Effect of Change in Land-use to High Pattern of Inundation on Sub-River System of Lowland Urban River

S. A. Hamim$^1$* and F. Usman$^2$
$^1$ Universitas Indo Global Mandiri, Palembang, 30129, Indonesia
$^2$ Institute of Energy Infrastructure, Universiti Tenaga Nasional, Kajang 43000, Malaysia

Email : *sumi_amariena@uigm.ac.id

Abstract. Flooding is a temporal condition of surface water where the level and debit are exceeding a specific allowable limit. Urban city flooding is an effect of unbalance city environment related to regulation function. Vulnerability to increasing of population and change of land use at rural area and urbanisation to the flood-prone area, illegal shelter, land development on the water catchment area, increase in population density are the most common source of flooding on an urban area. This paper presents a study on the effect of changing in land use to high inundation pattern on river sub-system (SRS) of Bendung River in Palembang City. The data is taken based on a digital elevation model (DEM) generated from high point data set from a Compact Airborne Spectrographic Imager (CASI) sensor. The model used in this study was a hydrological model using SMADA 6.0 and DUFLOW 3.6 for rainfall-runoff model and analysis of river system generating surface water profile. The ArcGIS was used to construct a surface water model related to DEM data to obtain inundated area, inundation maps, inundation height and geospatial analysis. Four scenarios are applied in this study area which was changing the type of land use to a green area, changing the type of land use to a settlement area, free up 30 m riverbank to a green area and free up 100 m riverbank to a green area. From this study, the change in runoff coefficient, $C$ value does not significantly reduce the inundation area in the area with more than 80% relatively flat topography. Increase the $C$ value by 10% resulted in an increase on the puddle area to 9.4%, while the flood area with an altitude of more than 1 m increased to 359%. The results of scenario with land used change 10% - 20%, contributed to the increase in the flood area of 9.4% - 12.1%. So that to reduce the high pattern inundation a structural approach combined with a non-structural approach should be enforced and implemented. Besides, land-use changes will be significant to reduce flooding when land consolidation is applied to a sub-river system (SRS).

1. Introduction
Flood is still a global issue in Asia to mitigate and prevent due to several factors [1], [2]. Flooding is a temporal condition of surface water where its level or its debit exceeding the specific allowable limit. Urban city flooding is an effect of unbalance city environment related to regulation function [3], [4]. Vulnerability to increasing of population and change of land use at rural area and urbanisation to the flood-prone area, illegal shelter, land development on the water catchment area, increase in population density are the most common source of flooding on an urban area [1], [5]. Land subsidence contributes to the extension of the flood-prone area [6].

Studies have conducted an attempt to solve flood problems in Palembang City [4 - 7]. A study that funded by European Commission on 1989 formulated a master plan on soil and water resources development on Musi River catchment area to assist the Public Work Department of Indonesia to approve the most suitable strategy and optimal programme for short and long term. One of the agenda
was rejuvenating rivers and flood mitigation in Palembang City. In 2003 under JICA fund, the drainage system plan of Palembang City has been evaluated concerning some events of flooding for the last two decades. From the study, it was found that dimension properties of the existing drainage system in Palembang City was not suitable to cater to the water level of the Musi River as the main river stream. A further study conducted by a collaboration of LAPI ITB and BAPPEDA of Palembang City created a new master plan of Palembang City's drainage system to address problems in some Sub-River Systems (SRS). The study used the longitudinal profile, cross-section profile measurement, and monitoring the amplitude of high and lower tidal on selected SRS. From the study, a different recommendation has given to the SSRS. For the SRS of Bendung River, the study recommended the use of a water pump to solve water puddle and to do normalisation of riverbanks. Meanwhile for Sekanak River recommendation was given to rejuvenate secondary and tertiary network of the drainage system, land-use management and land conservation. In 2008, flooding occurred along SRS of Bendung River. The primary source of flood problems was due to the morphology of the catchment area and flattened gradation on most area induced into the longer discharge time. Numerical analyses were conducted as well on a number of SRS in Palembang City. In 2009, using a hydrodynamic model in DUFLOW, the environmental condition of SRS of Jakabaring River has been studied to provide protection and mitigation procedures in fighting the flood problems. Construct water gates selected the structural approach at several locations of SRS of Jakabaring River. It gave a quite significant reduction of 4% of the inundated area by increasing the watergate opening from 1 m to 3 m. By adding three water gates with 3 m wide opening using the hydrodynamic simulation primary, this structural approach was able to address the flood problem on that area. The uncontrolled land-use change mainly causes the flood and inundation [7], [8].

