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Charlotte de Fraiture
Department of Land and Water Development, Water Science and Engineering, UNESCO IHE, Westvest 7 2611 AX Delft, The Netherlands

Robiyanto Hendro Susanto
Integrated River Lowland Coastal Development Management and Planning, Double Degree Program Pengelolaan Lingkungan, Universitas Sriwijaya, Palembang 30139, Indonesia

F.X. Suryadi
Department of Land and Water Development, Water Science and Engineering, UNESCO IHE, Westvest 7 2611 AX Delft, The Netherlands

Harrini Mutiara Hapsari Wahyu
Department of Architecture Engineering, Faculty of Engineering, Universitas Sriwijaya, Palembang 30128, Indonesia, harrinihapsari@gmail.com

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Urban Drainage Management and Flood Control Improvement Using the Duflow Case Study: Aur Sub Catchment, Palembang, South Sumatra, Indonesia

Charlotte de Fraiture[1], Robiyanto Hendro Susanto[2], F.X. Suryadi[1],
and Harrini Mutiara Hapsari Wahyu[3*]

1. Department of Land and Water Development, Water Science and Engineering, UNESCO IHE, Westvest 7 2611 AX Delft, The Netherlands
2. Integrated River Lowland Coastal Development Management and Planning, Double Degree Program Pengelolaan Lingkungan, Universitas Sriwijaya, Palembang 30139, Indonesia
3. Department of Architecture Engineering, Faculty of Engineering, Universitas Sriwijaya, Palembang 30128, Indonesia

[*]*e-mail: harrinihapsari@gmail.com*

Abstract

Urban flooding often times staggers the livelihood in an urban area, which most likely happens in the lowland urban area. Therefore, the existing urban drainage system should be improved in order to tackle the upcoming urban flooding events, which are more than likely to be more devastating than those in the previous years. The research location is in Palembang, Sumatra, Indonesia, where 30% of its urban part is a lowland area. The selected Aur Sub Catchment is located in Silaberanti. The main objective of this research is to improve the current drainage system in order to achieve the optimal design for urban drainage arrangement. This research was developed using Duflow Modelling Studio 3.8.3 in collaboration with ArcGIS 10.1 to schematize the drainage system and analyse the spatial and topographical condition of the research area. As a result, there are three development scenarios established by Duflow Modelling Studio in order to improve the drainage system in the research area. The first scenario is the current and extreme condition in the study area. The second scenario is the extreme condition, which is represented by the extreme rainfall. The third scenario is the improvement possibilities of the existing drainage system. There are three different types of improvements and modifications for the third scenario which are: canal dredging, canal dike/embankment, a pump installation, and a flap gate installation. In conclusion, based on three different scenario analyses, the most feasible, suitable, effective, and efficient alternative for overcoming the flooding in Silaberanti is a flap gate installation combined with dike construction in the flood risk sections of the river because it works automatically depending on the water level in the River.

Abstrak

Pengelolaan Drainase Daerah Perkotaan dan Perbaikan Pengendalian Banjir Menggunakan Studi Kasus *Duflow*: Sub-Daerah Tangkapan Air Aur, Palembang, Sumatra Selatan, Indonesia. Banjir di daerah perkotaan sering kali mengganggu laju penghidupan di daerah perkotaan, dan cenderung terjadi di daerah perkotaan dengan dataran rendah. Oleh karena itu, sistem drainase perkotaan yang ada harus ditingkatkan kualitasnya untuk mengatasi kejadian banjir perkotaan yang akan datang, yang kemungkinan besar efeknya akan lebih buruk daripada di tahun-tahun sebelumnya. Lokasi penelitian makalah ini adalah Palembang, Sumatra, Indonesia, dimana 30% daerah perkotaannya terdiri dari daerah dataran rendah. Sub-daerah tangkapan air Aur yang dipilih terletak di Silaberanti. Tujuan utama dari penelitian ini adalah untuk memperbaiki sistem drainase yang ada agar dapat mencapai desain optimal untuk pengaturan drainase perkotaan. Penelitian ini dikembangkan dengan menggunakan Duflow Modeling Studio 3.8.3 dan ArcGIS 10.1 untuk merancang sistem drainase dan menganalisis kondisi spasial dan topografi kawasan penelitian. Sebagai hasilnya, ada tiga skenario pembangunan yang dibuat oleh Duflow Modeling Studio untuk memperbaiki sistem drainase di daerah penelitian. Skenario pertama adalah kondisi saat ini dan kondisi ekstrem di wilayah studi. Skenario kedua adalah kondisi ekstrem, yang diwakili oleh curah hujan yang sangat tinggi. Skenario ketiga adalah kemungkinan perbaikan sistem drainase yang ada. Ada tiga jenis perbaikan dan modifikasi untuk skenario ketiga, yaitu: pengerukan kanal, konstruksi tanggul kanal, instalasi pompa, dan instalasi pintu *flap*. Makalah ini menyimpulkan, berdasarkan tiga analisis skenario yang berbeda, bahwa alternatif yang paling layak, cocok, efektif, dan efisien untuk mengatasi banjir di Silaberanti adalah instalasi pintu *flap* yang digabungkan dengan konstruksi tanggul di bagian-bagian sungai yang berisiko banjir karena pintu *flap* dapat bekerja secara otomatis tergantung pada permukaan air sungai.

