Dynamic Drainage Approach for Better Understanding of Flood in Semarang City

by L.m. Sabri

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ABSTRACT

Drainage master plan of Semarang designed at 2007 is still not able to overcome the floods. Many reasons can be addressed for this suboptimum masterplan. Some reasons are failure of pumping system and extreme rainfalls. Other reason which became the hypothetic of this research is the drainage master plan of Semarang still adopted static drainage approach. Usually the run-off will accumulate to the river or drainage system of the city. Contrary, sea tide creeps along the river or drainage system to inundate land. For the certain situation in Semarang, the streamline will change yearly due to the non homogenous land subsidence factors. This research used topographic map scale of 2000 and land subsidence map. Streamline for 2000 to 2022 periods were modeled using ArcGIS 9.3 to detect behavior of streamline affected by land subsidence. Overlaying those two models, the discrepancies of streamlines varies until hundreds meters. This dislocation of the streamlines indicated that the drainage system should be changed periodically to fit the run off dynamic. Conclusion of this research was the land subsidence parameter must be included to comprehensively understand flood in Semarang City.

Keywords: Dynamic drainage, Flood, stream line, land subsidence

1. INTRODUCTION

Semarang city is located at north coast of Central Java province. This city has very important role for business and development because of its geographic position as a node connecting western, eastern, and southern java. Beside many spatial advantages, about 20% of Semarang city whose critical central business district is also subject to the risk of coastal flooding. According to Topographic map of 2000, zero elevation area was about 100 hectares. Using the assumption of highest sea level as 68 cm above mean sea level, the area that influenced by sea was about 615 hectares.

Floods in Semarang city are almost unresolved problems. Floods, both introduced by rainfall and sea tide, occur in many days each year and inundate thousands hectares of industrial areas, public facilities, settlements, and fish ponds. Recently, some experts said that flood can not be prevented completely. The reasonable effort is just to reduce the risk of flooding. There are three options to succeed flood. First option is letting routine flood as ordinary natural phenomenon only if the impacts can be neglected. Second option is local prevention of flood applying rise up the level of street and housing. Third option is regional prevention utilized by huge drainage system that can cover all flood possibilities.

Commonly, runoff is a function of rain fall, infiltration, and evaporation and transpiration. Volume of water that inundate in certain area can be predicted using this function and multiplied it with catchment area and length of precipitation. In drowned area whose elevation below sea level, function of flood area is more complicated. Function of runoff can be simplified by neglecting the infiltration and evaporation effect, but the mixture of rainfall flood and tidal flood mechanism tends to be ambiguous function. Tidal flood propagates through the drainage system to and fro the flood plain area by a confusing function of space and time.

Masterplan of Drainage for Semarang city was designed at 2007. Implementation of the entire drainage plan needs much money and time. One of the biggest efforts is to build a kind of retention pool at estuary of Kali Mas river since two years ago. This dam is planned to hold the run off during high tide periods. Others plans documented in drainage masterplan of 2007 seem not being applied yet.

Through the years, the flood in this city is still uncontrolled. At January and February 2012, flood still inundated many places in Semarang. One of the reasonable excuse is development of drainage system planned at 2007 is still on going project. Many items plotted on drainage masterplan is still unimplemented yet. Other reason which became the hypothetic of this research is the drainage master plan of Semarang still adopted static drainage approach. Term of Static drainage approach in this paper is an approach that treats topographic as a static parameter without variable coefficient. Increase of rain fall intensity or land subsidence due to land compaction can be accommodated by enlarging drainage system or to lift the retain wall up, as seen on Figure 1.