Vulnerability to population density in an urban area has increased rapidly due to changes in land-use in rural areas, urbanisation in flood-prone areas; the existence of squatter settlements; construction (physical infrastructure of catchment areas) built under the standard and increasing settlement density [9], [10]. Some of the causes of urban flooding are related to flood problems in Palembang City:

a) Canalisation of inappropriate land use from natural waterways.

b) Changes in land use that increase runoff so that it affects the inundation.

c) The flow of water from the river during tide enters the city drainage system and reduce the capacity of urban drainage systems.

d) Blockage and clogged of channels and roadside drainage channels.

e) Material that causes soil erosion and then clogs drainage systems and drains holes.

f) Implementation of improper road cleaning resulting in clogging of roadside channel inlets.

2. Method

The study area in this paper is on Sub-River System (SRS) of Bendung River which is one of SRS in Palembang City. Figure 1 shows the 9 SRS at Ilir District of Palembang City. The development model to find out the behaviour of the drainage system in SRS of Palembang city is used. Simulation of the hydrological and hydraulic conditions of SRS of Bendung River provide a complete picture of the river system. The model used in this study was a hydrological model using SMADA 6.0 and DUFLOW 3.6 for rainfall-runoff model and analysis of river system generating surface water profile. The ArcGIS was used to construct a surface water model related to DEM data to obtain puddle area, inundation maps, inundation height and geospatial analysis. The digital elevation model (DEM) generated from high point data set from a Compact Airborne Spectrographic Imager (CASI) sensor as in figure 2.

The hydrological process and the hydrological conditions occurring in the SRS were predicted using the hydrological model. The rainfall data of the study area obtained from the Meteorology and Geophysics Agency (BMG) Kenten station in Palembang city for 25 years. The rainfall data analysed by frequency of rainfall plan with some repeat period using SMADA 6.0. The selected rain distribution pattern will then be used as input in the Duflow hydrodynamic model to see the relationship between rainfall, runoff, puddle height and flow velocity. The rainfall and runoff modelling using some input data such as DEM, land use map and land type map that has been generated earlier; daily rainfall data and observation debit data of water level measurement at the estuary of the SRS.
In this study, the hydrodynamic model analysed in DUFLOW, which can do steady flow as well as unsteady flow modelling. Flood control model in the SRS was generated with a non-steady flow model with the constraints of hydrological modelling results and the results of tidal observation forecasting at the sub-estuary of the SRS. The results were obtained in the form of hydraulic parameters such as water velocity, channel flow and water level in rivers and canals. In the modelling, the floodplain due to
overflow of water which cannot be accommodated in the SRS was generated using DUFLOW model combined with ArcGIS.

In the modelling, the floodplain required many scenarios, runoff of the hydrological model in the SRS and the tidal forecasting data at the river mouth. From this hydrodynamic model, the existing conditions of the SRS can be produced. By using different scenarios, the floods and its inundated area would be determined. The information is expected to be applied in environmental control of the SRS of Bendung River.

3. Results and Discussion

3.1. Morphometric Characteristics of SRS of Bendung River

Bendung River SRS has a surface area of 19.6 km². It is an urban drainage system about 8.9 km long. The Bendung River is the main drainage system discharging into the river Musi. Based on Palembang City's land-use map resulted from the 2004 analysis of aerial photography, land-use at Bendung Watershed is 75 per cent occupied by residences, 20 per cent businesses, and 5 per cent swamp-protected areas. The features of the SRS's morphometry can be seen in figure 3. On the Bendung River SRS are presented the DEM, flow direction, flow accumulation, sub-SRS, river order, slope, land use and soil type. From the findings of the watershed study, Bendung River's SRS is divided into 23 sub-SRS, with river order of 50 and an average branching rate of 3.2. River length varies from 8.9 km. Water density 0.9 km / km² and basin relief (i.e., highest point difference with the lowest point is 24.5 m).

Figure 3. The characteristics of the morphometry of the SRS of Bendung River.

The cumulative runoff coefficient for the Bendung River SRS is 0.70. It means that 30% of the overall precipitation in the SRS is infiltrated while 70% is runoff. The magnitude of the C value shows the SRS of Bendung River has been disrupted. It is shown when puddles occur in some areas during the rainy season. From field monitoring, the puddling happened in the SRS of Bendung River was usually caused by three major factors. The runoff discharge that cannot be accommodated by the Bendung River, stagnating flow from the Bendung River as a result of the high-water level of the Bendung River and inadequate drainage network which led to the Bendung River. Besides the three main points, there were also changes in land usage, reduced number of catchment areas and natural retention in the SRS of the Bendung River.

