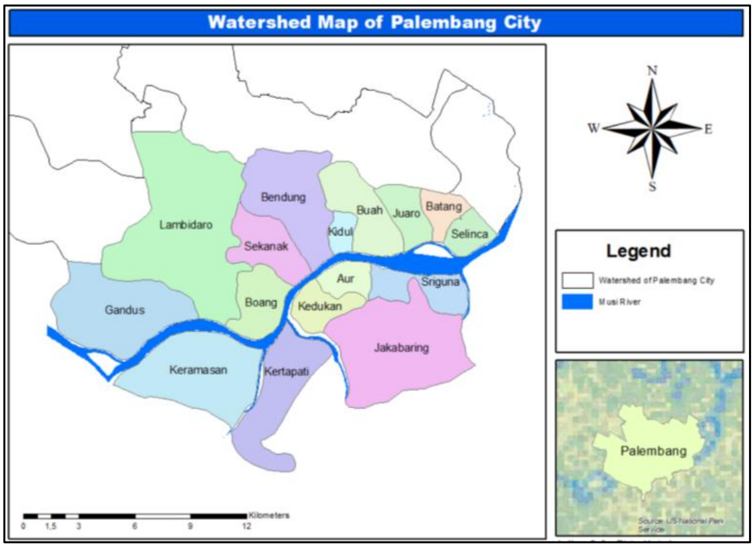

Fig. 1. Research location

2.2 Data Collection

The primary data used for this research are the survey questionnaire to collect flood points and documentation through direct interviews and Google Forms targeted at communities within the research watershed area. Secondary data:

i. Rainfall data: Rainfall data series from 2013-2022 derived from four Palembang City rainfall stations: Kenten, Plaju Pertamina, SMB II and Seberang Ulu I.
ii. Digital Elevation Model (DEM): Palembang City DEM data from http://tides.big.go.id/DEMNAS
iii. Musi River Tidal data: River level data in Palembang City from https://pasanglaut.com
iv. Thematic map: Thematic maps used are the administrative boundary of Palembang, watershed and river network obtained from the Palembang local authorities.

2.3 Research Method

For hydrological analysis, it is necessary to process data in order to determine the effective rainfall intensity and the design discharge. In order to calculate the design rainfall, this study used the average rainfall calculation, frequency analysis and fit test for all distributions. The average rainfall was calculated using the isohyet method with IDW tools on Arc GIS desktop. Frequency analysis involved four distributions: normal, gumbel, log normal and log Pearson III distributions. The Smirnov Kolmogorov test method was used to assess the goodness of fit for these distributions. To analyse the design discharge, rainfall intensity was designed using the Mononobe Method, Nakayasu method for synthetic unit hydrograph and distribution of rainfall according to the ABM method.

Hydraulic analysis was conducted to analyse the water profile along the river cross-section. The river channel geometry was extracted using the RAS Mapper tool and the water profile was simulated using HEC-RAS 5.3.1.

Spatial analysis was performed using ArcGIS 10.8 to process data and generate flood maps based on flood depth classifications outlined in the Ministry of PUPR Regulation No.12/2014.

3. Results

3.1 Hydrological Analysis

For this study, hydrological analysis calculations were conducted based on maximum daily rainfall data collected over a period of 10 years (2013-2022). The data was obtained from Meteorology, Climatology and Geophysics Agency (BMKG) from four rain stations located in Palembang City - Kenten, SMB II, Plaju Pertamina and Seberang Ulu I. The maximum daily rainfall data is presented in Table 1.

Table 1
Maximum daily rainfall of Palembang

No.	Year	Station			
		Kenten	SMB II	Plaju	Seberang Ulu I
1	2013	107.7	126.6	134	126
2	2014	111	117.3	85	94
3	2015	115.6	116.9	138	142
4	2016	172.4	172.4	104	92
5	2017	113.9	102	105.5	114
6	2018	97	115	82	128
7	2019	80.5	135	108	96
8	2020	90.6	88	135	98
9	2021	150	95	111	89
10	2022	188.7	89.6	106	67

The calculation of average rainfall in this research uses the isohyet method with IDW 3D analyst tools on ArcGIS. The following isohyet map in 2013 as shown in Figure 2.