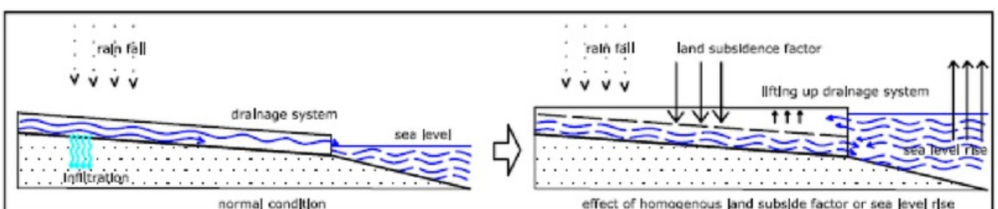

Figure 1: Lifting up the drainage system due to land subsidence and sea level rise factor

While the static drainage system assumes that the land subsidence numbers are homogenous for entire area, the dynamic drainage system applies non conformal land subsidence factor and ambiguous gravity potential. Spatial distribution and velocity of land drop tends to be heterogeneous every year. It depends on the soil layers below, ground water suction, and other factors. Changing of elevation might be followed by changing the water flow routes and dysfunction of existing drainage system (Figure 2). Another confusing problem that possibly occurs is gravity potential factor. In gravity study, falling and flowing of objects are not a function of geometrical height, but they tend to a function of gravity potential or geo-potential.

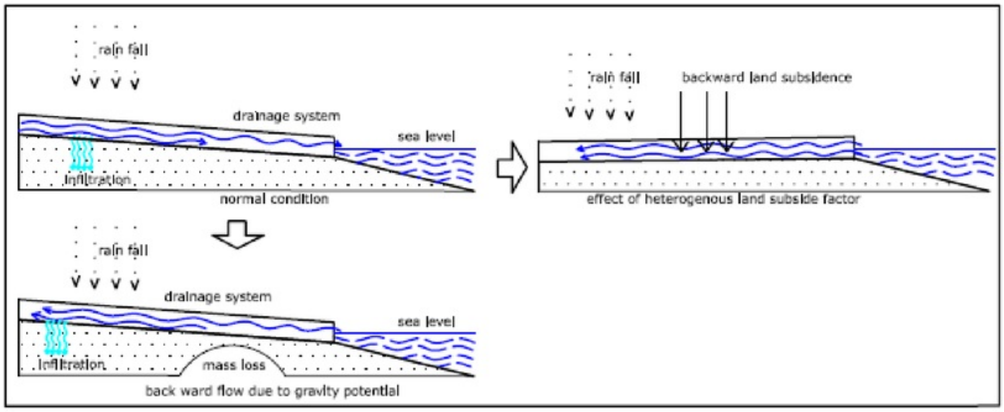

Figure 2: Failure of drainage system due to heterogeneous land subsidence factor and gravity potential change

Aims of this research are to generate the stream line model periodically based on land subsidence character and to assess the discrepancies of each stream lines.

2. METHODS OF RESEARCH

Flood, actually, is just like other natural phenomenon. Flood can occur in periods of one year, five years, ten years, or even hundred years. Flood is then categorized as disaster when it makes loss of lives and properties. Flood can be analyzed using topographic map that contain height data of the area. Increase of inundate area and frequency of flood are generally contributed by three additional factors, such as meteorological anomaly, land cover change, and land subsidence factors. Spatial data used for this research can be seen at Table 1.

Table 1: Spatial data

No.	Spatial Data	Source
1	Topographic Map, scale 1 : 5.000	Generated in 2000 from photogrammetric mapping by Dinas Pekerjaan Umum (Ministry of Public Work) - Semarang.
2	QuickBird Images	Captured in 2007 by Badan Pertanahan Nasional (National Land Agency) – Jawa Tengah
3	Land Subsidence Map	Based on 2002 to 2006 Radar Imageries published by Badan Geologi - Kementerian ESDM (Ministry of Energy and Mining)

There were many land subsidence maps available for this research. Generally, it was produced by three different methods: spirit levelling, GPS Levelling, and remote sensing. Each method has its own advantages and disadvantages. All methods introduced different land subsidence number at area of interest, as seen on Figure 3. Spirit levelling is still the best of methods in accuracy, but acquisition of dense levelling data in large area is still time consuming. Limitation of spirit levelling in size of measured area can be reduced using GPS levelling. Although GPS levelling are able to introduce the discrepancies between consecutive observations, height of the object is still in geometric term, not in physical term. In the future, an option in land subsidence study is remote sensing method, such as PS InSAR that applied in this research. This technique enables to detect the elevation area of interest in nearly continuous acquisition.