Keywords: DUFLOW, drainage system, inundation, urban drainage, urban flooding

1. Introduction

Palembang is situated in the lowland area in the southern part of Sumatra Island. A large river, called The Musi River, divides Palembang into two areas; Seberang Ilir and Seberang Ulu. The city has been growing rapidly in the past decade due to transmigration and urbanization. Most of the trans-migrants come from outside of South Sumatra as well as the rural residents who moved to the urban areas. Currently, the total population of Palembang is about 1.7 million people with a population density of 4,800 people per km2.

Palembang has a total area of 40,610 ha, whereas 11,750 ha is the lowland area. It can be argued that approximately 30% of the total area of Palembang is relatively flat (Figure 1). As a result of being located in the relatively flat area where the large river flows, flooding is one of many problems that this city has often faced. Flooding in the urban areas of Palembang happens once a year, especially during the rainy season in the period of October to April.

There are several factors that lead to the problem of urban flooding in Palembang. First is the change of land use/which has led to a decrease in areas of green open space, catchment area, and the swamp area. It is becoming a big problem during the rainy and high tide seasons. Because the capacity of the catchment area for restoring water has decreased, inundation happens. Moreover, land use changes in the upstream part lead to the accumulation of sediments in the downstream. Furthermore, there are some buildings, which are mainly for settlement, situated in some parts of the body of the river. These buildings are adversely affecting the drainage system in their ability to carry water.

Secondly, urban drainage condition in this area is still suffering from a lack of maintenance. The current condition of the system is not working well enough for tackling and maintaining the drainage for the whole area. Even though the drainage systems in some parts of Palembang are already adequate enough, they are not yet integrated. That condition means that the overall urban drainage system in Palembang is not working as expected. However, it is also common to see the physical damage of drainage structure in some parts of Palembang area due to the lack of regular maintenance.

Thirdly, human activities, such as littering the river with either solid or liquid waste, is very harmful to the water flow. Some people still lack the awareness about the

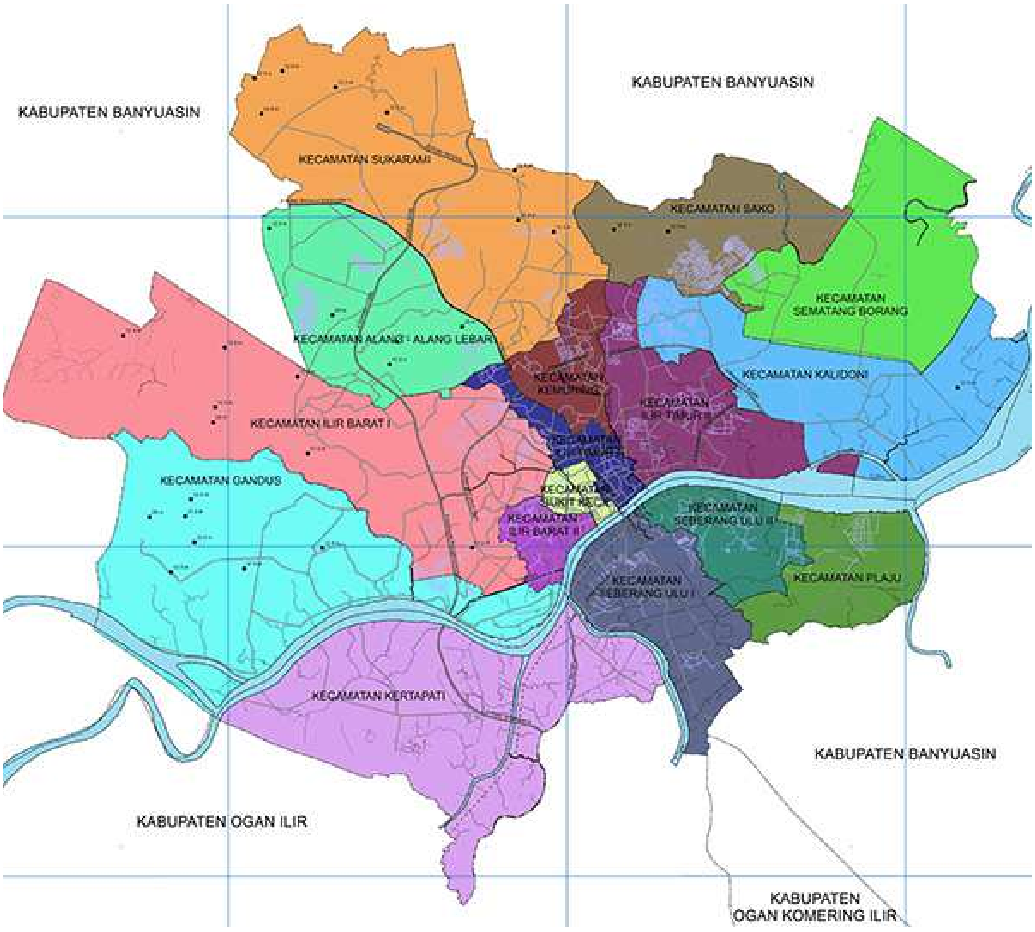

Figure 1. Map of Palembang

damage of waste disposal. For example, some households still throw their disposal directly to the river, and some industries throw their industrial waste to the river without being previously treated. The existence of solid waste in the body of the river decreases its capacity to carry water and, eventually, will cause inundation in the surrounding area.

