FLOOD MITIGATION USING GIS AND HYDRAULIC MODELLING OF URBAN AGRICULTURE DISTRICTPULOKERTO

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Abstract

Pulokerto village in Gandus district which located 12 km from the city center of Palembang is being preapred for urban agriculture area. But unfortunately, since Musi River is bordering Pulokerto village this area is highly influenced by spring tides. Every year large areas of Pulokerto are waterlogged with a height of 1-2 meters of water. Rice planting season can currently only be done once in a year because of flooding problems during the rainy season still not resolved and no sufficient water management system to irrigate rice fields during the dry season. Given these problems, it is necessary to conduct research that aims to identify the source of the problem. Some proposed technical solutions that is considered effective to overcome the flooding problems were tested through hydraulic modelling using DUFLOW Modeling Studio (DMS) and spatial analysisusing Geographic Information System (GIS). Based on the result, the application of gates in all five rivers within the system can significantly reduce the flooding area but still cannot overcome the extreme events whenever the highest tidal fluctuation overtops the road that serve as an embankment. Elevation of the road is expected to completely solve the flood problem in Pulokerto by creating a closed system without any influence from tidal fluctuation of Musi River.

Keywords: flooding, hydraulic modelling, GIS, floodgates, embankments

INTRODUCTION

General Background

The concept of urban agriculture is currently very difficult to be implemented due to increasing rate of indutrialization and urbanization. Pulokerto village and Pulokerto island in Gandus district which currently located 12 km from the city center of Palembang is being prepared for urban agriculture. The basic concept of urban agriculture is based on integrated water resources management for agricultural development program.

But unfortunately, sinceMusi River is bordering Pulokerto village this area is highly influenced by spring tides. Every year large areas of Pulokerto are waterlogged with a height of 1-2 meters of water. This tidal flooding greatly influence the rice planting season, harvesting capacity, fishing activity and the daily activities of local people. During the rainy season starts from December to March agricultural activity can not be done and to earn a living, peopleof Pulokerto turned to fishing. Rice planting season can currently only be done once in a year because of flooding problems during the rainy season still not resolved and no sufficient water management system to irrigate rice fields during the dry season.

Based on these problems, it is necessary to conduct research that aims to identify the source of the problem, how much volume of surface runoffand determine the existing capacity of the drainage system. Previous study on this area has been conducted by Marlina Sylvia, 2009, but the analysis focused only in River Rengas and Lacak. This study takes into account all five rivers within the system Air Hitam, Rengas, Lacak, Danu, and Tenang in order to find flood mitigation measures from different perspective.

Some proposed technical solutionsthat is considered effective to overcome the flooding problems were tested through hydraulic modelling. DUFLOW Modeling Studio (DMS) and spatial analysis by Geographic Information System (GIS) are used for the analysis. GIS technology will be used to integrate spatial data, which is derived fromtopographical map, land use map, and the data hydrograph from DUFLOW will be visualized through various forms of spatial analysis.

DUFLOW System Modeling Studio

Duflow is based on the one-dimensional partial differential equation that describes non-stationary flow in open channels DUFLOW is designed to cover a large range of applications, such as propagation of tidal waves in estuaries, flood waves in rivers, design, operation and maintenance of irrigation/drainage system. Basically, free flow in open channel systems can be simulated, where control structures likes weirs, culverts, flap gates, pumping stations and siphons can be included (Stowa, 2002). In this study, DMS-component RAM the precipitation-runoff processes and DUFLOW water quantity are used. DUFLOW water quantity performs one dimensional unsteady flow computations in a network of open water course in terms of water levels, discharge and velocity and RAM precipitation runoff module which can calculate the supply of rainfall to surface flow. RAM calculates the losses and delays that occur before the precipitation reaches the surface flow.During the simulation, the water is driven by external influences which arise from the effect of the surrounding conditions of the modeled area. These effects are the boundary conditions of the model which describe, for example, the amount of water that flows into the model from adjoining river basins during the simulation, the tidal variation of sea levels at the point where a river discharges into the sea (Clemmens et al,. 1993)

