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An Immediate Review of Flood Characteristics on Delta Lowland Sumatra using D8 Model Spatial Analysis

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Abstract: Middle Sumatra has become a highly urbanized and densely populated area. Middle- and downstream areas nowadays suffer from coastal flooding, river flooding, and rainfall induced urban flooding. Rapid developments, deforestation, loss of wetland areas and sealing off previously unpaved areas, have resulted in higher runoff and decreased the river's conveyance capacity. Increasing population will strongly influence the natural hydrological processes. Due to land pressure, substantial areas of peat swamps are being reclaimed for agriculture or for other land use. In natural conditions, wetland areas function as retention areas by storing flood water, thereby preventing or mitigating flooding in downstream areas. Unfortunately, large areas of the original forests in large peat forests have disappeared due to human activities such as logging and fires. Increasing population, industries, agriculture and plantations will increase water demand. Activities of ground water extraction will be increasing as well. However, this extraction can cause land subsidence. The already flood-prone deltaic areas, in which tides can propagate easily, are exposed further to floods due to land subsidence as well. Flooding along rivers occurs frequently, particularly during heavy rainfall and spring tides. A number of flood defence measures have been implemented since 1996 in the case study area, designed for return periods of 15 years. These measures include levees, pumps, and a drainage canal. Nonstructural measures within communities who live in the flood prone areas were implemented for flood mitigation as well. Still, flooding occurs yearly in many parts of Middle Sumatra. Since flooding has been identified as an important issue, in-depth researches into the exact causes of flooding are needed. Furthermore, strategies consisting of both structural and non-structural measures should be developed.

Keywords: *delta, lowland, flood, spatial, D8 model*

1. Introduction

Delta is a low-lying area which can be found at the mouth of a river. Flood is defined as a great flow of water especially, a body of water, rising, swelling, and overflowing land not usually thus covered; a deluge; a freshet; an inundation (S.N.Ghosh 2006). Recent concentration of floods occurs in many deltaic areas due to combination several factors and interaction of land and water at downstream areas.

A number of measurements have been taken, however sometimes; it was taken under too much an underestimate, without clearly description of flood characteristics and their interrelated cause. Therefore at the end, it is often found improper flood management which can cause flood in the next period.

The increasing demand for land strongly influences the land-use in a watershed. The land-use changes adversely affect areas that naturally absorb (flood) water such as, swamp, forest, etc.

Settlements and other anthropogenic activities in these areas strongly influence of flood discharge and the vulnerability to flood damage. The population of settlers and economic activities has grown rapidly in the cities, especially along the floodplains of the river.

1.1 Description of Study Area

Data was taken from USGS satellite, and the data is available in 90 m and 30 m grid at the source of http://earthexplorer.usgs.gov/. While do the assessment, this research was using combination both 90 m grid and 30 m grid due to the area of interest was influenced by two big sub river basins. Both river basins are located at the outside of the city. The 30 m grid was using in order to assess the affected area more detail. However, in some cases, it is often found the basins existed in the city boundary, in this case, single 30 m grid enough to be used for spatial assessment.

The study area is located at the middle of Sumatra which is situated on 100°28' – 102°12' East longitudes and 0°20' – 1°16 North latitudes and a lowland area which is located at less than 100 m elevation. A 345 km length river, Siak river flows from the west to the east island, cutting cross some cities including the capital of the Riau province, i.e. Pekanbaru. Siak river flows through a peat swampy area and drains into the Malacca strait, between Malaysia and Sumatra. The right and left banks of the river are occupied by an increasing number of people involved in various economic activities. The main function of the river is navigation, which has strongly supported the social economic development of the region and connected Sumatra to various important cities in the region.

1.2 Watershed and Rainfall Runoff Pattern

1.2.1. The river characteristics

Siak river has some unique characteristic, because of its relatively mild slope. The bed slope of the river is 0.002 at the upstream stretch (65 km), 0.00012 at the middle stretch (160 km) and 0.00006 along 120 km at the downstream stretch. The river course at the downstream and middle stretches is flat with a width of approximately 250 m – 300 m and the bed elevation 0f 12 – 24 m below mean sea level. The tide effect propagates in the upstream direction for nearly 240 km, where it even goes past several cities. The maximum difference of the tide-wave on the river is relatively large; 4 m (Siegel, Stottmeister et al. 2009). Due to the large tide influence and the mild slope, the river flows in two directions.