This research aims to study about the drainage system in Palembang city, particularly in the District of Seberang Ulu I area where this study was carried out. This integrated study of urban water management and flood protection is crucial for supporting further drainage system development and improvement in Palembang City.

2. Materials and Methods

There were four main steps taken to achieve the objectives of the research: Preliminary Stage, Data Acquisition and Collection Stage, Data Analysis, and Modelling Development. The methodology of this study is shown in Figure 2.

There were two key steps during the preliminary stage which were essential for the following steps. Those steps were the arrangement phase for the field survey and the literature review for the fundamental theory to deepen the knowledge and information about the research.

The arrangement for the field survey was done as the guide for the data collection in the field. In this stage, the schedule for data acquisition had been arranged. For instance, what kind of essential field data that was needed for this study, what kind of measurement that needed to be done, how to get the data in the field, and the estimated time to know how long the data would be completely developed.

The literature review examines the urban drainage, urban flooding, urban polder system, and modelling develo-pment for the study. This stage was done at the same time with the filed survey arrangement. Any activities during the field work were done based on the understanding from the literature review.

Modelling systems used for this study were ArcGIS and DUFLOW. ArcGIS was used for analysing the spatial data. Meanwhile, DUFLOW was used for the simulation of the suitable scenarios derived from the hydrological data of the study area. In addition, supplementary reading was essential for supporting the basic theory that had been developed from the literature review. Supplementary reading included the revision from the previous MSc theses, journals publications, books, articles, and more.

In the data acquisition phase, there were several types of data that had to be collected. Those data could be categorized into three different types: Primary Data, Secondary Data, and Additional Data. The description about the data and the source of the data are shown in Table 1.

In this study, ArcGIS and Duflow (Dutch Flow) were used in combination to produce the final result of the integrated design for the improvement of the urban drainage system in Silaberanti area. However, the liability of the available data and the competency of the model play an important role in running and simulating the scenario which is going to be developed.

First of all, the catchment delineation process was done for interpreting the sub catchment of the study area with ArcGIS. Catchment delineation analysis was processed with the hydrology tools in the spatial analyst. When the delineated catchment was derived from the analysis, the next steps to do were analysing and interpreting the results. In these steps, the most crucial part was the stream link order and the sub catchment for the stream which was represented the study area. Second of all, the topographical analysis was done with ArcGIS.

Duflow is a computer program to model steady-state and transient surface water systems (STOWA, 2000). Duflow consists of a one-dimensional network which is inter-connected with nodes and sections. Hydraulic structures can be added in the network to get to know the hydraulic performance, such as pump, weir, gate, etc. Specifically for this research, one of the main problems of flooding in this area is the lack of maintenance of drainage infra-structure and solid waste disposal. The scenarios which were based on the analysis were divided into three parts: widening the canals, dredging the canals, and the installation of hydraulic structures. The flowchart of ArcGIS and Duflow is presented in Figure 3.

Table 1. Sources and Detail for Data Acquisition

Type	Detail	Source
Primary Data	Hydraulic Data	In situ field measurement
Secondary Data	Spatial Data Hydrological Data Tidal Fluctua-tion Data USGS Data for GIS Modelling	Urban Planning and Development Board Meteorology, Climato-logy, and Geo-physics Agency of Palembang City in Kenten Class I Observation Station Indonesia Navy http://earthexplorer.usgs.gov/
Additional Data	Interview Discussion	In situ interview

