

Title: Jakarta Flood Hazard Mapping Framework

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Mr. Brinkman is working in the field of water and flood management in Indonesia for 20 years and was team leader of this project. Marco Hartman is an expert in GIS and water management, and has been working in Jakarta since 1997. The authors work for organizations that are at the forefront of water management. Their up-to-date knowledge of water management techniques combined with their experience in Indonesia was crucial in this project.

Abstract

Every year floods occur in Jakarta. Widespread flooding occurred in 1996, 2002 and 2007, inundating up to 40% of the city. Increasing population pressure and subsidence (10 cm/year or more) of areas already under MSL lead to an autonomous increase of flood risk.

This paper describes the work and conclusions from the Jakarta Flood Management Project. The project developed a Framework to find the decisive causes of, and proper measures against flooding. Main conclusions are:

- (1) successive rainstorm in January and February cause floods in the Jakarta area,
- (2) high sea tides in combination with subsidence cause floods in the Northern part of the city and
- (3) insufficient maintenance of infrastructure aggravates the floods.

An alarming conclusion of the project is that with the juxtaposition of the high sea tides and the subsidence rate, Jakarta heads towards disaster. Up to 4 million people and approximately 25% of the city will be affected by inundation from the sea within the next 15 years if no measures are taken.

Background

Jakarta, located on the northwest coast of Java, is the economical, political and cultural capital of Indonesia. The Metropolitan area, Jabodetabek, is the 6th largest metropolitan area in the world with a little under 20 million people. About 9 million people live in Jakarta itself, in an area of 660 km² (Forstall et al., 2004). 13 Rivers intersect the city. The biggest river, the Ciliwung, finds its origins South of Jakarta, near the volcano Gunung Gede. Figure 1 shows the study area.

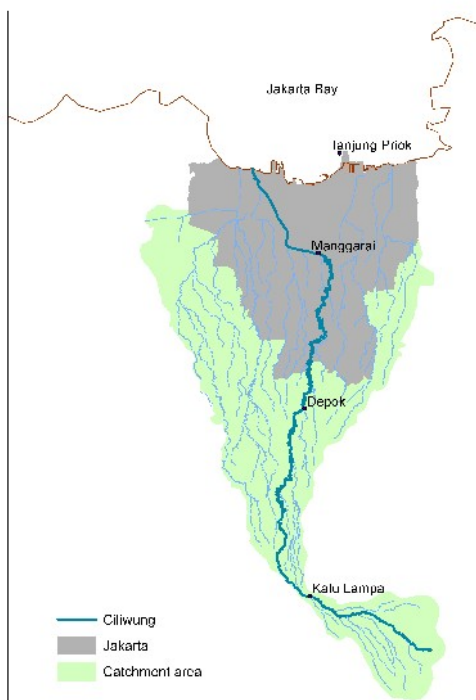
In some parts of Jakarta, flooding is a fact of life. (source: WHO, 2007) gives an overview of historic floods.

Table 1: historic floods in Jakarta

Year	Effect
1699	Ciliwung river floods old Batavia after Mount Salak erupts.
1714	Ciliwung river overflows after clearing forest areas in Puncak.
1854	New Batavia is a meter under water, caused by the raging Ciliwung.
1918	Extensive flooding. The Dutch colonial government begins work on the

Year	Effect
	Western Flood Canal (West Banjir Canal).
1942	The West Banjir Canal is completed, but Jakarta still floods.
1996	A flood sweeps through the capital. Approximately 10 people die.
2002	The Dartmouth Flood Observatory notes it as the largest flood in Jakarta's history, 25 people died.

In 2007 the greatest flood in the last three centuries inundated about 40 % of the city, killed 80 people and forced about 340.000 to flee. The authorities asked the Dutch government for help, in analyzing the cause of the flood and to assist in the preparation of non-structural measures.



This paper describes the Flood Hazard Mapping (FHM) part of the Dutch assistance. The ultimate goal of the FHM team was to describe the decisive causes of the floods by developing a FHM Framework for the Jakarta area. For a number of years, there was a lot of discussion on what could be the cause. Is it climate change? Is it subsidence? Maintenance of infrastructure? Urbanization? Reduction of areas with mangroves, construction of polders? Informal settlements? High tides? Every year during the rainy season, these discussions emerge after a flood hits the city. As a result, it was difficult for the authorities to focus on certain issues to combat the flood.

Figure 1: Study Area

For the first time ever the FHM Framework provides a comprehensive model of the Jakarta area, with which the 2007 event can be simulated and which enables the assessment of scenarios.

Description of the FHM Framework

The FHM Framework consists of 3 modules, for rainfall-runoff (RR), for hydraulics (1D) and for inundation calculation (2D).

For RR, the area is split up in 450 Hydrological Units. A Hydrological Unit database is set up, in which all available data is stored and can be visualized in ArcGIS. Data include area-elevation curves, population numbers, subsidence data, land-use characteristics and discharge methods (pump or gravity). If changes are known in the overall system (e.g. retention is planned, or new land-use data becomes available) an

updated RR model can be prepared automatically. The runoff is calculated with the Sacramento model. Rainfall is measured at 23 stations in and around the catchment area.