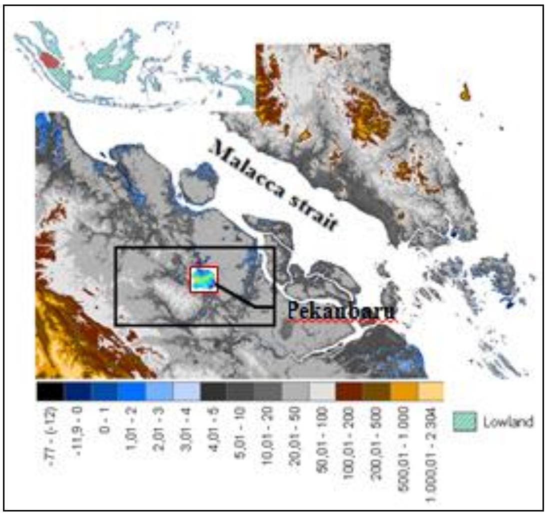

Figure 1 *Lowland area less than 100m and the area of interest (source: SRTM)*

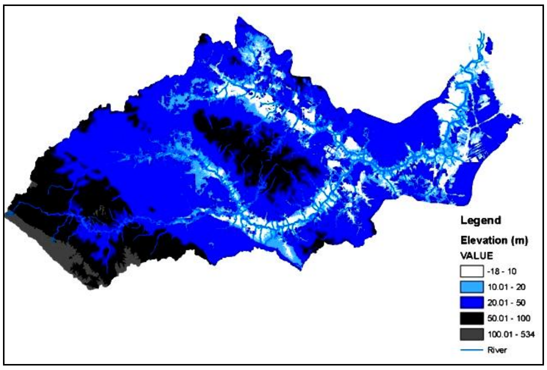

Figure 2 *Siak river and basin*

1.2.2. General climate conditions

The climate in Sumatra is tropical humid, due to two main seasons: the rainy and dry season. The rainy season starts in October until April. The maximum temperatures between around 32.6°C and 36.5°C, and the minimum temperatures vary between 19.2°C and 22.0°C. The minimum humidity is between 41% and 59% and the maximum humidity 98% and 100.

1.2.3. Rainfall, discharge and water level

Rainfall data was obtained from 4 rain gauge stations and 3 stations for discharge and water level measurements. It schematically represents the geometry data of cross sections along the Siak river from the capital city of Pekanbaru to Malacca strait. The discharge of Siak river in Pekanbaru is noted 1,447 m^3/s when the elevation from mean sea level is zero.

Rainfall, discharge and water level from existing recording stations are used to assess the trend of climate change due to the forest conversion into other land uses. Determination of hydrograph in Siak river basin carried out in upstream of river basin. In the downstream area, it cannot be obtained because it is affected by tides. In order to determine the hydrological changes in the river basin, correlation rainfall and water level data are set at two different points; upstream and downstream. The results are depicted in Figure 3 and Figure 4.

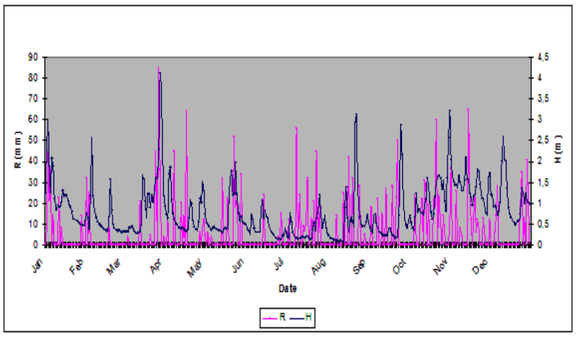

Figure 3 *Rainfall and water level correlation at upstream level*

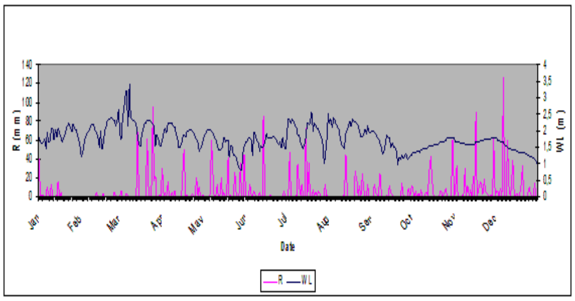

Figure 4 *Rainfall and water level correlation at downstream level*

Figure 3 presents rainfall runoff relationship at the upstream area. It indicates that increasing of river discharge is due to the rainfall event. In the Figure 4, water level rises continually, even though there were no rainfalls on February, March and July. Meanwhile during rainy season, there are no significant changes to water level. According to those two situations, rainfall will only be affected at the upstream stretch.

