EFFECT OF LANDUSE CHANGE ON URBAN DRAINAGE SYSTEMS IN LOWLAND AREAS
Case study: Bendung sub-river system

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SUMMARY

In the last decades, Palembang City has faced a serious problem related to urban drainage system and flooding. This problem requires a systematic solution especially on how to solve the flood problems. Land use change is apparently one of the most important factors that results in higher run-off while another factor concerns the operation and maintenance of the urban drainage systems in Palembang City which has to be improved properly. This research focused on land use change and land utility management.

In this research, the river sub-system of Palembang City was taken as the research unit. This was in order to evaluate the structural conditions in urban area by applying the land unit concept and using the landscape ecology approach. Because of that, the morphometric characteristics of sub-river system had to be identified as input to the scenarios related to hydraulic model, so as to map the run off, inundation, water level in the drainage system included geo-spatial analysis in a sub-river system.

The ultimate goal of this research was to develop a model for management of a river sub-system which can be used for early warning system in relation to the constructing permission (land use change) in the river sub-system area. This model integrates a geographical information system technique with urban drainage management and flood protection systems.
The above mentioned research approach were applied in the case study of Bendung sub-river system in Palembang City. It is proved that the integration between landscape ecology, urban drainage hydraulic and geographical information system is a useful tool and approach which can be used to evaluate the effect of any land use change on urban drainage system and its hydraulic performance in lowland areas.

To validate the model, a calibration on the inundation map with the field conditions is recommended.

Key words: Landscape ecology, land unit system, morphometric characteristics, urban drainage system, hydrodynamic modelling, GIS

1 INTRODUCTION

The development process of a city, usually will follow naturally the natural boundary. In the process will form the ecosystem which will determine the pattern of utilization of the space of the city. River environment or water bodies will get a negative impact caused by urban activities, such as illegal use and reduction of flood plain, surface and groundwater pollution, loss of biodiversity, intensification and extensification of agricultural land, water management complexity, etc. (Smeet, 2004). This impact will give negative influences on public health, a balance in urban ecology and the positive image of the related city.

Land use and utilization in spatial city planning contents a spatial element where its size and its spatial distribution can be shown in the environmental structure of the river sub system. City landuse change pattern such as reducing in open green areas, unproper distribution of the city development, infrastructure development (rad especially), land reclamation will influence significantly the run off coefficient C. Higher C values will also result in higher run off to the area. Due to the higher run off and limited drainage capacity of the system, as the result, inundation may occur in the urban areas. A balance between landuse change and storage and drainage capacity of the system in the river sub system which will finally determine the environment performance of the river sub system.

Flooding and inundation in urban areas is not only caused by the activities in upstream part. Inhabitants living near to the flood plain also contributed to the reducing of the land bearing capacity in the related watershed. The trigger of this problem is the limitation of the land bearing capacity in large urban areas/cities. In this case, Palembang is one of the large cities in Indonesia which is located on the coastal strip and indicated by the geo-morphological structure of the river basin where several branches were formed from one large river which is passing through the city. The topographical elevation of the area is less than 5.0 m+MSL (Mean Sea Level).

Various efforts and measures have been made to control the flooding. i.e. structural as well as non-structural, but the flooding problems haven't solved systematically yet. Many researches have been carried out in large urban cities in relation to the characteristics of the areas. In this case, Palembang City was taken as the case study due to their topographical condition which is relatively flat (lowland) and water level in the Musi River is still under the tidal influence. In this research the river sub system boundary was used as one complete unit in order to evaluate the environmental structural condition of the related river sub system. These conditions can be evaluated by using different approaches and completed with the development of a hydrodynamic model which can be used for evaluating and controlling the environmental conditions of a river sub system and can also be used as land allocation management and a policy for urban cities related to the development plan and permission. For the long term, this model could also be utilized and used to support an early warning system related to the land use change in urban areas and can be applied for other urban areas in Indonesia where they have similar characteristics with the research area of this study.

2 PROBLEM DEFINITION

Sub-river system in Palembang has two main drainage groups where 16 sub-river systems (SRS) debouch in the Musi River and other 3 SRS in the north part namely to Banyuasin District area. River system in Palembang is still influenced by the tides. In last recent years, Palembang City experienced with flooding and inundation which requires a systematic solution to this problem, how to eliminate or reduce flooding and its risk to the city. It means that the problem in Palembang City is the uncontrolled landuse change on the SRS as the result of this situation it will affect its environment and the hydraulic performance of the urban drainage system. For this purpose, this research should have to focus on restructuring the management and zoning aspects related to the landuse development in the SRS. In this case a mathematical modelling will be developed for a SRS to integrate different relevant aspects, i.e. hydrology, hydraulic, drainage, land management and land use allocation and geographical information system.

3 OBJECTIVES

This research focussed on the integration of all the thematic elements of the urban land use and utilization. To evaluate the effect of landuse change on the environmental structural condition of SRS, this research will limit their scope by considering only hydrology, hydraulic and the flooding pattern in the related area in order to control and manage drainage and flood protection systems.