Changes in land-use have also greatly affected existing water capacity and flow. The presence of changes in swamp functionality that previously was a shelter for rainwater transformed into another purpose that was no longer linked to its original function. With river capacity condition and creeks decreasing Bendung River's SRS is highly susceptible to puddling. From the results of the study, it can be seen that in the Bendung River SRS, which has a very high level of vulnerability, it reaches 32.25% and a high level of susceptibility is around 30.02%, which was affected by relief conditions of relative slope, altitude less than 3 m above mean sea level (MSL), slope of 0% to 3% and type of land-use dominated by buildings or settlements.

The community's social condition was closely related to people's behaviour within the Bendung River SRS. Inappropriate method of waste disposal results in the drainage system being interrupted. Many people set up buildings on the banks of the river and above the channel, either intentionally or
unintentionally, thereby inhibiting the water flow. Besides, from witnessing government-owned, private and community-owned infrastructure that minimise river area and channel crossings such as piped water pipes in the drainage channel and closing the outlet through telephone cables. The Musi River's rising waters also influence the drainage as it is stored and plentiful in the lower regions. The rising waters of the Musi River are caused by high sedimentation due to frequent upstream floodings from Komering River, Ogan River and Lematang River.

3.2. Hydrodynamic Model of the SRS of Bendung River

The SRS of Bendung River's hydrodynamic model was analysed with DUFLOW – ArcGIS model simulation as shown in figure 4. The model was analysed to describe runoff on the floodplain so that that field conditions can be approached. The first stages were conducted by developing a water network scheme based on DEM extraction with a flow pattern that resulted in SRS sub boundary and drainage line of the SRS of Bendung River. The network schematisation was built by entering the cross-profile data as well as extending the channel per segment based on the field measurement. The Bendung River cross-profile width ranges from 3.5 to 13.5 m.

The DUFLOW model boundary conditions in SRS of Bendung River consist of upper boundary conditions such as runoff from upstream SRS and downstream boundaries, such as water level at Bendung River estuary. The hydrological rainfall parameter is derived from the analysis of the distribution of maximum daily rainfall by Gumbell method for 25 years of 163 mm/day. The weighted C values of each sub-SRS are calculated from the results of spatial analysis of land use, slope inclination, soil type and flow density per sub-SRS. The amount of runoff per sub-SRS is calculated as the boundary conditions are included in the schematisation of the water system. The water level in every segment ranged from 1 m to 4 m above MSL, which is used in interpolating the water level in the SRS after being transformed into DEM the height of the puddle is obtained.

Furthermore, the inundated heights obtained were interpolated in the ArcGIS to obtain the inundation distribution that would occur with the 25-year annual retirement scenario as in Figure 3. The distribution of inundation is classified into six classifications, i.e. non-stagnant areas, flooded with an altitude less than 0.25 m, altitude 0.25 - 0.5 m, elevation 0.5 - 0.75 m, elevation 0.75 - 1 m and height of 1-1.25 m. The area of inundation distribution based on the height of the inundation can be seen in table 1.

| Height of inundation (m) | Area of flooding (ha) |
|-------------------------|-----------------------|
| No inundation           | 1,530.18              |
| 0 - 0.25                | 89.53                 |
| 0.25 - 0.50             | 91.92                 |
| 0.50 - 0.75             | 117.16                |
| 0.75 - 1.00             | 57.98                 |
| 1.00 - 1.25             | 36.03                 |

Figure 5 shows the distribution of inundation that occurs in the floodplain area, along the river up to 100 m from the edge of the river. From figure 4 after the distribution of flooding is arranged with a land-use map, it is known that the puddles occur in the area around the Seduduk Putih retention basin located behind the PTC Mall. The flooding was in varying depths ranging from 0.20 m to 1.0 m, high puddle up to 1 m during rain event more than 3 hours. Inundation also occurs behind IBA University, Gresik area, Perikanan areas, Swadaya area, Lebak Jaya area, Rawa Sari area and Rajawali area.
Figure 4. The Hydrodynamic Model of the SRS of Bendung River.

Figure 5. The distribution of inundation that occurs in the floodplain area.