1.3 History and Characteristics of Floods

It was noted at 2015, the number of population in the capital city of Pekanbaru is approximately 1.1 million with 7.5% annual population growth. Floods have affected a large number of people who live in flood-prone areas. Between 2002 and 2013 there were approximately 16 flood events, which affected approximately 110.000 people and 7000 ha agricultures. Although various efforts to mitigate the effects of the floods had been undertaken, e.g. constructing flood mitigation facilities that included water pumps, the actual problems still could not be prevented. Compared to the current requirements, the facilities and infrastructure were not sufficient.

The most affected area where the flood elevation reached up to 1.25 m and the average duration of inundation is 14 days. This city is susceptible to flooding, because 80% of the contours are lowlands, whereas the city is split by the Siak river which passes through its middle. Moreover, the city and its surrounding localities are growing rapidly, and are directly contributing to landscape change.

During the floods, some areas are temporarily inundated, while the others are permanently affected. This depends on the magnitude and genesis of the flood and the topography of the inundated area.

The water level of the floods rises gradually; in the same time flow velocities are decreasing. The average duration of inundation is 14 days. These floods occur during heavy local rainfall and coinciding high tides. In the last decade the number of events in which intense local rainfall caused flood of Pekanbaru has increased due to the increasing development of infrastructure, without any consideration of the impact of the infrastructural developments on the hydrological system and the environment.

1.4 Types and Causes of Floods

Flood is generally defined as a temporary inundation of land as a result of surface waters (stagnant or flowing) escaping from their normal confines or as a result of heavy precipitation (Münicher-Re 1997; Munich-Re. 2000). In general, a distinction can be made between five different types of floods (Douben 2002; Douben 2006); river, coastal, flash, stagnant and/or urban and lake floods. In Pekanbaru, all types occur, except for the latter. However, river flooding in combination with impeded drainage is considered most important.

1) **River Flood**. Flooding in Pekanbaru occurs seasonally during the rainy season. These floods are generally the result of copious rainfall continuing for a period of days (or even weeks) over a large area. The ground surface in the Siak river basin becomes saturated and cannot copewith any more water so that the rain flows directly into the tributaries and the Siak river. The floods in the Siak river do not occur abruptly but build up gradually, although sometimes in a short period of time. Generally, they last from a few days to a few weeks. The flood affected area is usually quite extensive because the bed of the Siak river, is rather flat. This type of flood is a problem in Pekanbaru, since important buildings and service are situated in these flood prone areas. Normally, these floods negatively impact the services and buildings in Pekanbaru on numerous occasions and in some cases even reqularly.
2) **Coastal or tidal flood**. In Pekanbaru, tidal flow is a high-low water sequence repeated twice a day. High tides reduce the conveyance capacity of the Siak river. When the discharge of Siak river increases due to impeded drainage system as a result of backwater effects.
3) **Flash flood**. A flash flood is the fastest moving type of flood. It happens when heavy rain collects in a stream, turning the normally calm area into an instant rushing current. The quick change from calm to raging river is what catches people off guard, making flash flood very dangerous. Many things can cause a flash flood. Most flash flooding is caused by slow moving thunderstorms and thunderstorms that repeatedly move over the same area. Flash flood waters move at very fast speeds and generally carry a huge amount of debris with them. Most of the (illegal) human activities (logging) in the upstream part of the Siak catchment might increase the probability of flash flooding in (tributaries of) the Siak river. The river slope in the upstream stretch of the Siak river is relatively steep (0.002), which causes the quick flow of floodwater. In Pekanbaru, flooding sometimes begins to occur within 1 hour after significant rainfall. The best response to any signs of flash flooding is to move immediately and quickly to higher ground.
4) **Stagnant and/or urban flood**. When land surface is converted from fields or woodlands to build up area, road and parking lots, it loses its ability to absorb rainfall. In recent years, a vast area of undeveloped land in Pekanbaru has been used for infrastructure development and has been paved or parking lots. In these areas, rainwater cannot be absorbed into the ground and becomes runoff, inundating basements and other places. Extreme local rain combined with and/or blocked drainage may cause inundation. This type of flooding depends on topographical and soil condition and the existence of adequate drainage facilities. In Pekanbaru this type of flooding mainly occurs in the lower-lying regions near the main river.