Special objectives of this research are:

- To analyse and evaluate the morphometric characteristics of a SRS and to analyse the urban drainage system of Palembang City and to set up land use system which based on the eco-system consideration;
- To identify the flood prone areas in order to improve the urban drainage and flood protection systems for Palembang City;
- To improve the urban drainage caused by land use changes

Previous researches

Some of the previous researches which can be listed are:

- A study on the Musi River basin and funded by the European Commission in 1989. The study formulated the water resources development master plan for Musi River Basin with the goal to assist the Directorate General of Water Resources Development, Ministry of Public Works to set up the policy, strategies and programmes for short as well as long term in Musi River Basin. One of the programme is to improve the river system and flood control;
- A study on integrated Musi River Basin management conducted by the Directorate General of Water Resources Development, Ministry of Public Works in cooperation with JICA (Japan International Cooperation Agency), 2003. The result of this study is setting up water environmental improvement programme for urban areas, namely Drainage management by community programme, River basin conservation programme and Main drainage system rehabilitation programme.
- Design of drainage masterplan and detail design of SRS Bendung and Sekanak. The study was carried out by BAPPEDA Palembang in cooperation with LAPI ITB, 2004. The aim of the study is to control flood and inundation in Palembang City. The result of this study is to propose a pumping system which will not be used continuously, but only when the water level in Musi River is too high and drainage capacity of Bendung SRS is not sufficient. Other recommendation is to improve the drainage capacity of the system by dredging and normalization of the main drainage system, to improve secondary and tertiary drainage system in Sekanak sub-river system, polder development in the sub-river system, socialization programme of society involvement related to flood control, included developing retention ponds programme;
- River Basin Authority VIII for South Sumatra in 2008 did review on the design of flood control system in Bendung SRS by using pump. The important conclusion of this study is that the drainage capacity of the Bendung SRS will be sufficient for debouching run off to Musi River if dredging can be done with about 0.5 m for Bendung SRS. Next to that constructing of 1m dike, installing pumping system in series were recommended. Next to that a free and clear landuse on the flood plain will also be needed for better flood control and management programme in the Bendung SRS.

4 METHODOLOGY

The research methodology composed of: literature review, primary and secondary data collection, mathematical model development which will cover a river sub system (hydrology, hydraulic of urban drainage system), model simulation, analysis, evaluation, conclusions and recommendation. Several steps of the research have been carried out in order to analyse the zonation system and its boundary and to analyse SRS environmental condition and to be able to describe the spatial relationship between landuse and the proper urban drainage system for Palembang City. Identify flood prone areas in Palembang City in order to formulate the proper urban drainage and flood protection systems.

Landscape ecology approach

An integrated approach for any development should be followed where the environment and ecology of the system must be considered in a balance with the development. In this case next to the present conditions, the expected future environmental conditions have to be analysed and evaluated as well. It means that an ecosystem approach has to be followed and one of this approached is Landscape Ecology proposed by Zonneveld (1989). Landscape Ecology is defined as... *Our perceivable environment which is considered as a cultulral commodity ... it has no borders and refers to concepts such as scenery, systems and strucuture...* (Antrop, 2000).

In this approach, the function of the ecosystem and the interaction between water body and city development should be in a balance and the land condition should be described and where the nature and ecosystem mapped by considering their spatial distribution.

Land unit Concept as an identification of a s*mall river environment unit*

Spatial identification of water bodies is based on the land units concept namely identification which obtained from the unit delineation of that are relatively homogeneous (Figure 1).

In a spatial form, physical component remains as the river environment which is used as the basis for identifying factors that affect to the environment and this is easier to be mapped in comparison to other elements. In the river environment process, the different interventions to the physical components will remain to affect its watershed services to its environment.

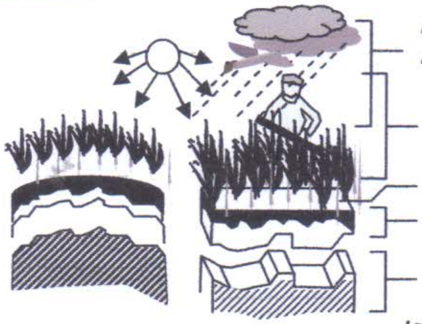

Figure 1 Land unit concept (Zonneveld, 1979)

Land unit concept can be set up by using a holistic approach but it can also be confronted with the land unit which is derived from reductionistic approach. Skidmore (1997) make a differentiation between holistic approach in using remote sensing interpretation in one hand, and reductionistic approach which is often used in researches which utilizing and applying geographical information system. It means that land unit concept by using holistic approach will be the unit system which was defined directly where land characteristics were deducted by means of logical relationship and in other hand a reductionistic approach used logical consequence relationship from a modelling mainly by overlaying the related layers geographical information system.