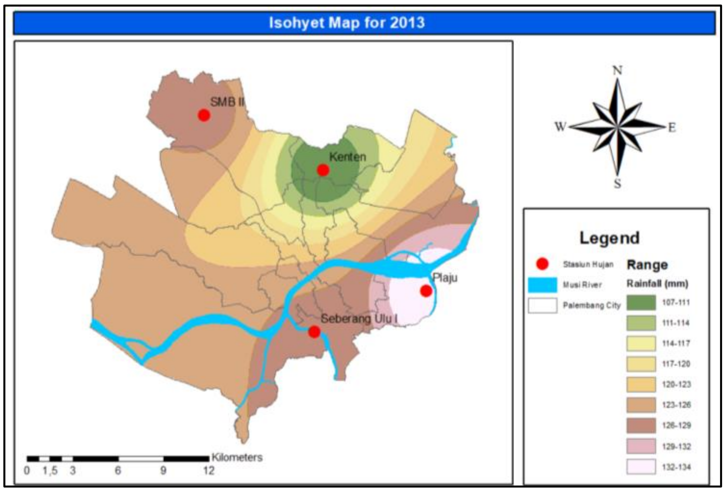

Fig. 2. Isohyet map for 2013

Table 2 below shows calculated average rainfall data from four rain stations in Palembang City.

Table 2
Recapitulation of the average rainfall of Palembang City

No.	Year	Station				Average
		Kenten	SMB II	Plaju	Seberang Ulu I	
1	2013	107.7	126.6	134	126	122.58
2	2014	111	117.3	85	94	102.76
3	2015	115.6	116.9	138	142	127.83
4	2016	172.4	172.4	104	92	136.11
5	2017	113.9	102	105.5	114	109.47
6	2018	97	115	82	128	107.83
7	2019	80.5	135	108	96	103.48
8	2020	90.6	88	135	98	100.26
9	2021	150	95	111	89	111.30
10	2022	188.7	89.6	106	67	113.19

The Gumbel distribution was selected for future calculations after conducting the Smirnov-Kolmogorov suitability test with a 5% confidence level on four probability distributions. This is because the Gumbel distribution has a value of Δ max < Δcr and the smallest value compared to other distributions so it is acceptable. Gumbel distribution is one of the most widely used probability functions for extreme values in hydrologic and meteorological studies for prediction of flood peaks [16]. Table 3 contains a summary of the Smirnov Kolmogorov test.

Table 3
Recapitulation of Kolmogorov Smirnov test

Distribution	Δ maks	Δ_{cr}	Description
Normal distribution	0,30729	0,41	Accepted
Gumbel distribution	0,08492	0,41	Accepted
Log Normal distribution	0,27593	0,41	Accepted
Log Pearson III distribution	0,77454	0,41	Rejected

Table 4
Design rainfall with Gumbel distribution

Return period (years)	Xt
2	111,14
5	125,91
10	135,2
25	146,03
50	155,64
100	164,28

From the results of the previous Smirnov Kolmogorov suitability test, it was determined that the maximum daily rainfall from the Gumbel distribution was used to calculate design rainfall intensity. Intensity-Duration-Frequency (IDF) curves were generated using the modified Mononobe method. Empirical Methods of rainfall intensity and IDF such as; Talbot, Mononobe, Hasper Der Weduwen and Van Breen are suitable for the Indonesian region [17]. IDF for return periods of 2, 5, 10, 25, 50 and 100 years as shown in Figure 3.