An early identification process as presented in Table 1 is performed in order to determine the causes of flooding in the affected areas. An overview of the most frequently occurring causes indicates that the majority of the causes of floods in Pekanbaru are nearly 75% related to human interference (man-made).

Based on the early identification, floods in this area are caused due to a combination of at least three of four major types of floods.

However, according to the list of classification, river flooding with impeded drainage is considered as the most important.

***Table 1** An overview of causes and types of floods in the most affected area*

No	Cause of Floods	Types of Flood				Natural	Manmade
		River	Coastal	Flash	Stagnant		
1	Heavy rain	√		√	√	√	
2	Tide propagation		√			√	
3	Backwater				√	√	√
4	Drainage system	Maintenance			√		√
		Inadequate design and construction			√		√
5	Dikes	Maintenance	√	√			√
		Inadequate design and construction	√	√			√
6	Pumps	Capacity	√			√	√
		Operation	√			√	√
		Maintenance	√			√	√
7	Sealing ground surface (concrete and asphalt)	√		√	√		√
8	Deforestation and palm cultivation	√		√			√
9	Settlement and industrialization in flood prone areas	√	√	√	√		√
10	Garbage and waste	√			√		√

2. Remote Sensing and GIS for Surface Water Hydrology

Application of remote sensing in hydrology is intended to detect, identify and map the land surface. Hydrological interpretation of remote sensing techniques performed to estimate the appearance of landscape features interaction with hydrological processes. Distribution of runoff derived from rainfall data can be performed with the data processing and analysis using DEM (Digital Elevation Model). Data DEM derived from SRTM radar image, extraction of DEM is used as a slope map-making, as well as to assist in the interpretation of landforms. In addition, data was also analyzed DEM hydro-modeling such as network flow and the determination of land cover map derived from Landsat TM imagery. Visual interpretation of the colors used in the manufacture of composite landform map of the study area.

Processing of DEM which is derived data from SRTM radar image produced hydrological assessment of flow determination, such as watershed delineation, flow direction, sink, flow accumulation, stream order, stream link and stream line, flow length, snap pour.

2.1 D8 Flow Model

D8 model is a determination model of a stream direction based digital elevation model (DEM). It is very important in hydrology modeling in order to find out which way a landscape flows. There are eight valid output directions relating to the eight adjacent cells into which flow could travel. This approach is commonly referred to as an eight direction (D8) flow model and follows an approach presented in Jensen and Domingue (1988).

The direction of flow is determined by finding the direction of steepest descent, or maximum drop, from each cell.

D8 model is connected with ArcGIS under spatial analysis tool. Using the elevation data which is generated from DEM, it assumes that the water particles in every cell from DEM flows into the one of the nearest grid.

For every grid cell on the surface, grid processor will detect the steepest directions (Fairfield and Leymarie 1991; Tarboton 1997; Tarboton 2003; Tarboton 2005). The stream direction is a function of a point, on each matrix 3x3. On each matrix 3x3 of nearest grid cell, grid processor will stop on a central point that is in the middle and will find out the lowest region in the grid matrix 3x3.

However, it depends on the direction of a stream; each grid output will have its own value as shown as the following figure:

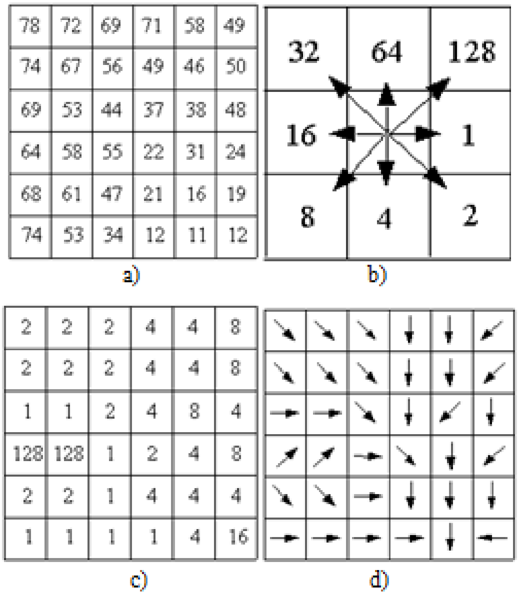

Figure 5 *The analysis of flow direction and accumulation using D8 model, a) Elevation b) Flow direction code c) The value of grid d) Arrow symbols of flow direction*