River ecosystem structure and cathment area

River ecosystem composed of two different elements, i.e. a dynamic of hydrological process and the physical element of the system. Dynamic hydrological element consists of water as the main part and climatological part which is interrelated to precipitation, evaporation, humidity and temperature. Next to that, the physical element consists of land (topography, geomorphology and soil) and vegetation. According to Lant (2004), a river ecosystem structure composes of:

- *Channel* (catchment area), A discrete area and significant element of surface water, which can be permanent or non permanent;
- *Floodplain*, area where water will be stored or places where excess water will be overflowed or during flood. In this case, it is included lower spots such as swamps and lakes, depressions, or retention ponds in the surrounding area;
- *Riparian zone* or riparian area is a transitional zone, bordering the edge of lake, rivers, streams ponds and wetlands, which exerts a direct influence on or is influenced by river and stream channels or lake margins, and thus influences the water and aquatic ecosystems contained within them.

Hydrological cycle in a watershed

The hydrologic cycle is a process that describes the storage and movement of water between the biosphere, atmosphere, lithosphere, and hydrosphere. Water can be stored in any one of the following major storages: atmosphere, oceans, lakes, rivers, soils, and groundwater. Precipitation that falls as rain evaporates, sublimates, runs off the ground surface (runoff) or soaks into the ground (infiltration) (Hubbart, 2011).

Morphometric Parameters

a. Area and shape of watershed, the size or area is very important related to the parameter estimation and will affect the run off coefficient of the related area. Wisler and Brater (1959) concluded that larger watershed area the average precipitation intensity per event per each area will also decrease. This is related to the concentration time, the time for the furthest water particle to reach the outlet and the intensity of the precipitation itself. According to Miller (1953) described in Seyhan (1977), to define the shape of a watershed, a circularity ratio can be used to follow the approach proposed by Gregory:

$$Rc = \frac{4\pi A}{P^2} \quad (1)$$

Where: A= watershed area (km^2), P = Wetted perimeter of the watershed (km)

If Rc > 0.67 the shape of the watershed would be round, Rc between 0.34 – 0.66 would be elliptic shape and Rc < 0.33 the shape would be a long one.

The relationship between the rate of flow peak and the cathment area is shown below in the rational method (Black, 1991):

$$Q_p = k_1 A^z \rightarrow Qp = 0{,}002778\ CIA \qquad (3)$$

Where:
Q_p = maximum run off in m^3/s;
k_1, C = run off coefficient;
I = rainfall intensity mm/hrs;
A= cathment area (ha);
^{z} =exponent number.

This method should be used where the cathment area is less than 300 ha (Goldman et al, 1986 in Asdak, 2004). For larger cathment area, it is suggested that the area is divided into sub cathment areas and finally this method can be used for each sub cathment area.

b. Bifurcation ratio is a ratio between number of river segments to number of river segment which is one order higher (Mekel, 1970).

$$Rb = \frac{N}{Nu+1} \qquad (4)$$

Where:
Nu = number of the -1 order rivers/streams;
Nu + 1 = number of the u +1 order rivers/streams;
Rb = ratio the first order bifurcation

c. Concentration time tc, time which is needed by precipitation particle to travel from the most upstream point to the outlet when the land is saturated and all the small depressions reaches their maximum capacity to store water.

d. Topography as slope, stream density and depression spots will affect the rate and volume of surface run off. Watershed with steep slope with a high density of streams will result a higher surface run off in comparison with the mild ones and with lower stream density. The flow density will affect the concentration time where it means that shorter concentration time and the rate of surface run off will be higher. The relationship between flow density and the length and watershed area is given in Eq (5):

$$D_d = L/A \qquad (5)$$

Where:
D_d= flow density/flow (km/km^2) L= length of total rivers/streams within watershed (km); A = area of watershed (km^2).

Effect of landuse change to the hydrological condition of watershed

The growing and development of upper part of watershed and outside flood plains may increase flood flow where control of storage and reducing run off will be an important and should be considered carefully. The change of land cover and land slope are often affect evapotranspiration, interception, infiltration, surface run off and flow in drainage systems. Too much land cover change and very steep land slope will affect more to soil erosion. (Quiroga et.al, 1996). Hydrological response of a watershed can be varied depends on the specific relationship between land structure and landuse. According to Asdak (2004), the impact of land use to surface run off can be defined as a run off coefficient, as a ratio between surface run off and rainfall intensity. C value is one of the indicators to define the physical conditions of a watershed and C value will vary between 0 to1. C= 0 means that all precipitation water will intercept and infiltrate to soil and on the contrary C= 1 means all precipitation water will flow as surface run off. The main factors which influences C value is soil infiltration rate, land slope, land cover and rainfall intensity. Other factors which will affect C value are soil characteristics and conditions, soil density level, soil porosity and depression storage (Suripin, 2004). For a watershed with heterogeneous landuse, C value for the related watershed can be based on the weighted values as Eq (6)

$$CDas = \frac{\sum_{i=1}^{n} Ci\, Ai}{\sum_{i=1}^{n} Ai} \qquad (6)$$

Where:
Ai = area of land which specific cover i; Ci= run off coefficient with type of land cover i; n = number of different land covers.