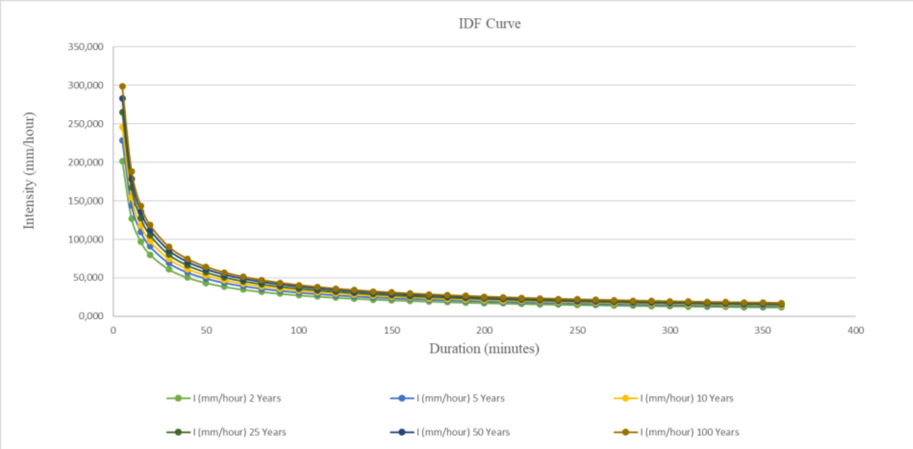

Fig. 3. IDF modified mononobe plan rainfall intensity

This study utilizes the Synthetic Unit Hydrograph method, specifically the HSS Nakayasu model, to determine the peak discharge. The Nakayasu Synthetic Unit Hydrograph (HSS) is a popular method used in water resources planning, especially in the analysis of unmeasured flood-discharged watersheds [18,19]. Several parameters are required for calculating the peak discharge using Nakayasu HSS, including channel area, main river length, alpha parameter (α) and rainfall unit (R0). The research focuses on seventeen watersheds directly adjacent to the Musi River in Palembang City. Table 5 summarizes the Nakayasu HSS calculations for each of these watersheds.

Table 5
Recapitulation of Nakayasu HSS in Palembang City watersheds

				Nakayasu HSS	
No.	Watershed	Watershed area (km^2)	Length of main river (m)	Peak time (hour)	Peak discharge (m^3/s)
1	Gandus	24.844	2839.248	0.698	6.383
2	Lambidaro	49.586	5995.750	1.177	7.549
3	Sekanak	10.441	4435.163	0.953	1.963
4	Boang	9.111	3291.368	0.774	2.111
5	Bendung	20.407	5361.528	1.089	3.360
6	Kidul	2.800	1419.147	0.429	1.169
7	Buah	12.235	5526.989	1.112	1.972
8	Juaro	6.340	1606.995	0.468	2.426
9	Batang	4.429	3550.831	0.816	0.973
10	Selinca	4.463	3253.597	0.767	1.042
11	Nyiur	22.218	2308.606	0.604	6.598
12	Aur	4.531	1951.67	0.537	1.513
13	Sriguna	8.271	2048.12	0.555	2.671
14	Kedukan	6.251	2749.40	0.682	1.643
15	Keramasan	24.950	6010.58	1.179	3.792
16	Kertapati	17.616	8548.16	1.509	2.092
17	Jakabaring	32.513	6687.22	1.208	4.823

Once the rainfall distribution has been calculated, the design discharge calculation results for each return period can be obtained. For each return period, a maximum discharge value will be used for the hydraulic analysis. Table 6 summarizes the peak discharge values for each return period across the entire watershed.

Table 6
Recapitulation of design discharge

Watersheds	Design discharge (m^3/s)					
	2 years	5 years	10 years	25 years	50 years	100 years
Gandus	44.245	50.125	53.822	58.133	61.958	65.398
Lambidaro	157.818	178.789	191.976	207.354	220.998	233.267
Sekanak	27.799	31.493	33.816	36.525	38.928	41.089
Boang	18.686	21.169	22.731	24.552	26.167	27.620
Bendung	61.304	69.450	74.573	80.546	85.846	90.612
Kidul	3.699	4.190	4.499	4.860	5.180	5.467
Buah	37.358	42.323	45.444	49.085	52.314	55.219
Juaro	8.446	9.568	10.274	11.097	11.827	12.484
Batang	9.762	11.060	11.875	12.826	13.670	14.429
Selinca	9.010	10.207	10.960	11.838	12.617	13.317
Nyiur	44.149	50.015	53.704	58.006	61.823	65.255
Aur	8.042	9.111	9.783	10.567	11.262	11.887
Sriguna	15.299	17.332	18.610	20.101	21.424	22.613
Kedukan	15.210	17.232	18.503	19.985	21.300	22.482
Keramasan	98.965	111.567	119.796	129.392	137.906	145.562
Kertapati	85.383	96.729	103.864	112.184	119.565	126.203
Jakabaring	132.201	149.768	160.816	173.697	185.126	195.403

3.2 Hydraulic Analysis

This study used the HEC-RAS (The United States Army Corps of Engineers Hydrologic Engineering Centre's River Analysis System) program version 6.3.1 to conduct hydraulics analysis. River geometry was modelled with HEC-RAS tools, specifically RAS-Mapper, to simulate a steady flow. The steady component module calculates water surface profiles from steady input discharge information at associate upstream and models the water surface elevation on the top of a base altitude for the flow speed [20]. Input data used to model the river geometry includes the Digital Elevation Model (DEM), Palembang City River network and the design discharge for each river. DEM data for Palembang City was downloaded from https://tides.big.go.id/DEMNAS and saved in shapefile format. This data was then extracted using ArcGIS 10.8 software. Based on the DEM results, the elevation for the research area ranges from -3,267 m + MSL to 41,572 m + MSL, as shown in Figure 4. This DEM data is used as reference for the river geometry modelling process in HEC-RAS.