From the observation of flow patterns and flow accumulation, the inundated areas are the locations of the accumulated flow in the SRS of Bendung River, which is a water storage area and riverbank. Figure 6 shows the overlay of the inundation area on flow pattern and flow accumulation spatial data. The influence of Musi River tides on SRS of Bendung River is grouped into three classifications into (1) a high tidal influence of 0 - 0.10 m (upstream area); (2) a tidal influence height of 0.10 - 0.50 m (middle area) and (3) a tidal effect of more than 0.50 m (downstream area). This tidal influence is the basis for the classification of Sub-SRS of Bendung River upstream area of 1516.9 ha, middle area of
256.8 ha and downstream area of 213.5 ha. When viewed from the result of overlapping between the distribution of inundation and tidal influence of Musi River as in figure 7, the flooding that occurs in SRS of Bendung River is still influenced by the tides, especially in the downstream and central part of SRS of Bendung River. It indicates that the water flows into the Bendung River is suppressed by the high tide of Musi River.

**Figure 6.** The distribution of inundation that occurs in the floodplain area.

**Figure 7.** The distribution of inundation that overlaid on the tidal influenced area.

3.3. *The scenario of Land-use in the SRS of Bendung River*

Land-use is one of the primary and dynamic elements of the SRS characteristics that play a role in determining the hydrological system in an SRS. Land-use change from one type of land-use to another type becomes one of the focus of SRS environmental management or controlling activities. In the hydrological system in the SRS environment, the role of open green areas (OGA) is significant with the magnitude of the possibility of human intervention. The OGA can affect soil surface conditions and further affect the size of the surface flow. In this study, several land-use zonation scenarios were conducted to see the effect of land-use change on the inundation distribution that will occur. Considering the existing condition of SRS Bendung which has been dominated by settlement, to determine the
scenario of land-use zoning becomes an obstacle to change the settlement of citizens into a green area (urban forest, park or other land use type) that aim to reduce the amount of runoff. The enforcement has an impact on the amount of compensation that will be incurred by resettlement or land consolidation program. It is precisely in SRS of Bendung River catchment areas, such as swamps, OGA that still exist and the limited number of currently built new settlements or storehouses as a place of economic activity. In this study land-use change in the SRS of Bendung River will be simulated in four scenarios as follow:

1) Changing the type of land-use that is still possible to be converted into a green area (urban forest, park) to decrease the value of runoff coefficient, C;
2) Changing the type of land-use that may still be converted into a settlement increasing the runoff coefficient, C;
3) Freeing up the riverbank of Bendung River (floodplain) along 30 m into a green area;
4) Freeing up the riverbank of Bendung River (floodplain) along 100 m into a green area.

In this study, the first scenario with a change of land use type will change and reduce the total runoff coefficient value from 0.70 to a total C of 0.67. The change in the C value of only 3% shows that land utilisation in Bendung River is still dominated by the developed area (more than 80%). The results show that the effect of land-use change only reduces the inundation to 0.01 – 0.03 m, this can be expressed as not significant for the decrease in inundation height but affects reducing the inundation area to 4.1%. The puddle area and the puddle height are reduced to 0.1 m in the upstream SRS of Bendung River behind the PTC mall and the direction of the Seduduk Putih retention pond. This first scenario means there is a contribution from the addition of green open space to decrease the area and the puddle in the SRS of Bendung River.

The second scenario is by adding or conducting settlement development in green areas and water catchment areas, increasing the runoff coefficient from 0.70 to 0.90. It aimed to show the effect of land-use change on the inundation distribution that will occur and can be as an explanation that the environmental conditions of an SRS become more disturbed. The inundation distribution patterns generated by the second scenario can be used as a pattern of the SRS environmental control. As a result of this scenario, the effect of land-use change (i.e. C = 0.90), the inundation depth increased from 0.1 m to 0.5 m, and the puddle area increased to 12.1% (i.e. increased by 468.26%) for the puddle area with an altitude higher than 1m. The central and upstream areas of the SRS of Bendung River experienced an increase in inundation ranges from 0.3 m to 0.4 m in the areas of Rawa Sari, Lebak Jaya, Seduduk Putih, Swadaya and Perikanan. The areas in the middle of the SRS of Bendung River on the flood plain, on the existing condition, are not flooded into flooded 0.2 m to 0.4 m due to the impact of scenario 2. Figure 8 shows the scenario 1 and scenario 2 of the analysis.
Increasing the $C$ value by 10% (i.e. $C = 0.8$) resulted in an increase on the puddle area to 9.4%, while the puddle area with an altitude of more than 1 m to 359%. The results of scenario 2 showing changes in land-use with the land type that cannot withstand runoff (building settlements) of 10% - 20%, contributed to the increase in the inundated area of 9.4% - 12.1%. The third and fourth scenarios, liberating the riverbank (flood banks) along 30 m and 100 m into green areas, has shown a change in the value of $C$ to 0.70 and 0.69. Inundation depth reduction was not significant (only 0.5% for scenario 3 and 2.54% for scenario 4), but there is a high inundation increase of up to 0.3 m in the downstream area of SRS of Bendung River. Figure 9 shows the effect of liberating the riverbank on the pattern of inundation.
4. Conclusion