Urban flood

Urban flood can be caused by internal problem in the service area as well as external. One of the important aspects is the very fast grow of the urban population and next to that landuse change in the watershed, uncontrolled groundwater exploration, urbanisation in the flood prone areas, illegal settlement, quality of the construction and also the increase of settlement density (Munich Re., 2002; Pelling, 2003). Management of urban flood system is a multi discipline process. According to Parkinson and Mark (2005), the objective of short term flood management strategy is to control run off, flood protection and mitigation water pollution strategy. For mid term, development and improvement of water quality, water conservation of natural catchment areas and its hydrological components. Finally, the objective of long term is to protect and conserve natural resources and to promote awareness to the environmental issues.

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For this approach, as the first step is to delineate the watershed and its flow accumulation for each SRS. Topographical data of Palembang City with the scale of 1:1,000 which completed with the spot height elevations were used. This data was used in combination with the aerial photos of Palembang City from year 2004 by applying a digital stereophotogrametry technique. Based on these data a DEM 5 m model with 0.25m interval was created.

An overlay technique was applied for several parameters in order to derive the surface slope, soil infiltration potential, surface cover/vegetation and the surface condition related to the drainage capacity (drainage density) of the area.

Thematic map approach and land units' concept
The main characteristic of thematic map approach is to analyse the landscape components which is different one to each other and will be used for synthesizing. The result of the analysis of a certain thematic maps was analysed independently in order to get one component which is the target of the study. The application of map overlay technique was used in order to evaluate the spatial association and the relationship between different thematic maps. See Figure 3. By doing this technique, the components of created ecosystem can be mapped and identified clearly. It means that all the related information how the contribution of its topographical characteristics, geology, geo-morphology and vegetation can be identified. Topographical and geomorphological characteristics can be used to evaluate the landform and all the related processes on the land surface (Gunawan, 1993). Morphometric of streams (length or dimension of streams) can be used to evaluate the flow pattern and flow density and also the land slope. Vegetation or cover and its landuse can be used to identify the type and density of the cover which will be affecting to surface run off. In environmental management of sub-river system and urban drainage systems, maps of land units and urban drainage were based on land use and landuse change that will influence run off and will also change the present urban drainage systems based on its lay out and maximum flow capacity.

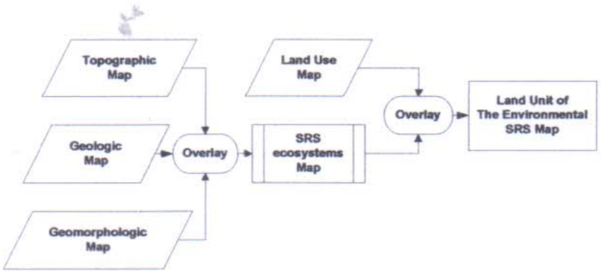

Figure 3 Spatial mapping process for thematic land unit

Modelling of urban drainage management system
The flow chart of the modelling system is presented in Figure 4.

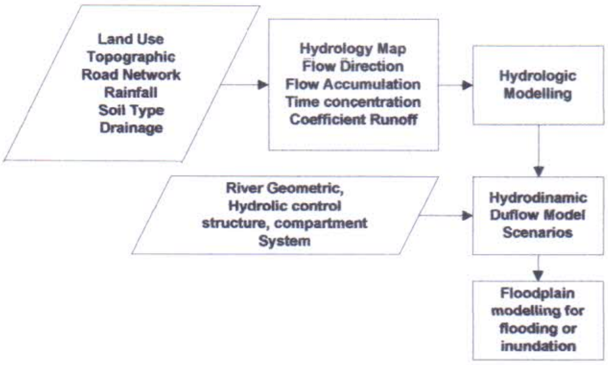

Figure 4 Flow chart of model urban drainage system

There are three different steps and models (see Figure 4) were used to do the modelling of urban drainage management system such as this study. These three models are:

a. Hydrologic model
Hydrologic model is a numerical model which can be used to analyse the hydrological process in a sub-river system. Next to that a design frequency analysis was also completed for different return periods by using Smada 6.0 computer program.

b. Hydrodynamic model
In this research DUFLOW hydrodynamic unsteady model was. The result of hydrological model was used as the boundary conditions to DUFLOW (run off from each sub sub-river system) in combination with the water level fluctuation at the downstream boundary (in the Musi River). As the output are the flow parameters (water levels and discharges) in the sub-river system.

c. Flood plain modelling for flooding or inundation
By transferring the output of DUFLOW model to ARCGIS, a flooding or inundation map can be prepared. In this case, an overlay technique was used between the DEM and water level layer.

This modelling system will be used to evaluate the existing conditions as well the conditions related to the selected scenarios for the future potential development of the area.