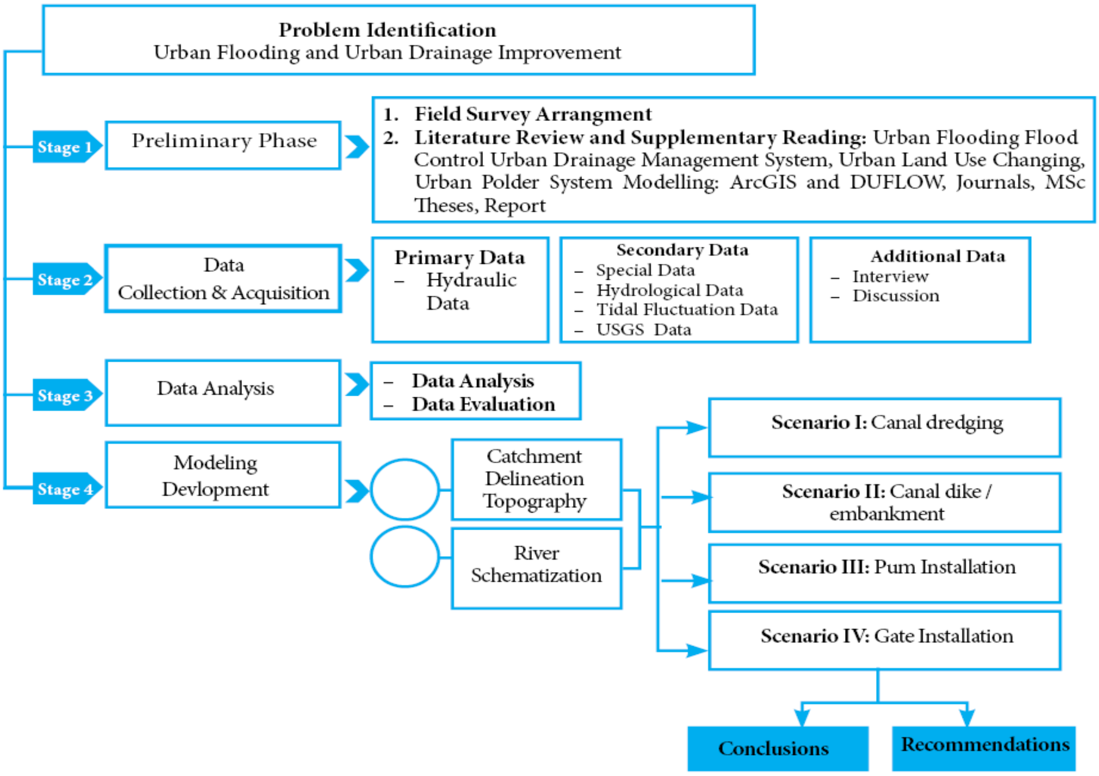

Figure 2. Research Methodology Flowchart

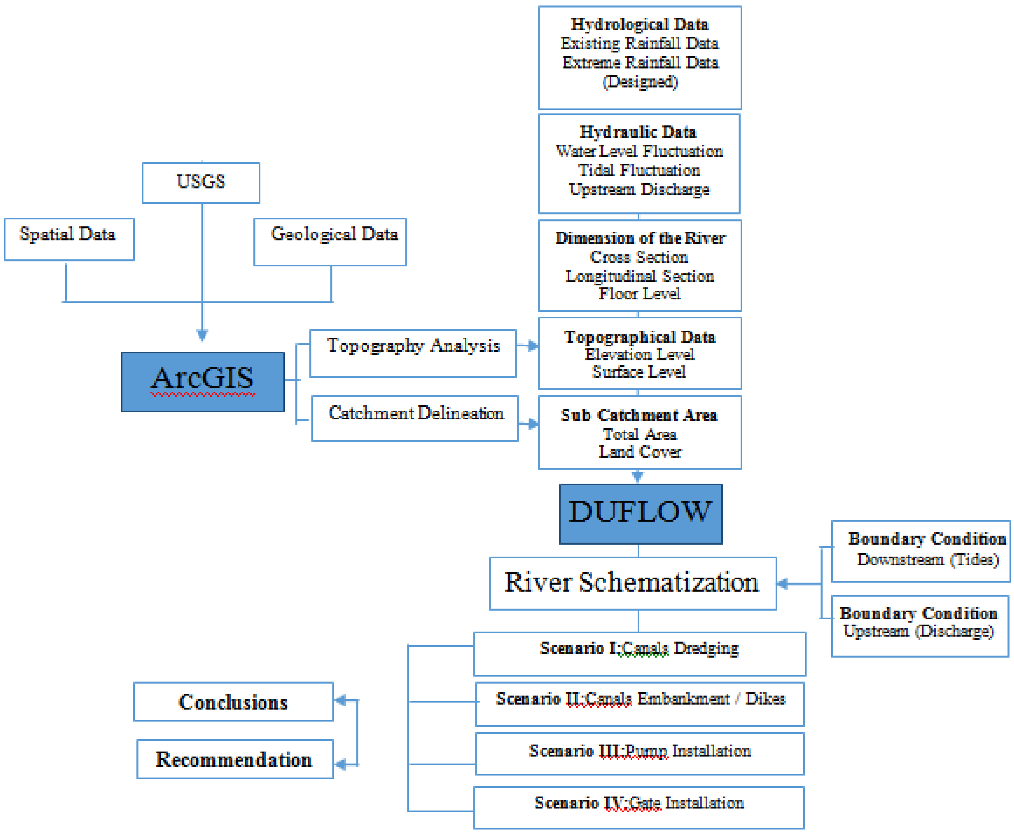

Figure 3. Flowchart of ArcGIS and DUFLOW Modelling Development

3. Results and Discussion

Spatial Data Analysis: Catchment Delineation and Topography Analysis. The main aim of catchment delineation is to determine the exact area of the watershed for the study area including the sub watersheds which surround it. There were several steps for delineating the catchment using the spatial analyst tool in ArcGIS. First of all, the DEM Data which had been retrieved online from the USGS website needed to be prepared in the ArcMap. Then, the raster image, which had been projected, was evaluated with several tools in the hydrology tools from spatial analysts, such as flow direction, sink, fill, flow accumulation, stream link, stream order, stream to feature, basin, snap pour point, basin, and watershed. The result of catchment delineation surrounding the study area is represented in Figure 4.

Figure 4 shows the specific sub catchment for the research study. This map was derived by determining the stream link of the Aur River as the area of study. As a result, the sub catchment of the Aur River in detail can be determined from the map of the catchment surrounding the research area. Meanwhile, Figure 5 shows the stream link of the research area which is indicated by the blue line. The stream link represents the river to be developed in advance for this research. This stream link represents the condition of the Aur River, which is the study area for the main river studied in this research.