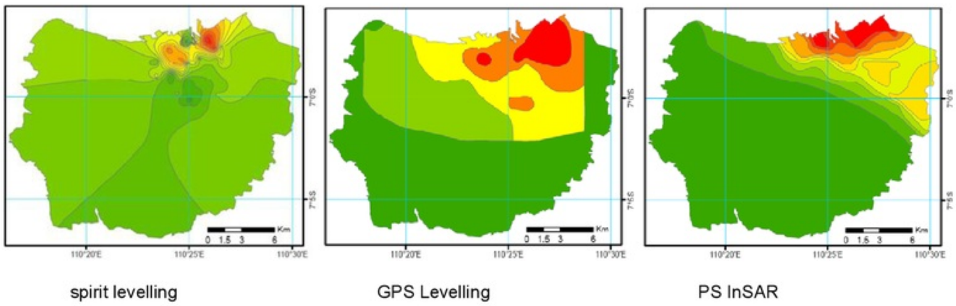

Figure 3: Land subsidence maps based on acquisition method

Equipment of Digital Elevation Model (DEM) and all inheritance data, such as Flow Direction, Flow Accumulation was ArcGIS 9.3 environment. Primary data for generating DEM were Topographic Map and Land Subsidence Map. Elevation modelling applied spot height data contained in Topographic Map. The existing spot heights were then interpolated by kriging method in Spatial Analyst tool to produce DEM of 2000. Earth surface elevation in 2007, 2012, 2017, 2022, and soon can be easily modelled by adding elevation in year 2000 with multiplication result of land subsidence and prediction interval since year 2000, as illustrated below:

$$DEM\ (t) = DEM\ (2000) + \{Land\ Subsidence\ Factor\ x\ (t - 2000)\}$$

Occasionally, DEM could not be used for hydrology analysis, because of sinking areas in the model. These area had to be filled using "Fill" tool in ArcGIS 9.3. Filled DEM were then applied as material for generating flow direction using the Flow Direction tool. Flow direction maps were then processed to introduce flow accumulation map. Flow accumulation maps in raster had to be converted into vector form for measuring dislocation of stream line between years of interest. Diagram of work flow in ArcGIS 9.3 environment can be seen in Figure 4.