The Hydrological Units drain into rivers, which are modelled in a 1D hydraulic Sobek Model. 13 Rivers, in total nearly 600 kilometres long, are included; the geometry is described with about 2300 cross-sections. The most up-to-date cross sections were used. Recording dates for these cross sections varied between 1997 and 2006. In addition, the design cross-sections were stored in a database.

The third part of the Framework is the 2D inundation model, which is used to simulate overland flow in case the calculated water levels exceed the cross section. For this purpose a DEM (Digital Elevation Model) was constructed using contour lines with an interval of 1 meter and spot height measurements (about 78000). Measurements for these were done in 2005. The DEM was prepared as a TIN (Triangular Irregular Network). The 2D module of SOBEK was used for these calculations.

Calibration of the model was done using measured water levels at selected gauging stations in the system, as well as on inundated areas. Combining data from authorities on inundation and from extensive field visits the conclusion was that the Flood Hazard Mapping Framework provided adequate results (Udo et al., 2007 and Hartman et al., 2007). 18 Water level stations are situated in the catchment area. A field visit was made to all of them in order to assess the status of the stations and to propose possible improvements.

The FHM Framework was used to determine the decisive causes for flooding.

Causes – rainfall & climate change

The Jabodetabek area has a wet season that runs approximately from December till May. Maximum rainfall amounts are generally observed in January and February, due to heavy monsoon rainfall. Differences in rainfall volumes between the wet season and the dry season are especially noticed in the northern part of the Jabodetabek area. In the southern part of the area orographic effects cause relatively high rainfall amounts, even in the “dry season”.

The rainfall in the area is characterized by high intensity short duration storms. Even in the wet season, long dry spells can occur between storm events. Rainfall is generally concentrated in the afternoons and evenings, with 60%-80% of the rain falling between 14:00 and 21:00 (NEDECO, 1973).

The flood of 2007 consisted of two peak events in the downstream Ciliwung. The first peak was caused by one day of heavy rainfall in Jakarta, recorded on February 2. However, daily values are recorded at 7:00 in the morning. This means that a large proportion of the recorded rainfall on February 2 actually originate from February 1. As a result of the heavy rainfall downstream, the peak water level in the Ciliwung at Manggarai rose to 9.51 m (all water levels are with respect to local gauge datum) at

around 9:00 in the morning of February 2. There was no flood warning from upstream, because the water level upstream in Katu Lampa and Depok was not alarming. Two days later, on February 4, heavy rainfall was recorded mainly in the upstream located stations. This time Katu Lampa issued a warning. Rainfall in Jakarta on February 4 was not extremely high, but the water coming from upstream caused even higher water levels in the downstream Ciliwung than during the first peak flow (10.61 m vs. 9.51 m). The peak flow of the Ciliwung at Depok occurred on February 3, indicating that most of the cumulative rainfall in the upstream area that was recorded on February 4 (at 7.00 in the morning) actually fell on February 3. The maximum water level in the Ciliwung river at Depok was significantly higher than during the flood event of 2002: 4.92 m vs. 3.10 m. Downstream in the Ciliwung river, at the Manggarai gate, the water level was a little higher than in 2002: 10.61 m versus 10.50 m. Figure 2 shows the recorded rainfall on the 2nd and 4th of February.

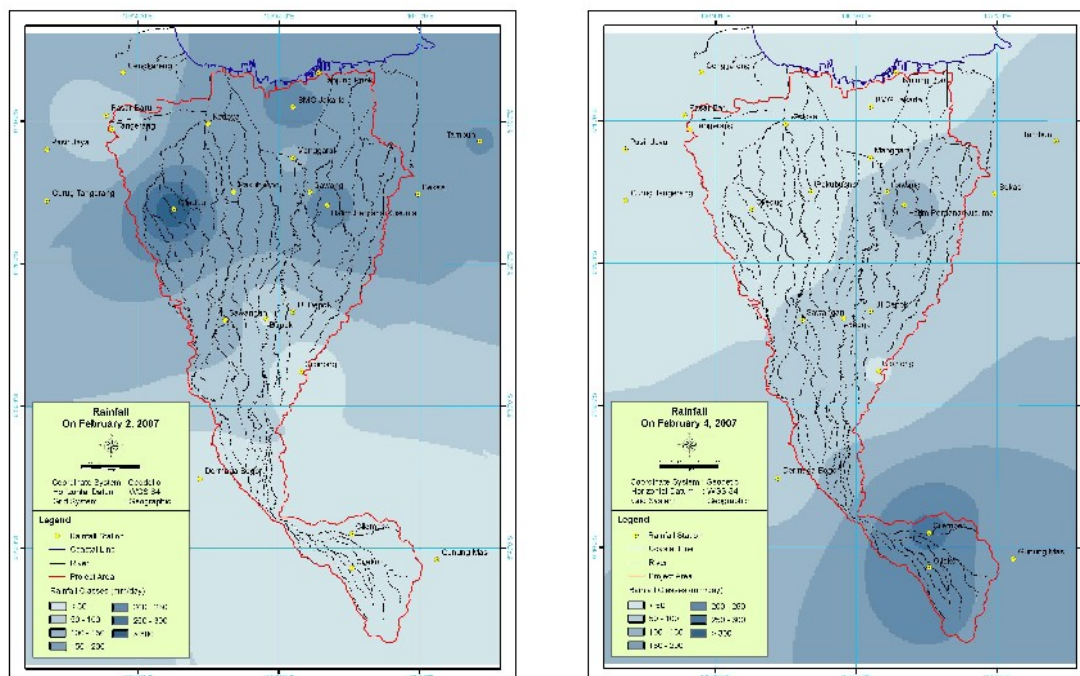
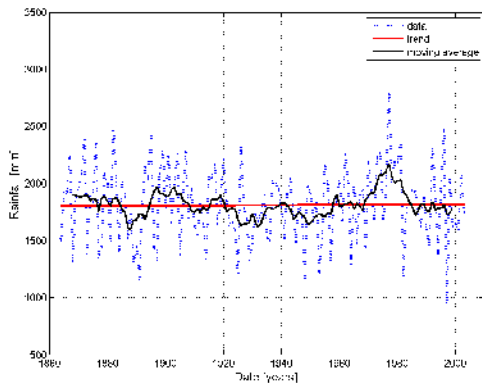