Topography analysis determined the height of the study area above the mean sea level. In general, Palembang lies in the low contour zone, approximately 0–8 m above the mean sea level. In the topography analysis, the divisions of the contour line for each district in Palembang will be determined. Digital elevation model (DEM) was used for the topography analysis of this research. By using the SRTM data, which havd previously been analysed for the catchment delineation, the topographical condition of Palembang could be determined.

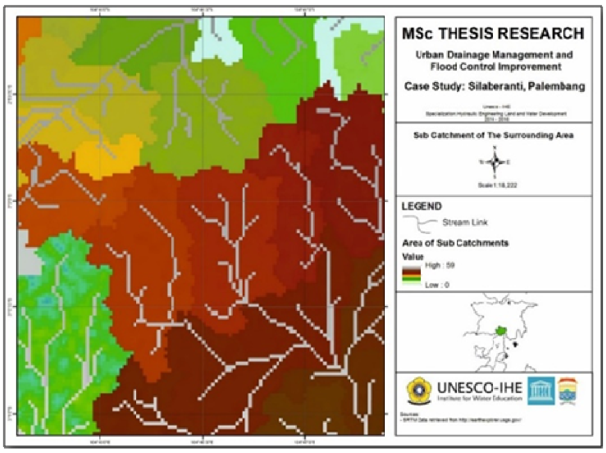

Figure 4. Map of Catchments Surrounding the Research Area

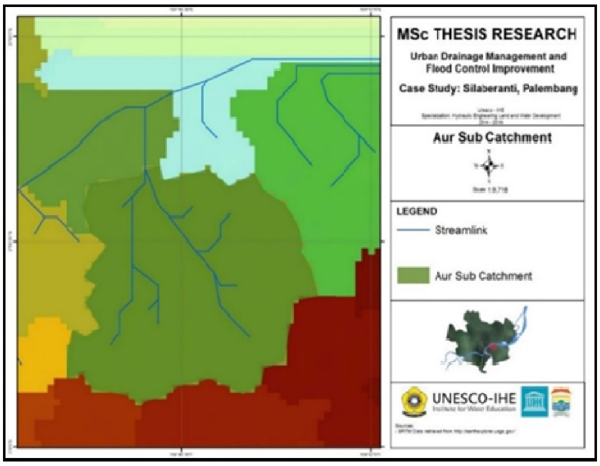

Figure 5. Aur Sub Catchment

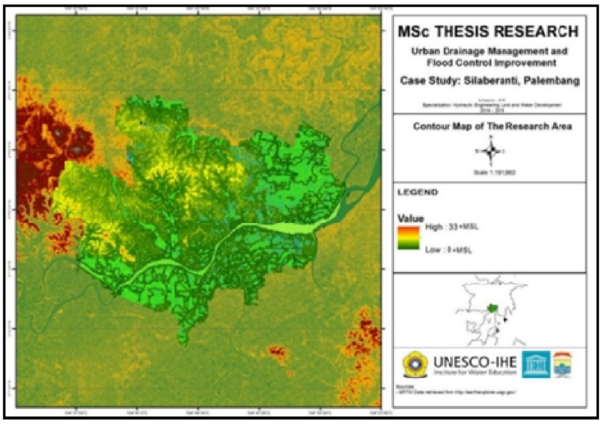

Figure 6. Contour Map of Palembang

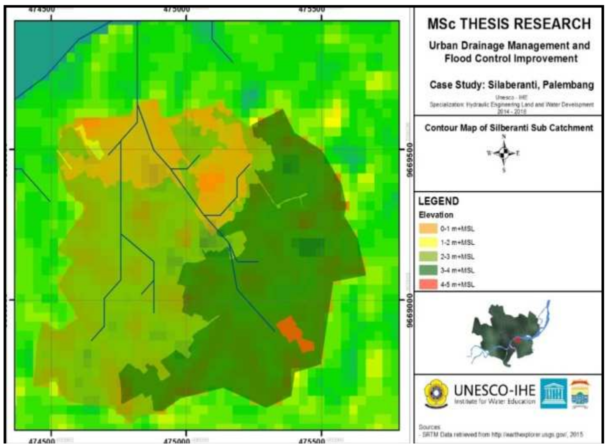

Figure 7. Contour Map of Aur Sub Catchment

The contour interval of 10 m was chosen for this analysis in order to define the contours with greater detail and accuratey. The result of the topographical analysis of Palembang is shown in Figure 6.

The highest elevations, indicated with the yellow colour, are mostly located in the North-West area of Palembang. On the other hand, the lowest elevations, specified with the green colour, are located in the Southern and Eastern parts of the urban area. Furthermore, the specific contour map of the research area of Silaberanti sub district or Aur sub catchment can be determined from the contour map of Palembang city by clipping the map with the shapefile of the sub catchment area. The result of the contour map for the study area is shown in Figure 7.

Silaberanti, which is the study area of the research, is located in the lower part of Palembang. It can be clearly seen that the range of topography elevation in Aur sub catchment is from 0 m+MSL to 5 m+MSL. The area which is closer to the stream has a lower elevation than the area which is located farther downstream. The descriptions for the elevation of the area in Silaberanti can be found in Table 2.

Hydrological Data Analysis: Rainfall Analysis. There were three general methods of the distribution analysis of the rainfall used in this research, namely Normal Distribution, Gumbel Type I Distribution, and Log-Pearson Type III Distribution. The comparison between those three methods for extreme rainfall prediction with the return period T is presented in Table 3.