6 ANALYSIS AND EVALUATION

Palembang is a city with low topographical elevation where it is about less than 5m+MSL. The total area of Palembang is about 40,061 ha. Tropical climate with two different seasons, i.e. rainy and dry season. Average temperature is between 26^0C to 29^0C. Landuse pattern in Palembang City up to 2004 was dominated by small village streets and unused land (33.1%) and settlement/housing 29.9%. Based on the landuse analysis in 2004 for Palembang City, in fact most of the land was built where the percentage reached about 45%. The area was not yet built is about 50. % and the rest water bodies (rivers/streams/creeks) was 4.6%.

The landuse map of Palembang City is presented in Figure 5.

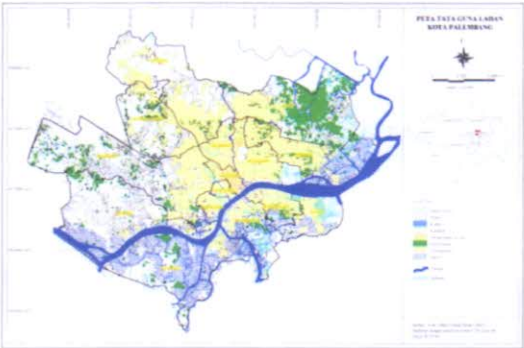

Figure 5 LanduseDistribution in Palembang City

Sub-river system in Musi area

Palembang City has drainage systems which can be grouped into two flow directions, namely 16 sub-rivers drain to Musi River and another group of 3 sub-rivers drain to Banyu Asin district. Musi River is one of the largest rivers in Indonesia which divides the City into two regions, namely Seberang Ulu and Seberang Ilir. This research will focus on the Bendung SRS which flow in the Seberang Ilir region as shown in Table 1 and Figure 6.

Table 1. River sub system in Palembang City

Sub-river system	Cathment area (km^2)
Bendung	19.60
Boang	9.92
Buah	9.92
Gandus	28.67
Juaro	3.45
Lambidaro	65.25
Lawang Kidul	2.57
Sekanak	10.39
Selincah	11.42

Figure 6 Research Bendung area sub-river systems in Palembang City

Morphometric parameters sub-river systems in Bendung area

The delineation process for sub-river systems in Bendung area was based on flow pattern and its flow direction. The flow direction and flow pattern were derived from the *Digital Elevation Model* (DEM) with the resolution of 5 m. DEM of the research area is presented in Figure 7.

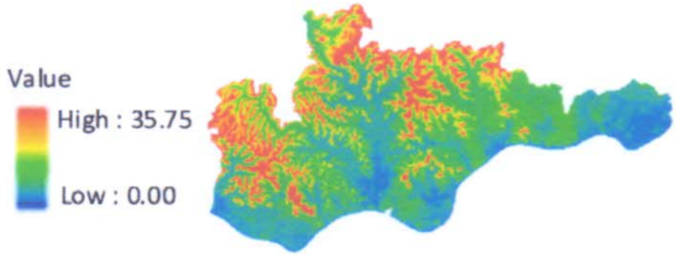

Figure 7 DEM of the study area

By using DEM 5m, a detail drainage network on the upper part as well as lower part in the study area can be obtained clearly. From the delineation of the watershed it is found that the boundary of the watershed is slightly different from the boundary from the previous studies which was used by the Palembang Municipality for planning purposes. This difference can be seen in the flow pattern as the result the total area of the watershed is also different. The topographical elevation of the sub-river system Bendung varies between 0,04 m to 25,0 m+MSL.

Bifurcation ratio(Rb), Bendung SRS has the stream order from 1 till 3. The classification of the stream order was used for analysing network bifurcation for each sub-river system. Average bifurcation ratio Rb is an indicator ratio between number of river segments and number of the order higher of the related river segment. The analysis used the method of Strahler where as the result is the average Rb value is 3.2. Rb value < 3 was assumed as not normal with a high flood and with a slow reduction in time. Rb value between 3and 5 defined as normal with a moderate peak flood and also moderate reducing of flood and Bendung sub-river system can be categorized into this class. According to Verstappen (1983), Rb value between 3.0 and 5.0 from a sub-river system the effect of its geological structure of the area can be neglected. It means the effect of its geological structure to the drainage network in Bendung sub-river system can be neglected.

Slope, Next to this analysis the land slope can also be derived as shown in Figure 8.

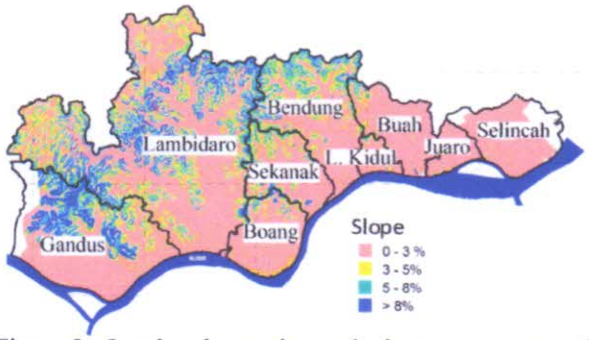

Figure 8 Land slope in sub-river systems of Palembang City

Land slope in the research area is relatively flat and only between 0 and 3 %, it is especially along Musi River and upper part of Bendung SRS has 5-8% land slope.