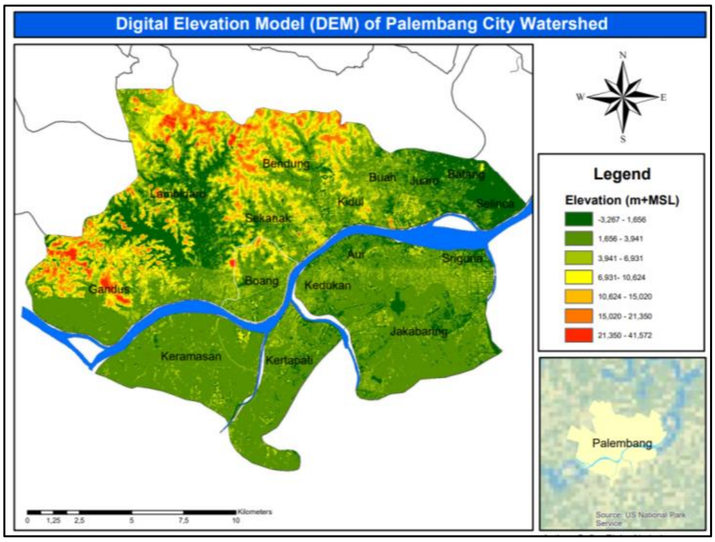

Fig. 4. Digital Elevation Model (DEM) of research locations

Using the RAS-Mapper tool, several critical components must be created to represent a river's geometry accurately. These include a river channel, bank lines to the left and right of the river, determining the flow direction (Flow Paths) and creating cross sections of the river (Cross Section). Cross sections of the river channels are created at approximate intervals, with more detailed sections on a sharp turning or change in the width of the rivers. The river bank profile needs to be modified in HEC-RAS using the cross-sectional data to create an improved river bank profile for hydraulic modelling [21].

Based on the river geometry data that has been created, a steady flow river simulation was conducted using the geometry data and river discharge data for the 5 and 10-year return periods that were previously calculated. In this simulation, there are two boundary conditions at the downstream section of the simulated river; the normal depth and during the highest tide.

Sea level rise poses a significant threat to shorelines and the environment in terms of flooding densely populated areas and associated coastal ecosystems [22]. This poses more threat to Palembang as it is lying on considerably flat topographic area. The latest data on the highest and the lowest Musi River water level for the past year (January-December 2022) were obtained from the website https://pasanglaut.com. Then, the highest value from this data has been selected and can be found in Table 7.

Table 7
Musi river water level for the year 2022

No	Month	Highest water level (m)	Lowest water level (m)
1	January	3.2	0
2	February	3.1	0.1
3	March	2.8	0.4
4	April	2.3	0.8
5	Mey	1.6	0.8
6	June	2.6	0.3
7	July	2.9	0.1
8	August	2.7	0.3
9	September	2	1.1
10	October	2.3	0.6
11	November	2.7	0.2
12	December	2.7	0.3

* Source: *https://pasanglaut.com*

The results of flood inundation simulation under normal depth and highest water level conditions for each watershed can be observed in the Result RAS-Mapper layer, as depicted in Figure 5 and Figure 6.