Table 2. Elevation in Aur Sub Catchment

No	Elevation (m+MSL)	Total Area (ha)
1	0-1	0.12
2	1-2	15
3	2-3	39
4	3-4	40
5	4-5	1
	TOTAL	95.12

Table 3. Probability Distribution of Normal, Gumbel Type I, and Log Pearson Type III for Design Rainfall

Return Period/ Tr (Years)	Frequency Analyses for Design Rainfall (mm)					
	Normal Distribution		Gumbel Type I Distribution		Log Pearson Type III Distribution	
	K_{Tr}	X_T (mm)	Y_{Tr}	X_{Tr} (mm)	K_{Tr}	X_{Tr}(mm)
2	0.00	113.40	0.37	109.78	0.08	112.83
5	0.84	133.05	1.50	133.06	0.86	133.30
10	1.28	143.34	2.25	148.47	1.22	144.15
20	1.52	148.96	2.97	163.25	1.36	148.65
25	1.64	151.76	3.20	167.94	1.58	155.67
50	2.05	161.35	3.90	182.39	1.79	162.88
100	2.33	167.90	4.60	196.73	1.98	169.58

Furthermore, based on the value of the extreme rainfall prediction for each distribution, the goodness of fit test calculation is presented in Table 4.

Table 4. The Goodness of Fit Test: Smirnov – Kolmogorov

Number of Data (n)	Difference of Critical value		
	Normal Distribution	Gumbel Type I Distribution	Log Pearson Type III Distribution
1	14.68	-5.56	20.24
2	8.04	-6.25	14.30
3	-0.21	-9.66	9.44
4	-0.04	-5.17	5.13
5	-0.22	-4.60	4.38
6	0.52	-2.57	3.09
7	-1.52	-3.10	1.58
8	23.95	23.94	0.01
9	26.16	26.68	-0.52
10	27.93	29.16	-1.23
11	0.03	1.65	-1.62
12	-0.57	1.58	-2.14
13	-2.14	0.67	-2.81
14	0.03	2.45	-2.42
15	12.48	15.24	-2.76
16	1.95	5.15	-3.20
17	1.87	5.00	-3.13
18	2.00	5.18	-3.19
19	0.37	3.72	-3.36
20	-2.40	1.22	-3.62
21	-1.71	1.69	-3.40
22	-1.18	2.13	-3.31
23	-1.08	2.25	-3.33
24	-0.56	2.95	-3.51
25	4.69	8.35	-3.67
26	0.91	3.75	-2.84
27	0.21	2.95	-2.74
28	-0.24	2.56	-2.80
29	-0.91	2.00	-2.90
30	-0.73	1.46	-2.19
31	-0.76	0.96	-1.72
32	0.24	1.52	-1.28
33	0.03	0.16	-0.13
34	1.65	0.90	0.75
35	1.12	-0.21	1.33
36	-0.66	-2.32	1.66
37	-15.58	-10.70	-4.88
38	-4.04	-8.71	4.67
39	0.79	-9.44	10.22
Max. Difference Δ_{max}	27.93	10.70	46.89
Critical value 5% Δ_0	23.75	35.58	25.50
Fit test correlation	rejected	accepted	rejected

From the table, we can conclude that the Gumbel Type I Distribution could be accepted, according to the lowest value of the maximum differences (Δmax). Therefore, the result of Gumbel Type I Distribution was used for the calculation of maximum daily rainfall with the return period T. The highest rainfall intensity was 202.8 mm/hour a return period of 100 years and duration of 5 minutes. On the other hand, the lowest rainfall intensity was 4.08 mm/hour with a return period of 2 years and duration of one day. The Intensity – Duration – Frequency (IDF) Curve based on the table above is presented in Figure 8.

Modelling Analysis: River Schematization. The schematization of the Aur River was done with the Duflow Modelling Studio which built up a channel network with 44 nodes and was connected with sections. The starting point of this schematization is in the downstream part, which is the Musi River (SEC MUSI 1, NOD1), and the ending point is the upstream part of the Aur River (SEC P27+11 – 00+1361B, NOD35). However, the Aur River starts where SEC P2 – 00+42A, NOD3 is situated, as shown in Figure 9.

Scenario 1: Existing Condition. For the existing condition, the simulation was affected by the tidal intrusion with the highest rainfall during the rainy season in 2015. The scenario of the existing condition used a one-day simulation. In this simulation, the data for tidal intrusion during that day functioned as the input as well as the rainfall data. Based on the rainfall data series, the rainfall during the day of the simulation was 28.75 mm/day for one hour. The simulation day was the day with the highest rainfall and tides during the wet season.

Scenario 2: Extreme Conditions. The extreme designed rainfall with the return periods of 25 years and 50 years was chosen for an extreme condition simulation. For the return period of 25 years, the designed rainfall was 98.58 mm/day for 60 minutes. Meanwhile, the designed rainfall for the return period of 50 years was 104.53 mm/day for 60 minutes. The water depth of flooding between NOD29 and NOD35 was approximately 0.40–0.86 m and after dredging it reduced to around 0.27–0.71 m. The water level during flooding after canal dredging could decrease by up to 0.14 m. However, the inundation still happened in the risky sections of the Aur River.