GIS for Spatial Distribution of Flood Conditions

A GIS (Geographic Information System) is designed to accept geographic data from a variety of sources, including maps, satellite photographs, and printed text and statistics. In this study ArcGIS 10 is used to analyse spatial data to generate flooding map. ArcGIS is a system of parts that can be deployed on a single desktop ordistributed on a heterogeneous computer network of workstations and servers. ArcGIS consists of some application extension perform any GIS task, simple to advanced, including, including mapping, data management, geographic analysis, data editing and geo-processing (Environmental System Research Institute, 2001)

Methodology of Study

In general, the methodology applied in this research consists of several phases; literature review, data search, data acquisition, data analysis, modeling, result and discussion in comparative perspective and recommendations. The sequence of each phase is described in Figure 1.

Based on the situation and problem definition, data interpretation and analysis was performed using:

1) Rainfall data analysis (rainfall intensity computation and run-off calculation) was performed using standard statistical procedures as input for DUFLOW simulation model;
2) Modeling/simulation by DUFLOW 3.6 to simulate the existing flood management system; the flow parameter (Q and h) in the open water system and the boundary condition for system level and alternative scenarios in regard to extreme sea level rise for recommended future development.
3) Spatial Analyst extension from ArcGIS 10 is used to derive catchment area, interpolate contour map to make Digital Elevation Model, calculate specific landuse area and visualize the data hydrograph from DUFLOW to make flood distribution map.

TheDuflow modeling utilizes geometry data in each cross sections of river systems referred to existing dataand field survey in relation with existing hydraulic structures. The boundary conditions at the upstream ends are specified by computed discharge hydrograph based on the existing land use condition and measured rainfall. The boundary conditions on downstream ends are tidal fluctuation of Musi River. The schematization of all five river network systems using Duflow nodes and sections is described in Figure 2.