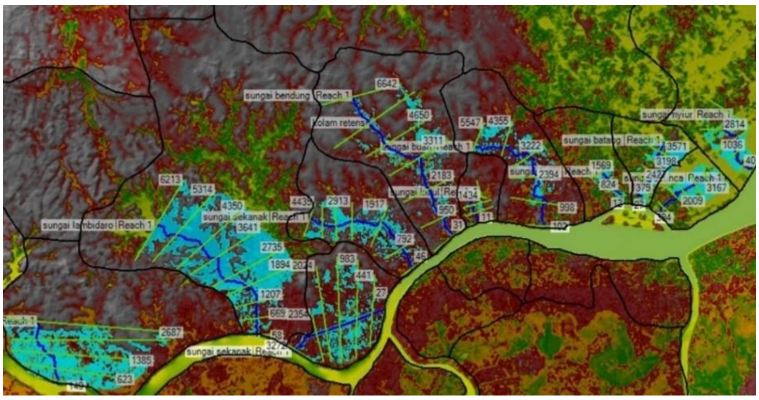

Fig. 5. Steady flow simulation for normal depth

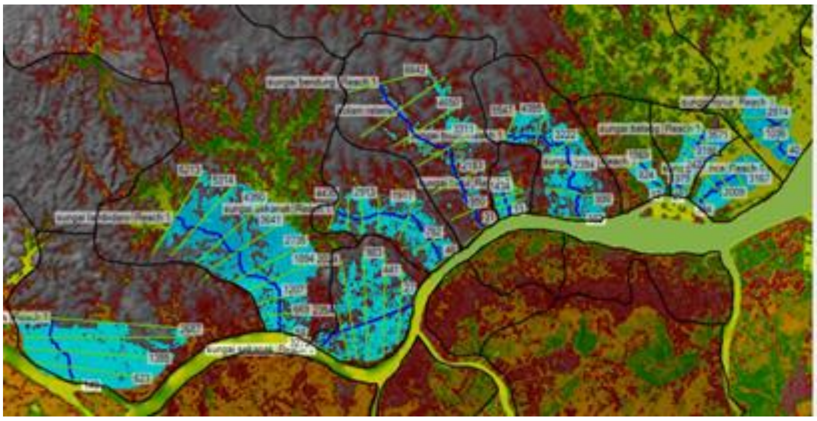

Fig. 6. Steady flow simulation for maximum water level

3.3 Spatial Analysis

A simulation was run in RAS-Mapper to obtain the flood inundation map and saved in raster format (.TIF). This data was then re-analysed using ArcGIS for reclassification based on depth. Additionally, flood location points were collected from field surveys. These flood location data were used to verify the flood existing in the research area.

The following table contains a recapitulation of flood existing in the research area, which can be seen in Table 8.

Table 8
Flood location points

No.	Flood location points	Flood depth
1	Kel. Kemang Manis, RT 4, No. 242	50 cm
2	Jl. Srijaya Negara, Lrg. Tembesu 5	10-20 cm
3	Jl. Putri Rambut Selako	40 cm
4	Jl. Buncis 137, 9 Ilir, Kec. Ilir Tim. II	15 cm
5	Jl. Lettu Karim Kadir	20-30 cm
6	Jl. Kemudi III No 961 Sungai Buah Ilir Timur II	30 cm
7	Jl Perintis Kemerdekaan lrg. Produksi Lama, Kel. Duku, Kec Ilir Timur III	20-80 cm
8	Jl. May Zen, Kel. Sei lais, Kec. Kalidoni	50 cm
9	Gang Kgs. Mukti, Sungai Pangeran	30 cm
10	Jl. POM IX, Lorok Pakjo	50 cm
11	Jl. Politeknik, Ilir Barat I, Kota Palembang	25 cm
12	Jl. Sekip Bendung, 8 Ilir	25 cm
13	Jl. R. Sukamto, 20 Ilir D II	50 cm
14	lrg banten 4, Kel. 16 ulu, Kec. Seberang Ulu II	15 cm
15	Jalan KH.Wahid Hasyim, Kel. 2 ulu, Kec. Seberang ulu 1	20-30 cm
16	Jl. KH Azhari 12 Ulu Seberang Ulu 2	40 cm
17	Jalan Swakarsa, Kel. Kemang Agung, Kec. Kertapati	15-20 cm
18	Jalan Mahameru Kec SU II Kel 16 Ulu	12 cm
19	Jalan Jaya VI Kec SU II Kel 16 Ulu	10 cm
20	Jalan Jendral Ahmad Yani	40 cm
21	Jl.Ki Anwar Mangku Lr.Nasional RT.45 RW.16 NO.19A Kel.Plaju Ulu Kec.Plaju	20 cm
22	Jalan A Yani, Lrg antara, Kel. 7 ulu, Kec. Seberang Ulu I	10 cm
23	Jalan kimarogan Lorong Wijaya Kel. Kemang Agung, Kec. Kertapati, Palembang	5-10 cm

HEC-RAS simulation results were used to inform ArcGIS reclassification, in accordance with Ministry of PUPR Regulation No. 12/2014. The flood map obtained is shown in Figure 7 and Figure 8.

Flood location data from field surveys were overlaid with flood maps to ensure compliance with simulation results.