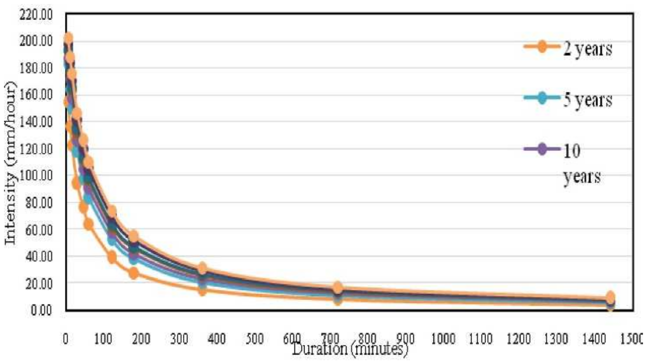

Figure 8. IDF (Intensity - Duration - Frequency) Curve from the Van Breen's Method

Figure 9. Aur River Schematization

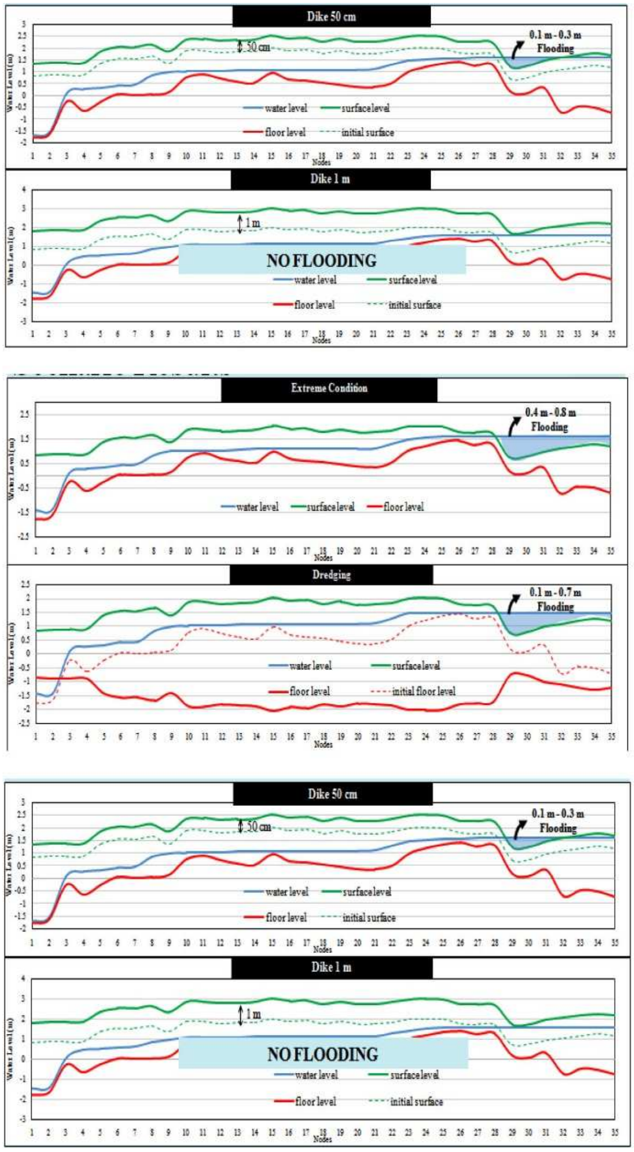

Figure 10. Result Comparison of the Analyses

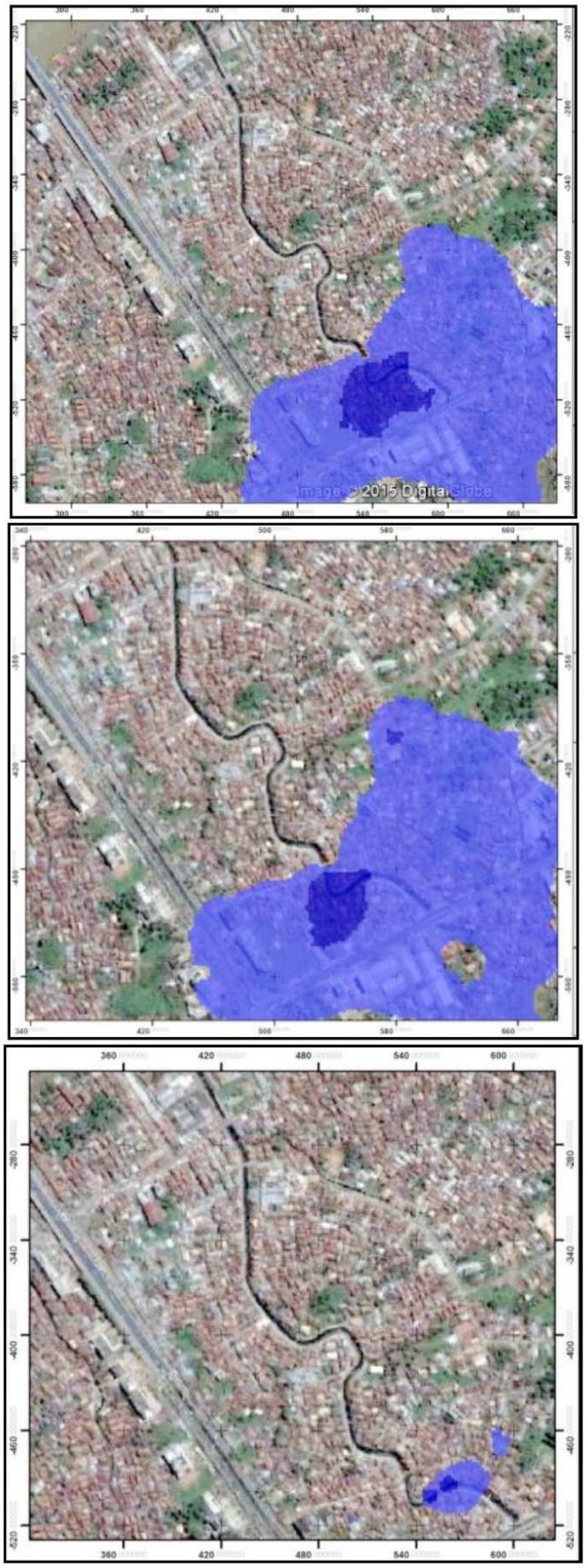

Figure 11. Comparison of the Flooding Areas

Scenario 3: Improvement Possibilities of the Existing Drainage System. For this scenario, 1 m dredging was applied for the whole system. Besides the dredging, the roughness coefficient of the canal increased by cleaning the disturbance of the water flow in the canal, such as solid waste and aquatic vegetation. Furthermore, building a dike along the canal could be one possible solution for protecting this area from flooding. Therefore, development of a dike was implemented for the scenario with the Duflow Modelling Studio. This scenario consists of two different types of dike construction for the system. Lastly, pumps could be used to control the water level in certain depressed areas of a channel to reduce the risk of inundation. For this scenario, a pump with a capacity of 12 m^3/s was installed in the downstream part of Aur River, where the water level was influenced by tidal fluctuation. The result comparison between those scenarios is shown in Figure 10 and Figure 11.

4. Conclusions and Recommendations

There are several conclusions drawn from the analyses and discussions for the improvement of the urban drainage system in Silaberanti, South Sumatra, Indonesia. These conclusions also answer the earlier research questions. The conclusions are as follows: (a) The main causes of flooding in Silaberanti area are from the tidal intrusion from the Musi River to the Aur River system, the high intensity of the rainfall during a wet season, the existing condition of the drainage system which is quite inadequate to accommodate the existing condition, the flat topographical condition of the research area, and the changes in land use due to urbanization; (b) The existing condition of urban drainage in Silaberanti is not well maintained and cannot prevent the problem of flooding in a proper way. There are a lot of solid waste disposal and aquatic vegetation in the canal which block the flow of water. In addition, the conveyance capacity and the dimension of the river are not appropriate for the drainage system in this area. Thus, the drainage system needs to be improved; (c) Technical approaches for coping with the flooding in Silaberanti area are going to be implemented based on the result of the modelling analysis. Technical approaches include canal dredging, canal dike/embankment, a pump installation, and a flap gate installation; (d) Canal dredging is not recommended for the urban drainage improvement in Silaberanti because it only reduces the water level during flooding by 0.1 m. Furthermore, the