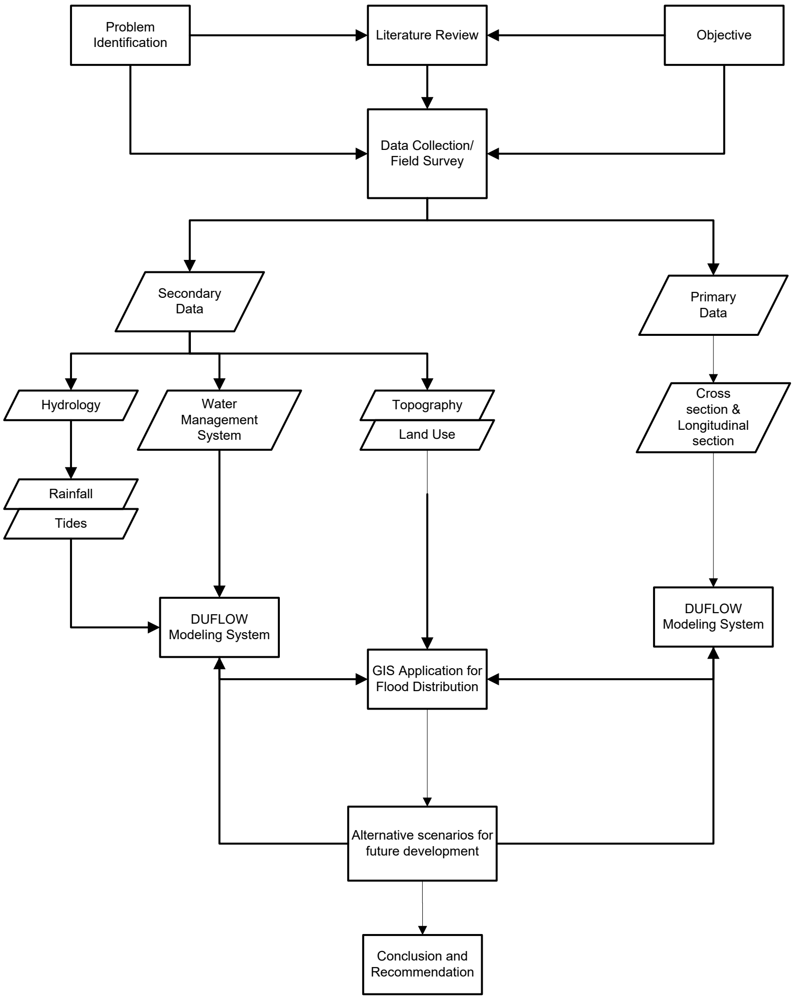

Figure 1. Research Methodology

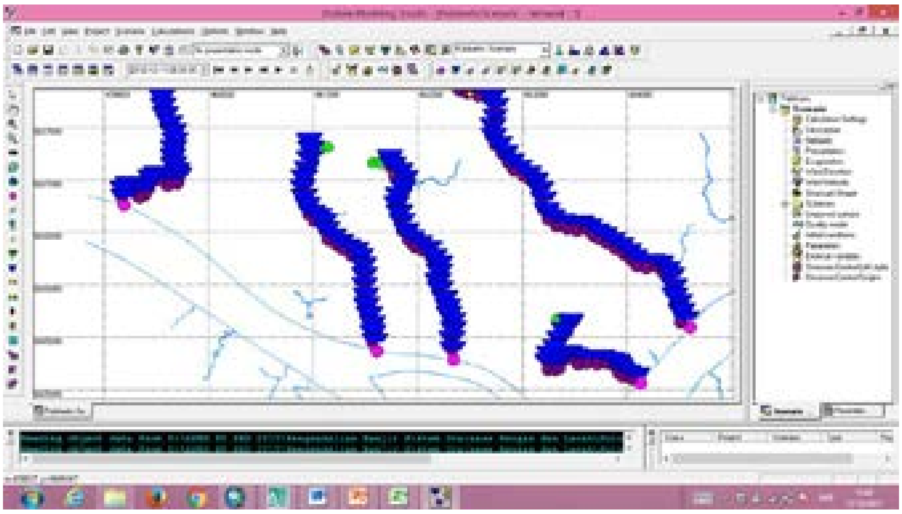

Figure2. Network system for hydraulic modeling using DUFLOW

RESULTS AND DISCUSSION

Time series data of rainfall were taken from Geophysics and Meteorological Institute (BMG) local weather stations in Kenten, Palembang. The annual maximum frequencies for 40 years from 1976-2015were used to calculate the return period. Intensity-duration frequency for the study area is shown in Figure3. Design rainfall of a 25-years return period is used as an input for rainfall-runoff module of DUFLOW model.