Circulation Ratio (Rc), Based on the analysis it was found that $Rc < 0.33$ and the flow frequency Fs was 2.55 for the research area. This Fs value is influenced by impermeability of sub surface materials, vegetation, surface relief and low infiltration rate (Reddy et al, 2004 and Shaban et al, 2005 in Ozdemir, 2009).

Drainage density (Dd), The value of Dd reflects run off potential, infiltration capacity, climatological condition and land cover on the sub-river system (Verstappen, 1983). Dd value reflects also the interaction between several factors which control surface run off in the SRS finally will influence the water and sediment flow through the outlet. The flow density in Bendung SRS is 1.15 km/km^2 and this value indicates that the drainage system is poor in Bendung SRS and most of the times will be inundated by heavy rainfall.

Basin relief (Bh), Bendung SRS had the highest texture ratio. The higher relief of the sub river system (Bh) is 24,5 that indicates the gravity flow condition of the area, low infiltration and higher surface run off.

Rugedness Number (Rn), Indicates the complexity of the structure of the area. The increase of peak discharge as a result of the change in efficiency between the surface relief condition and stream density (Pathon, 1988 in Ozdemir, 2009). The high Rn value was found in Bendung SRS. This high Rn value indicates that the area is more sensitive to the land erosion and increase of the peak run off.

Concentration time (*Tc*), in Bendung SRS is 53,13 and this value indicates that long travelling time will be needed for the most upstream water particle to reach the outlet. All morphometric parameters in a sub-river system are inter-related with its drainage network and will determine the capacity of the system as a whole related to possible flooding and inundation. The morphometric parameter of Bendung SRS is shown in Figure 9.

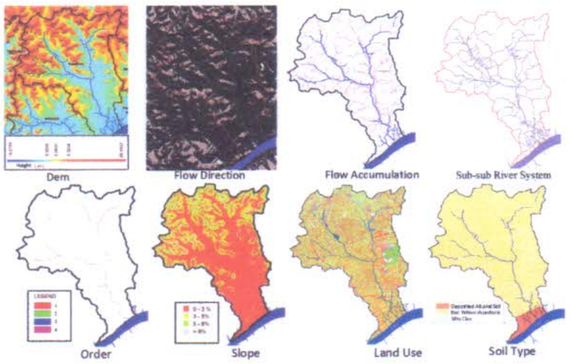

Figure 9 Morphometric parameters in Bendung river Sub- system

Vertical condition of the sub-river system

Vertical condition of Bendung SRS is defined as its soil types and vegetation. Soil types in Palembang City composed of deposited alluvial soil, sandy silt, red yellowish podsolic and silty clay. Parent materials of the deposits are silty clay and sand.

Bendung SRS covers an area of 1,960 ha is a main urban drainage system with the length of 8.85 km and drained to the Musi River. Based on the analysis of the landuse map of Palembang City as a result from the aerial photo (2004) interpretation it is shown that 75% of the land use on the Bendung SRS was dominated by settlement and housing, 20% offices, trading/services and the remaining 5% is conservation swamps (Figure 10).

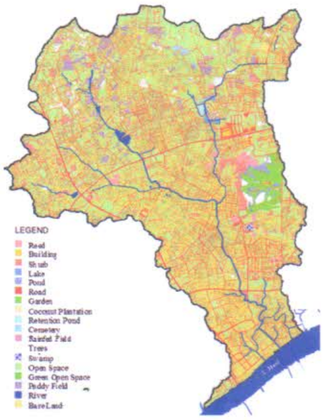

Figure 10 Land use map for Bendung sub-river system

Run off coefficient (C), The C values are influenced by several factors, i.e. infiltration rate, land slope, surface cover or vegetation, condition and characteristics of soil, groundwater, density of soils and rainfall intensity. The total value of the surface run off flow gets a weighing factor according to the defined classification. Land cover classification is made based on their contribution to surface run off and they were grouped and scored into 12 classes. Land slope in the research area was divided into 4 classes, i.e. slope less than 3%, 3-5%, 5-8% and more than 8%. Infiltration rate conditions related to surface run off are divided into five classes, i.e. very low or < 2.5 mm/hrs, low or 2.5 - 15 mm/hrs, moderate or 15-28 mm/hrs, high or 28-53 m/hrs and very high or > 53 mm/hrs. Water storage conditions were divided into four classes based on the modified Linsley (1959) and Meijerink (1970) where flow density < 1 km/km^2 means poor drainage condition and permanently inundated, 1-2 km/km^2 as normal drainage condition where only less than 2% of the total area will be inundated, flow density 2-5 km/km^2 means very good drainage condition, and when the flow density is > 5 km/km^2 means even in the extreme condition there is no inundation in the area.