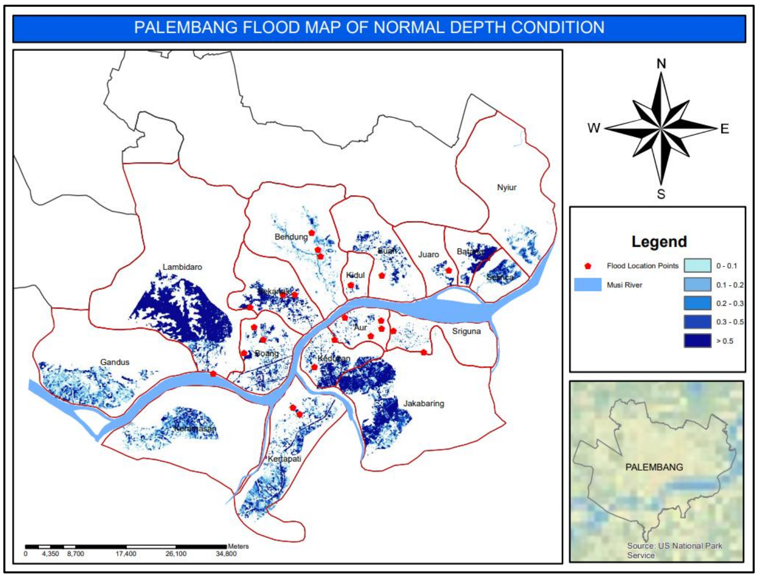

Fig. 7. Palembang flood map of normal depth condition

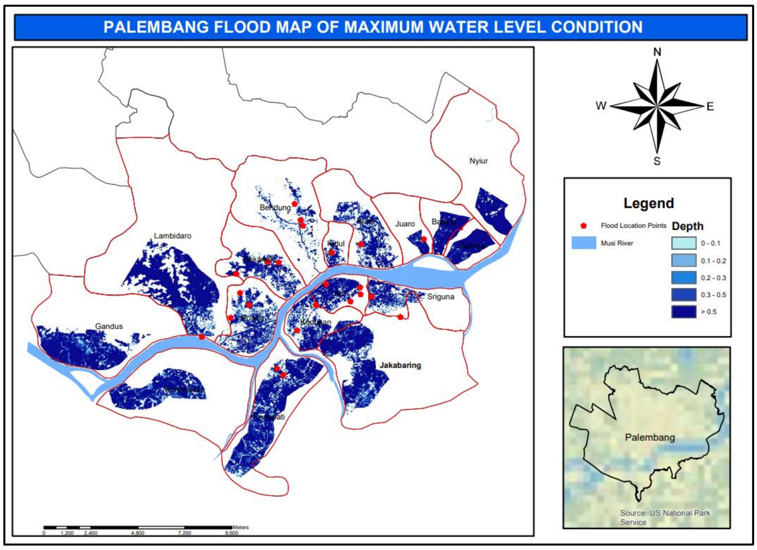

Fig. 8. Palembang flood map of maximum water level condition

Table 9 shows average inundation height and affected area for both normal depth and maximum water level conditions.

Table 9
Average height and area of flood inundation

No.	Watershed	Average flood depth for normal condition (m)	Flood area (Ha)	Average flood depth for maximum water level condition (m)	Flood area (Ha)
1	Gandus	0,26	347,41	0,70	629,88
2	Lambidaro	2,09	721,53	2,25	837,92
3	Sekanak	0,82	126,95	1,08	217,87
4	Boang	0,61	113,04	0,81	317,99
5	Bendung	0,70	108.08	0,70	108.08
6	Kidul	0,54	7,04	1,01	48,69
7	Buah	0,48	77,81	0,99	268,42
8	Juaro	0,52	17,81	1,65	57,96
9	Batang	1,06	99,73	2,76	189,44
10	Selinca	0,35	90,38	3,21	209,36
11	Nyiur	0,24	67,67	3,17	213,96
12	Aur	0.48	19.74	1.2	196.92
13	Sriguna	0.26	10.53	0.94	168.25
14	Kedukan	0.68	127.03	0.94	221.92
15	Keramasan	0.3	255.68	0.69	500.42
16	Kertapati	0.34	333.18	0.81	805.93
17	Jakabaring	0.69	548.36	0.93	658.77

4. Conclusions

After conducting hydrological analysis, each watershed has a different design discharge for a specific return period. For the Gandus watershed, the design discharge during a 10-year return period is 53,822 m^3/s. In the Lambidaro watershed, the design discharge for the same return period is 191.98 m^3/s. Meanwhile, the Sekanak watershed has a design discharge of 33,816 m^3/s, the Boang watershed has 22,731 m^3/s and the Bendung watershed has 74,573 m^3/s. The Kidul watershed has a design discharge of 4,190 m^3/s for a 5-year return period, while the Buah watershed has 45,444 m^3/s for a 10-year return period. The Juaro watershed has 10,255 m^3/s for a 10-year return period and the Batang watershed has 11,098 m^3/s for a 5-year return period. The Selinca watershed has a design discharge of 10,244 m^3/s for a 5-year return period. Lastly, the Nyiur watershed has a design discharge of 44,927 m^3/s for a 10-year return period.