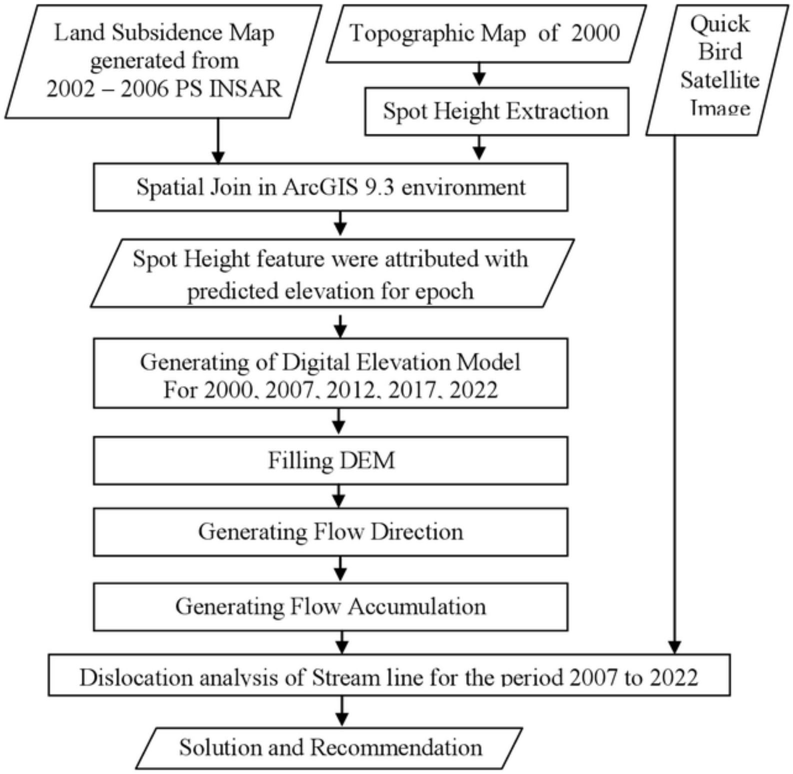

Figure 4: Flow of work

3. RESULTS

Heterogeneous land subsidence factor in entire area introduced different DEM for each predicted year. It caused streamline from 2000 to 2022 always changing. Illustration of dynamic streamline can be seen on Figure 5 as it shows water flow vectors at Tanah Mas regency – Semarang. Back to the past, Tanah Mas regency was the first real estate in Semarang. Although applying polder system and lifting up environment elevation, this area is still threatened by flood. In this area, run off direction on 2000 was same with direction of Kali Semarang River. At 2007, flow direction vector seems to rotate slightly in clockwise direction. This year, 2012, run off at Tanah Mas regency will flow to north direction. In the next ten years, at 2022, flow direction will cross Kali Mas river.

Dynamic streamline must be anticipated by introducing dynamic drainage system to prevent flood driven by runoff and tidal mechanism. Elevating the retain walls was always the common solution for overflow of the river. Run off trapped around the drainage system were then sucked by pumping system.

In fact, that solution could never be a real solution. According to hydrology modelling above, natural streamline of Semarang always changing every year. Theoretically, the natural stream line or run off must converge to man-made drainage. In urban area, this ideal condition could not be fulfilled. It is almost impossible to re-route existing river or drainage system in the city. In the past, optimizing the drainage system had been applied to Kali Semarang river by introducing incision called Kali baru canal. Apathy of people yearly living in flood plain area makes the drainage turnover more difficult.

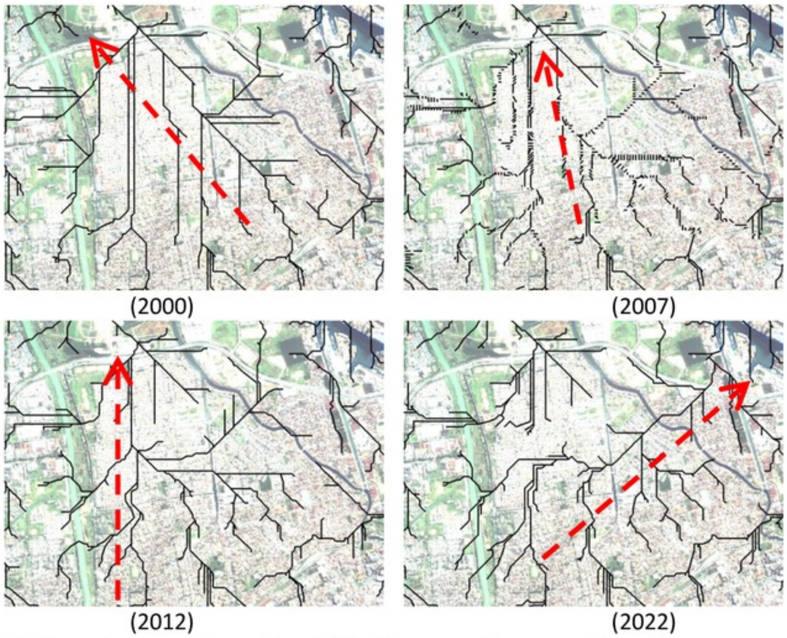

Figure 5: Dynamic streamline at Tanah Mas Regency - Semarang due to heterogeneous land subsidence

Hypothetically, this deviation will lead flood due to river overflow or sub optimum of runoff wasting system. In this circumstance, enlarging dimension of drainage system and placement of pumping system must fit to dynamics of natural drainage system. Suction equipment at least must be installed at intersection of natural streamline and unnatural streamline.

4. CONCLUSIONS

Land subsidence is a significant factor for flood occurrence in Semarang city. According to modelling result, land subsidence factor leads inconsistency of stream line in area of interest. Unconformity of stream line will increase as rate of land subsidence changing annually. Characteristic of flooding in Semarang can be traced by applying dynamic drainage approach.

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