Landuse in SRS in the case study area was distributed heterogeneously and for that reason, the C-weighted as in equation (6) is a proper method to be used to define the C value of each pixel. The spatial distribution of C-values for Bendung SRS is 0.71 presented in Figure 11. It is clear that for the settlement area (blue pixels) the C value will be much higher in comparison with other land use in the SRS.

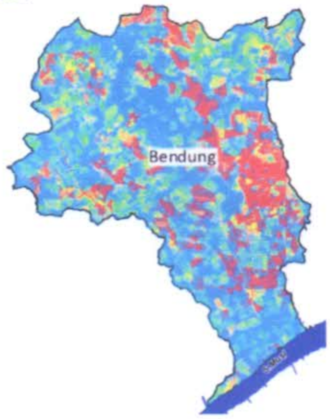

Figure 11 Spatial Distribution of C values in Bendung SRS

Rainfall data

Based on the rainfall data, design rainfall with 25 years return period has been determined as well as hytograph which will be used as input to DUFLOW model. The extreme daily rainfall data were taken from Kenten rainfall station which covers a period of 26 years from 1984 till 2009. By using *Smirnov-Kolmogorov test*, it was found that Gumbel distribution is acceptable for further application and based on that 163 mm/day was found for daily rainfall with 25 years return period.

Cross-sections of the sub-river system

In this case study, cross-sections were measured at every 100 m and will be used for the DUFLOW model schematization. During the field measurement some constraints should be overcome, especially related to the illegal used of the flood plains and next to that for improper maintenance of the water bodies, measuring cross-sections will face some difficulties in relation to the weeds in the water bodies.

Inventarization of the retention ponds

The investigation in order to inventorize retention ponds in the study area has been carried out where in Bendung SRS there are 6 retentions ponds are found, i.e retention pond Polda covers an area of 0.54ha, retention pond Talang Aman with the surface area of 1.58ha, retention pond Ario Kemuning with the surface area of 1.70ha, retention pond Suka Bangun with the surface area of 0.67 ha, retention pond Seduduk Putih with its surface area of 2.22 ha and retention pond IBA with the surface area of 1.10 ha.

Based on the field survey and investigation, it can be concluded that in general the storage capacity of the ponds reduced significantly due to sedimentation where in some ponds the thickness of the sedimentation varies between 0.50m-1.50m. Next to that the control structures for inlet and outlet (gates) were damaged in most of the cases.

Tidal water level observation

Water level observation had been carried out in order to get the water level fluctuation in Musi River where the SRS discharges their run off. This observation has been done for a period of 15 days and these data were used as the downstream boundary condition to the hydrodynamic model of the SRS. In this case the highest water level is 2.21 m+MSL.

Analysis of the inundation on the Bendung SRS

DUFLOW-Arc GIS simulation model has been done for Bendung SRS in order to figure out the run off distribution in the system. For this purpose SRS was delineated by using the DEM of the area where the flow direction, flow pattern and drainage lines will be created (see. Figure 12).

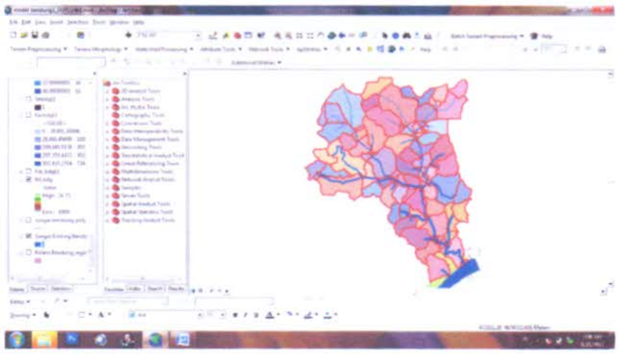

Figure 12 Bendung SRS as the result of spatial analysis of the flow pattern

The schematization of the Bendung SRS as shown in Figure 13 was based on the geometrical data of the system.

Figure 13 Bendung SRS schematization for DUFLOW model Boundary conditions

For DUFLOW model, as upstream boundary conditions are the run off from each SRS and as the downstream boundary condition is the water level fluctuation at the mouth of Bendung River. To determine the run off from each sub basin, a weighted C (run off coefficient) has been used based on the spatial land use distribution, land slope, soil type and the density of the drainage system for each sub basin. From the DUFLOW model result, the water levels in the drainage system of Bendung Basin are presented in Figure 14.