The Gandus watershed experiences an average flood depth of 0.70 meters, which covers 629.88 hectares. Meanwhile, the Lambidaro watershed has an average flood depth of 2.25 meters, with an inundation area of 837.92 hectares. The Sekanak watershed sees an average flood depth of 1.08 meters, covering 217.87 hectares. The Boang watershed has an average flood depth of 0.81 meters, affecting 317.99 hectares. The Bendung watershed has an average flood depth of 0.70 meters, flooding an area of 108.08 hectares. The Kidul watershed experiences an average flood depth of 1.01 meters, covering 48.69 hectares. For the Buah watershed, the average flood depth is 0.99 meters, with an area of 268.42 hectares. The Juaro watershed has an average flood depth of 1.65 meters, covering 57.96 hectares. The Batang watershed experiences an average flood depth of 2.76 meters, with an inundation area of 189.44 hectares. The Selinca watershed flood depth of 3.21 meters, covering 209.36 hectares. Finally, the Nyiur watershed experiences an average flood depth of 3.17 meters, covering 213.96 hectares.

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References
[1] Avand, Mohammadtaghi, Alban Kuriqi, Majid Khazaei and Omid Ghorbanzadeh. "DEM resolution effects on machine learning performance for flood probability mapping." *Journal of Hydro-Environment Research* 40 (2022): 1-16. https://doi.org/10.1016/j.jher.2021.10.002
[2] Sadhwani, Kashish and T. I. Eldho. "Assessing the vulnerability of water balance to climate change at river basin scale in humid tropics: Implications for a sustainable water future." *Sustainability* 15, no. 11 (2023): 9135. https://doi.org/10.3390/su15119135
[3] Sethu, Vasanthi, Peck Loo Kiew, Swee Pin Yeap and Lian See Tan. "Time to Get Serious about Sustainable Water Management." *Progress in Energy and Environment* (2020): 13-15.
[4] Feng, Boyu, Ying Zhang and Robin Bourke. "Urbanization impacts on flood risks based on urban growth data and coupled flood models." *Natural Hazards* 106, no. 1 (2021): 613-627. https://doi.org/10.1007/s11069-020-04480-0
[5] Rubinato, Matteo andrew Nichols, Yong Peng, Jian-min Zhang, Craig Lashford, Yan-peng Cai, Peng-zhi Lin and Simon Tait. "Urban and river flooding: Comparison of flood risk management approaches in the UK and China and an assessment of future knowledge needs." *Water science and engineering* 12, no. 4 (2019): 274-283. https://doi.org/10.1016/j.wse.2019.12.004
[6] Piazza, Paola and Nadia Ursino. "On the reason to implement a sustainable urban drainage nature-based solution to decrease flood threat: A survey." *Sustainability* 15, no. 12 (2023): 9798. https://doi.org/10.3390/su15129798
[7] Chen, Yu and Jacopo Gaspari. "Exploring an Integrated System for Urban Stormwater Management: A Systematic Literature Review of Solutions at Building and District Scales." *Sustainability* 15, no. 13 (2023): 9984. https://doi.org/10.3390/su15139984
[8] Fernandez, Helena Maria, Fernando Granja-Martins, Olga Dziuba, David AB Pereira and Jorge MGP Isidoro. "Comparison of ratioing and RCNA methods in the detection of flooded areas using Sentinel 2 Imagery (case study: Tulun, Russia)." *Sustainability* 15, no. 13 (2023): 10233. https://doi.org/10.3390/su151310233
[9] Antzoulatos, Gerasimos, Ioannis-Omiros Kouloglou, Marios Bakratsas, Anastasia Moumtzidou, Ilias Gialampoukidis, Anastasios Karakostas, Francesca Lombardo *et al.,* "Flood hazard and risk mapping by applying an explainable machine learning framework using satellite imagery and GIS data." *Sustainability* 14, no. 6 (2022): 3251. https://doi.org/10.3390/su14063251
[10] Kasiman, Erwan Hafizi. "Flood Mitigation for Sungai Pinji, Ulu Kinta, Perak Using HEC-HMS and HEC-RAS Model." *Frontiers in Water and Environment* 2, no. 1 (2024): 10-27.
[11] Uyeno, Marcio Takashi, Lucas Gabriel de Souza Bairros, Juliana Azoia Lukiantchuki, Cristhiane Michiko Passos Okawa and Sandro Rogerio Lautenschlager. "Introducing an Innovative Design Approach for Drainage Systems: Facilitating Shallow Aquifer Recharge and Mitigating Flooding." *Sustainability* 15, no. 18 (2023): 13584. https://doi.org/10.3390/su151813584
[12] Ghosh, Supriya, Soumik Saha and Biswajit Bera. "Flood susceptibility zonation using advanced ensemble machine learning models within Himalayan foreland basin." *Natural Hazards Research* 2, no. 4 (2022): 363-374. https://doi.org/10.1016/j.nhres.2022.06.003
[13] Swain, Kishore Chandra, Chiranjit Singha and Laxmikanta Nayak. "Flood susceptibility mapping through the GIS-AHP technique using the cloud." *ISPRS International Journal of Geo-Information* 9, no. 12 (2020): 720. https://doi.org/10.3390/ijgi9120720
[14] Loumi, Kahina and Ali Redjem. "Integration of GIS and Hierarchical Multi-Criteria Analysis for Mapping Flood Vulnerability: The Case Study of M'sila, Algeria." *Engineering, Technology & Applied Science Research* 11, no. 4 (2021): 7381-7385. https://doi.org/10.48084/etasr.4266
[15] Isia, Ismallianto, Tony Hadibarata, Muhammad Noor Hazwan Jusoh, Rajib Kumar Bhattacharjya, Noor Fifinatasha Shahedan, Norma Latif Fitriyani and Muhammad Syafrudin. "Identifying Factors to Develop and Validate Social Vulnerability to Floods in Malaysia: A Systematic Review Study." *Sustainability* 15, no. 17 (2023): 12729. https://doi.org/10.3390/su151712729
[16] Patel, M. B. "Flood frequency analysis using Gumbel distribution method at Garudeshwar Weir, Narmada Basin." *Int. J. Trend Res. Dev* 7, no. 1 (2020): 36-38.