inundation in some stressed sections in Aur River is still likely to happen in the future; (e) Dike construction alongside the Aur River is one of the feasible possibilities. A 1 m dike construction can reduce the inundation rate during the flooding event, especially in the sections which are in the high flood risk area; (f) A pump installation provides a better result than the previous scenarios. After the installation of a pump with a capacity of 12 m^3/s in the downstream area of Aur River, the inundations in the risky sections disappeared. However, a pump installation requires a high cost for implementation and operation; (g) The most recommended drainage system improvement is a flap gate installation. It is the most feasible enhancement for the urban drainage system in this area. The considerations include the low cost, effectiveness, and efficiency of the implementation, operation, and maintenance; (h) Practical approaches, such as the implementation of the concept "Living with Water", can help the future development in Silaberanti. For example, by applying the construction of houses which are resilient for flooding condition, such as *Rumah Rakit* (Floating Houses) and *Rumah Panggung* (Elevated Houses). In addition, the revision of governmental urban policies needs to be taken into account for the upcoming improvement.

A number of recommendations can be derived from several analyses in this study for improving the urban drainage system in Silaberanti, which are: (a) The Ministry of Public Works of Palembang City should consider the future extreme condition for the improvement of the urban drainage system in Silaberanti. For instance, the urban drainage designs for 100 years return period should include a larger catchment area, climate change, sea level rise, and urban land use changes; (b) The Palembang City Government, particularly the Urban Planning and Development Board and Ministry of Public Works, should provide the actual and reliable data of the measured urban drainage system in Palembang so that it is not difficult to acquire the data when they are needed for another scientific research in the future; (c) Further systematic approaches, such as Cost Benefit Analysis and Cost Estimation Analysis, should be taken into account for further research. Cost Benefit analysis can be used to decide the most feasible project between several projects. Meanwhile, Cost Estimation Analysis aims to provide the budget estimations or a funding requirement of a project; (d) The Palembang City Government needs to be stricter in granting a permit for building settlement along the canal or river, specifically in Silaberanti area, in order to prevent illegal housing. Illegal housing causes land use to change from flood prone areas to residential areas and increase the rate of flooding.

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