The use of remote sensing data are best used in applications in the field of surface hydrology is to relate the characteristics of the surface land surface hydrologic processes that take place. DEM data processing can be used as an analysis in knowing the direction of the flow and accumulation of runoff that took place, so as to know the sub-sub-drainage that exist in the watershed.

2.2. Raster Based-Model for Flood Inundation

Raster imagery counted that the watershed covers about 1,102,600 ha and it is originated in very different landscapes, in the highlands and in the coastal plain. The rivers in the lowland are draining mainly peat lands and palm plantations. The topography is relatively flat and the range of land slope is around 0 - 2%.

The geographical layout of the Siak river basin area is illustrated in Figure 6. The river basin area is split up into two separate river basins; upstream and downstream to determine the influence of land use developments on flooding in Pekanbaru city. Pekanbaru as a center of socio and economic activities is located on the hydrological boundary of these sub river basins. In this case, the development of these two sub river basin will strongly impact to the city and the flood management should be taken from whole these two sub river basins, not only from the city itself.

Based on the analysis of spatial, the characteristic of flood in the city is facing tidal influences from the Malacca Strait, urban/stagnant floods from city itself, flash and river floods from the upstream of the river basin. The illustration of this combination phenomenon is figured out as Figure 6.

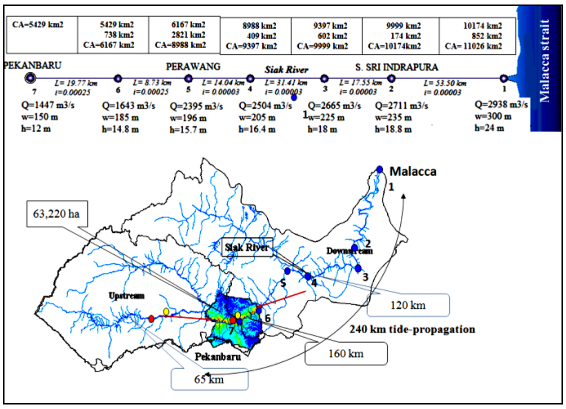

Figure 6 *The influence of upper and lower sub river basin Pekanbaru*

By considering the magnitude of the ratio of the river basin area upstream of Pekanbaru, it can be explained that Pekanbaru covers 12% of upstream watershed and 11% of downstream watershed with the total city 23% of the whole watershed.

Table 2 *The ratio of river basin area of Siak related to Pekanbaru*

No	Area/Stretch	Total Area (Ha)	Total Area of Pekanbaru related to the Siak river basin (%)
1	Pekanbaru city	63,220	100
2	Upstram to Pekanbaru	542,900	12
3	Downstream to Pekanbaru	559,700	11
4	Total area of Siak river basin	1,102,600	6

Therefore developments in the Siak river basin area have most probably a significant impact on water resources and flooding in Pekanbaru. The land use changes in the upsteam watershed might contribute significantly to flooding in Pekanbaru. A suggested approach for flood mitigation in Pekanbaru is the combination of integrated Flood Management practices in the Siak river basin area with the implementation of flood defence measures in Pekanbaru.

Flow accumulation illustrates in Figure 7, the concentration of surface runoff, the black and red pixels are the river basin where the water flows to these locations. It is compared with the actual flooding, where the spatial analysis with D8 model is similar with the actual flooding.

The more tightly the drainage network and the steep slopes of the surface flow (runoff) is getting higher, and the value of pixel and the thicker the meeting means the more capacity into surface water. At this location the flow accumulation and concentration of many streams and collected in Pekanbaru leading up to the watershed outlet.