[17] Takeleb, Aderita Mariana, Qonaah Rizqi Fajriani and Miguel Antonio Ximenes. "Determination of Rainfall Intensity Formula and Intensity Duration Frequency (IDF) Curve at the Quelicai Administrative Post, Timor Leste." *Timor-Leste Journal of Engineering and Science* 3 (2022): 1-10.

[18] Chalid, Abdul and Bagus Prasetya. "Utilization of a pond in East Jakarta for a sustainable urban drainage system model." In *IOP conference series: Earth and environmental science*, vol. 437, no. 1, p. 012018. IOP Publishing, 2020. https://doi.org/10.1088/1755-1315/437/1/012018

[19] Sejati, Wahyu, Dina Paramitha AH, Fathya Khansa, Aryo Setyo Maulana and Dwi Julianingsih. "Flood disaster mitigation using the hec-ras application to determine river water levels in the old city area of jakarta." *Aptisi Transactions on Technopreneurship (ATT)* 4, no. 2 (2022): 121-134. https://doi.org/10.34306/att.v4i2.253

[20] Ghadai, Madhusmita, Deba Prakash Satapathy and M. Narashimham. "Analysis of hydrodynamic behaviour of brahmani river using hec-ras." *Technology (IJARET)* 11, no. 8 (2020): 490-499.

[21] Pandey, Smita, A. D. Rao and Raktim Haldar. "Modeling of coastal inundation in response to a tropical cyclone using a coupled hydraulic HEC-RAS and ADCIRC model." *Journal of Geophysical Research: Oceans* 126, no. 7 (2021): e2020JC016810. https://doi.org/10.1029/2020JC016810

[22] Tang, Wenwu, Heidi S. Hearne, Zachery Slocum and Tianyang Chen. "GIS-Based Scientific Workflows for Automated Spatially Driven Sea Level Rise Modeling." *Sustainability* 15, no. 17 (2023): 12704. https://doi.org/10.3390/su151712704