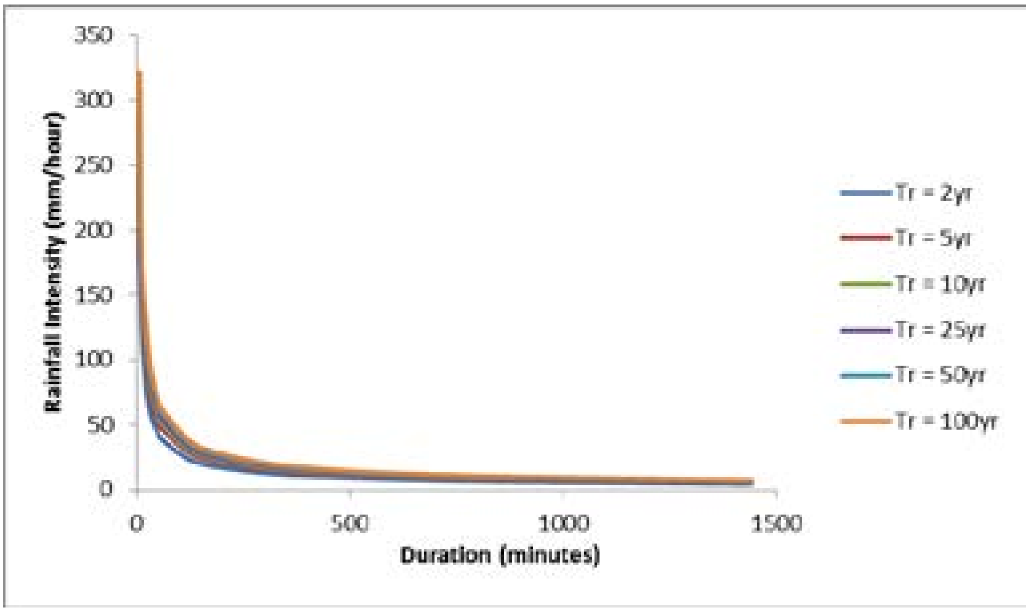

Figure 3. Intensity Duration Frequency for study area

Four scenarios have been simulated using DUFLOW for all five rivers in the system (Air Hitam, Rengas, Lacak, Danu, and Tenang) in order to determine the current situation and their individual responses during high tides. Water level fluctuation of Musi River was used as downstream boundary conditions and rainfall-runoff from the maximum rainfall intensity as upstream boundary condition. The four simulation scenarios are:

- The existing condition of study area in response of annual Musi River fluctuation;
- The existing condition of study area in response of extreme Musi River fluctuation;

- Flood mitigation scenario using gates in five rivers within the system;
- Flood mitigation scenario using combined scenario of gates and embankments (dikes).

In the graph of simulation results of existing conditions, water level in all five rivers is highly influenced by Musi River tidal fluctuations due to open system. High tide reaches two meters on the river mouth while further upstream the water level will be reduced due to the loss of energy.Simulation results of each scenarios from DUFLOW then interpolated and overlayed with topographical map using ArcGIS. The flood distribution map for existing condition is shown in Figure4.

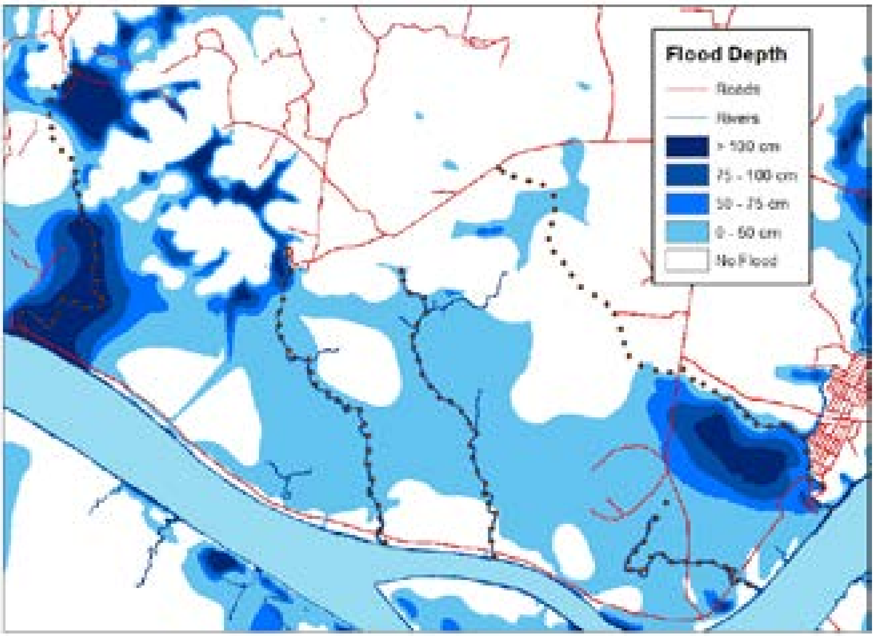

Figure 4. Flood map for existing condition

From the figure above shows that with the given boundary conditions and the condition of the existing primary channelcoupled with the tides fromMusiriver, then most of the agricultural land / paddy field is inundated especially during the rainy season. Simulation result for the existing condition of study area in response of extreme Musi River fluctuation is given in Figure 5.This condition is caused by the elevation of the highest tidal elevation exceeds the road which serves as anembankment (overtopping). However, the local community has been anticipating the arrival of the annual flooding by raising their houses up to 1,5 meters from the ground.