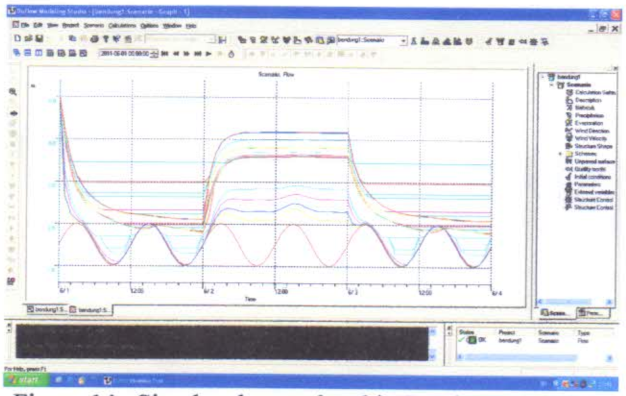

Figure 14. Simulated water level in Bendung SRS

Based on the simulation result, the inundated areas can be plotted by linking it with ARCGIS as shown in Figure 15 and 16. The increased of run off coefficient C due to landuse changes extended the inundated area to 9.4% for C= 0.8 and the inundated area with water depth more than 1 m to 359.4%. Effect of landuse change by increasing the value of C became 0.9 extended the inundated area to 12.1%. While the inundated area with water depth more than 1 m increased to 468.26%.

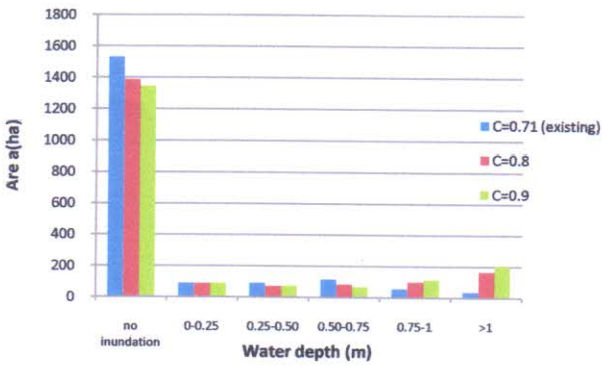

Figure 15 Inundation area with varies of C values

The model simulation result has been compared with the field information when there was a heavy rainfall and where the inundated spots are and the depth of inundation in this sub-river system.

Based on this existing condition, some scenarios will be developed for the future conditions and development, especially related to the land use change, urban drainage system development and flood protection system for each river basin. As the result, an urban drainage system management related to the river basin and its environmental consideration will be developed.

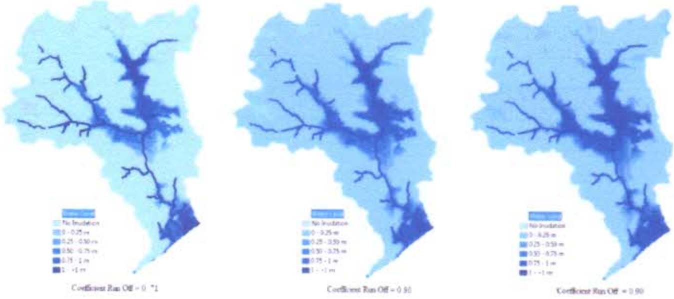

Figure 16 Inundation distribution on Bendung SRS with C values 0,71, 0,8 and 0,9

7 CONCLUSIONS AND RECOMMENDATIONS

Based on the spot height elevation data and digital elevation model (DEM) 5m resulted in a very clear Bendung SRS which relatively different from the previous studies. This result will also influence drainage control pattern for each SRS.

From the SRS morphometric parameter analysis for this case study, it was found that a SRS shape is dominated by the topographical condition (similar to watershed delineation) and the hydrograph of the runoff depend on the shape as well. Next to that, stream order, area of sub-river system, tributary order, stream density, flow frequency, ratio of the texture, basin relief of the land surface, concentration time, run off coefficient are inter-related to each other with its drainage network.

Run off coefficient C which is a ratio between peak run off to rainfall intensity is influenced by the major factors such as infiltration rate, land slope, land cover, and soil characteristics. This case study for C value of Bendung SRS is 0.71.

Effect of landuse change by 10% and 20% increasing of the C values could extend the inundated area with water depth more than 1 m up to 359.4% and 468.26% concecutively. It is well fitted with the actual physical condition of the area. Higher value of run off coefficient C is influenced by the distribution percentage of the landuse condition while the area is dominated by developed area (paved). This is in line with the conventional approach for the average condition of an area.

From the case study of Bendung SRS, it can be concluded that the application of an unsteady hydrodynamic model such as DUFLOW is very important and useful to be applied for the flood and inundation analysis in a sub-river system.

The result of the environmental condition of Bendung SRS by using a spatial analysis in combination with a hydrodynamic model with 25 years return period it was found that the inundation depth varies up to 1.25 m with the total inundated area of 392.6 ha .

In order to get an overall image about the urban drainage system the same approach could be applied to all sub-river systems in Palembang City.

Such a SRS analysis could be followed by modelling development scenarios that take into consideration: (1) The landuse change; (2) Masterplan of drainage system and; (3) a proper measurement (structural as well as non-structural).

From this study it is recommended that the approach and model can be used not only for sub-river systems in Palembang City, but also for other urban lowland areas in Indonesia that to some extent have similarity in morphometrical characteristics.

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