The Bendung River’s water level in SRS changes every time when there is a change in the value of $C$ impacting the amount of runoff in the SRS. Changes in land use in the form of green areas can tolerate significant runoff in response to smaller runoff by settlements resulting in more debits. Although relatively stable soil conditions cause water absorption to be lower, since that area which can previously absorb water transform into water-resistant buildings. The incapability to absorb, would increase the river runoff and cause flooding due to insufficient channel/river storage capacity. The flood event becomes worse by the effect of the tides on the Musi river. From the results of Scenario 1, 3 and 4, it was observed that with relatively flat topography conditions in the SRS of Bendung River, the adjustment in $C$ value does not significantly reduce the flood area in the land-use region by more than 80 per cent. So, a structural approach combined with a non-structural approach is needed to reduce the area and height of flooding in the SRS of Bendung River. Besides, land changes will be significant when land consolidation is undertaken in SRS of Bendung River to reduce inundation. The danger that the community may face along flood banks caused by flooding should be minimised by responding to the environment, raising the floor of the house or building a house with house poles on stilts. If relocation of settlements is possible, the flood banks may be used as catchment areas, green open areas, gardens, parks so that no harm is caused when inundated.
Acknowledgement

The authors would like to thank Universitas Indo Global Mandiri, Indonesia for the opportunity to publish this paper in collaboration with Universiti Tenaga Nasional, Malaysia.

References

[1] E. Mignot, X. Li, and B. Dewals, 2019. Experimental modelling of urban flooding: A review," J. Hydrol., 568, no. November 2018, pp. 334–342.
[2] L. Alfieri et al., 2018. A global network for operational flood risk reduction," Environ. Sci. Policy, 84, no. March, pp. 149–158
[3] S. M. Starr and N. E. McIntyre, 2020. Land-cover changes and influences on playa wetland inundation on the Southern High Plains, J. Arid Environ., 175, no. December 2019, p. 104096
[4] V. Radović and I. Iglesias, 2019. Extreme Weather Events: Definition, Classification, and Guidelines towards Vulnerability Reduction and Adaptation Management" in Climate Action, 2020th ed., 46(02). Springer, Cham.
[5] A. Abdelkarim, A. F. D. Gaber, A. M. Youssef, and B. Pradhan, 2019. Flood hazard assessment of the urban area of Tabuk city, Kingdom of Saudi Arabia by integrating spatial-based hydrologic and hydrodynamic modeling," Sensors (Switzerland), 19(5).
[6] S. Amariena Hamim, F. Usman, and A. Kurnia Shalihat, 2019. Determination of Land Subsidence Caused by Land-Use Changing in Palembang City using Remote Sensing Data, 187, no. IcoSITE, pp. 101–106.
[7] S. A. Hamim, F. X. Suryadi, and F. Sjarkowi, 2013. Effect of Uncontrolled Landuse Change to the Inundation Pattern and Its Possible Measures Case Study: Lambidaro Lowland Sub System in Palembang," Proc. 35Th Iahr World Congr. Vols I Ii, no. September 2013, pp. 3577–3588
[8] F. Usman and S. A. Hamim, 2018. Determine environmental structure condition of river sub system of Palembang City's rivers using geospatial analysis," Int. J. Eng. Technol., 7(4), pp. 424–430.
[9] P. D. A. Dinar, Sarino, A. L. Yuono, J. C. Imroatul, and S. A. Hamim, 2018. Integration of surface water management in urban and regional spatial planning," Int. J. GEOMATE, 14(45), pp. 28–34, 2018.
[10] C. Bae and D. K. Lee, 2020. Effects of low-impact development practices for flood events at the catchment scale in a highly developed urban area," Int. J. Disaster Risk Reduct., 44, no. September 2019, p. 101412.