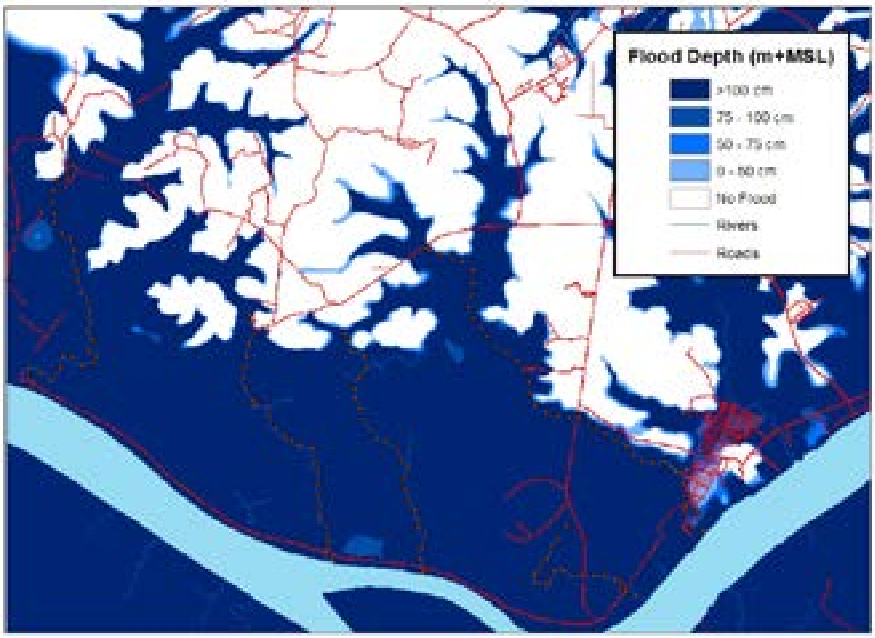

Figure 5. Flood map for extreme events

Next scenario is the recommended solution to reduce the extent of inundation in the area Pulokerto with the addition of the floodgates for the five rivers that affect water level in the area of study. With the closed system it will be easier to manage the water system and overall functioning as long storage. Modeling simulation results show that the addition of gates lead to differences in water level fluctuations in upstream and downstream systems. At the time of floodgate is closed, the water level fluctuations that affect upstream areas caused by rainfall runoff discharge will decrease automatically when the conditions in the downstream has stabilized. The flood distribution map of the third scenario (using floodgates) is given in Figure 6.

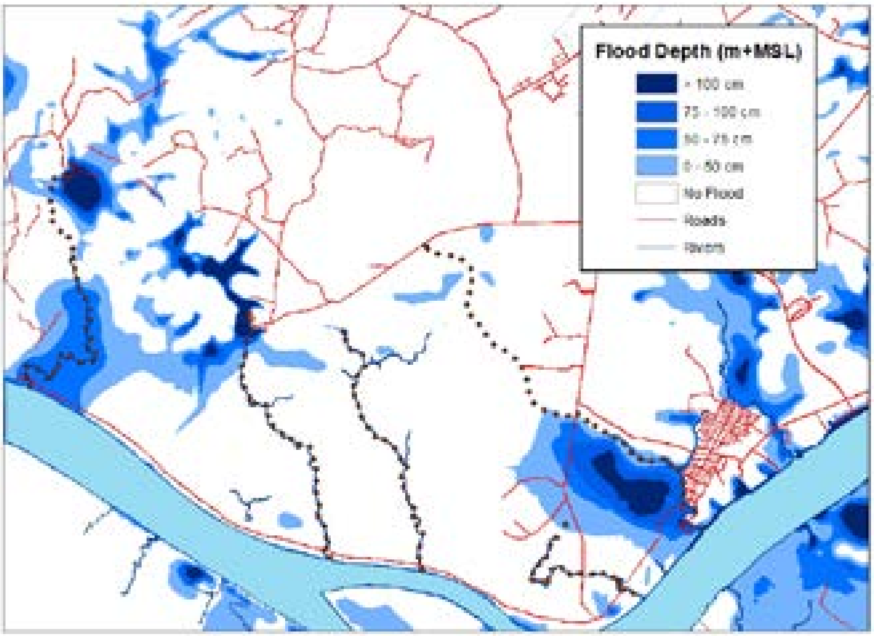

Figure 6. Flood map using gates in five rivers within the system

Based on the analysis of spatial data, it appears that the addition of floodgates can significantly reduce the inundated area but can not overcome tidal fluctuation overtops the embankment. The addition of floodgates can avoid the effect of high tides during the rainy season and maintain the level of ground water in order not receded during the dry season.The summary of flooding area for various flood mitigation scenarios based on the analysis of spatial data is given in Table 1.