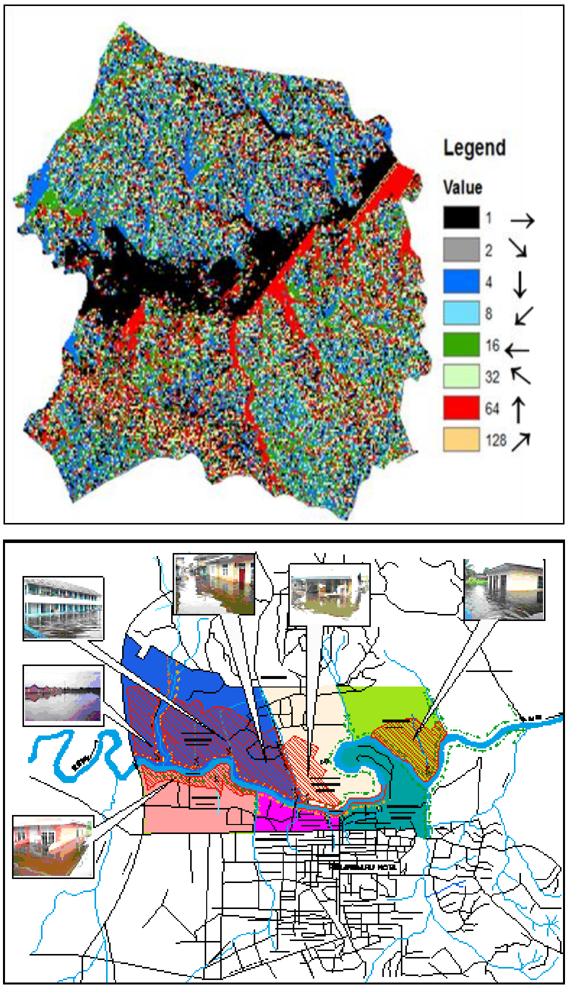

Figure 5 *The flow direction and actual flooding*

The more tightly the drainage network and the steep slopes of the surface flow (runoff) is getting higher, and the value of pixel and the thicker the meeting means the more capacity into surface water. At this location the flow accumulation and concentration of many streams and collected in Pekanbaru leading up to the watershed outlet.

2.3 Raster-Based Model for Flood Volume

The area of Pekanbaru city is 63230 Ha and flood was reached up until 1.25 m, affected a number people who live at flood prone areas. Without consideration of flood management, flood can be occurring every year due to the combination of flood types. According to analysis of raster based model for flood volume in this city, if flood reached up to 1.3 m, then there will be 12% of this city will be inundated with total volume 75 million cubic meters (see Figure 8). In fact, this area has been threatening by twice a year or yearly floods ever to reach until 14 days, even a number of flood measurements such as levee, pumps and canals have been taken.

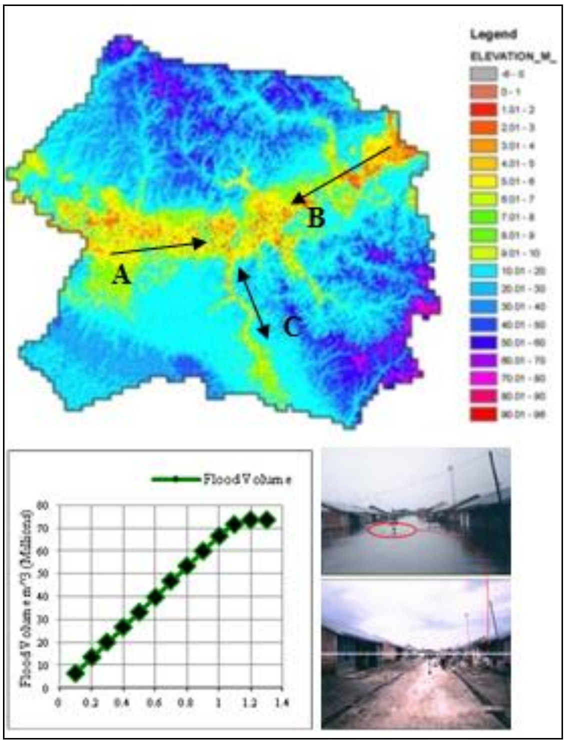

Figure 8 *The flood elevation and water volume*

3. Conclusion

Based on the research study, it is assessed that the type of flooding on delta lowland occurs by combination tidal influences, urban/stagnant floods from city itself, flash and river floods from the upstream of the river basin.

By considering the magnitude, the city ratio of the river basin is 23% of the whole watershed. Therefore developments in the river basin have most probably a significant impact on water resources and flooding in the city.

Flow accumulation and concentration of many streams and collected in the city leading up to the watershed outlet.

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