Table 1. Flooding area for various flood mitigation scenarios.

Flood Depth	Flooding area (ha)		
	Existing	Extreme events	Gates
0-50 cm	662,5	101,4	297,5
50 – 75 cm	142,6	48,3	141,2
75 – 100 cm	95,5	72,6	65,6
>100 cm	109,9	974,7	76,8

Based on the result derived from spatial data analyses, with the given boundary condition and existing capacity, most of the agriculture area will be inundated. The application of gates in all five rivers within the system can significantly reduce the flooding area but still cannot overcome the extreme events whenever the highest tidal fluctuation overtops the road that serve as an embankment/dike. Elevation of the road is expected to completely solve the flood problem in Pulokerto (Figure 7) by creating a closed system without any influence from tidal fluctuation of Musi River.

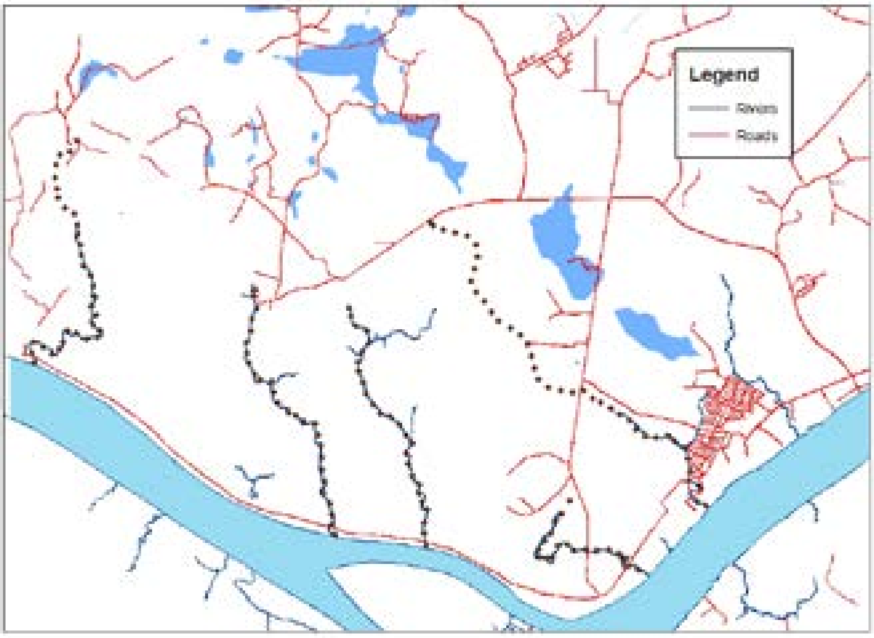

Figure 7. Flood map using combined scenario of gates and embankments (dikes)

CONCLUSION AND RECOMMENDATION

Four simulation scenarios that represent proposed technical solutions to overcome flooding problems in Pulokerto district have been tested through hydraulic modelling by DUFLOW Modeling Studio (DMS) and spatial analysis byArcGIS. Flooding area derived from applying flood elevation on every cross section into ArcGIS based calculated DEM showing that the construction of gates and embankments (dikes) may serve as optimum flood mitigation measures for the study area.

It is recommended that further coordination with other relevant agencies such as the Departments of Agriculture to regulate the availability of water for farming during the dry season.Technical measures on maximum tidal elevation, elevation of embankment/road, river discharge and non-technicalflood mitigation measures of economic feasibility should be accountedbefore construction.

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