Figure 2: Rainfall events February 2007

The widespread floods that occurred in 1996 occurred early January as well as early February (NEDECO, 1997). The 2002 flood event occurred end of January / early February (NEDECO, 2002). In all cases, several successive days of intense rainfall were recorded.

Long rainfall records were analyzed to determine the possible impact of climate change. The only dataset available for this are the monthly totals, which are recorded since 1860. A trend analysis is presented in the following figure. The trend line is horizontal, indicating no clear trend. The moving average shows a distinctive peak in the 1970's, but after that period it fluctuates around the average.



The outcome of this analysis does not exclude the possibility that climate change has an effect on rainfall in and around Jakarta, since it could have impact on the intensity of showers, or other characteristics. It does show however that statements about climate change being the cause of the floods problems cannot be proven with the current available data.

Figure 3: Trend analysis monthly rainfall

The following conclusions are drawn with respect to hydrological and meteorological characteristics of the flooding in Jakarta:

- Flooding from heavy rain mainly occurs in January or February.
- Clear distinctive successive rainstorms often cause Jakarta floods.
- Wet antecedent conditions add to the problems.
- Effects of climate change are not evident.

Causes – high tides & subsidence

The maximum tide levels have been analysed, based on predicted water levels (Diermanse, 2007) covering a 100-year period (1920 to 2020). For the prediction of the tidal water level, the tidal constituents for Tanjung Priok, have been used. From this 100-year predicted water level, the maximum spring tide levels have been taken. These are plotted in Figure 4.

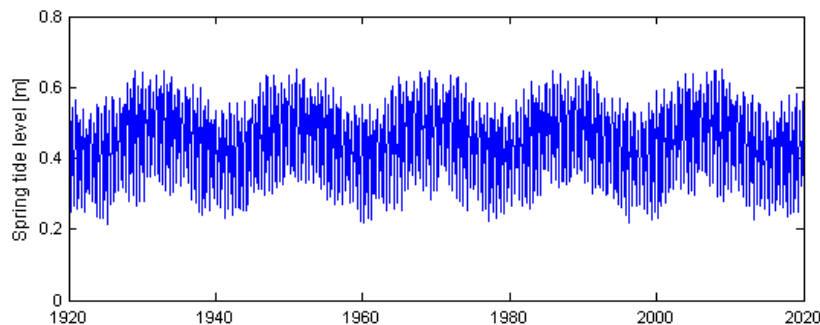


Figure 4: Maximum spring tide levels at Tanjung Priok from 1920 to 2020 based on water level predictions.

The maximum spring tide levels in Figure 4 clearly show a periodicity between 18 and 19 years. This periodicity is caused by the fact that the moon's orbit around the earth is elliptical. Therefore, the moon is never at the same distance from the earth from one month to the next. It takes 18.6 years for this cycle to repeat. It is clear that between 2005 and 2010 this 18.6 years cycle reaches a peak.

From the analysis (Diermanse, 2007) it was concluded that during the 2007 flood, the maximum tidal levels were not exceptionally high. It appears that during the 2007

flood, the high waters were fortunately not at the maximum of the occurring spring-neap tide cycle.



Figure 5: Flooding as a result from high tide, November 2007, North Jakarta

During the analysis of the tides, it became apparent that the peak of the 18.6 years cycle occurs around 2007 / 2008. From the FHM Framework a forecast was made that the end of November 2007 the high tide will result in widespread flooding in North Jakarta.

The forecast was spot on: a large part of the city was flooded, while there was no rain at all, only a very high tide (see Figure 5 for an impression, on the left side you see the sea defence wall). The toll road, connecting Jakarta with the International Airport had to close and numerous flights were cancelled. About 18 years ago, nothing did happen due to the fact that subsidence was not an issue yet.

Figure 6 shows the recorded subsidence in Jakarta. It is obvious that the further North, the larger the subsidence is, up to 12 cm per year. Subsidence was not a direct cause for the 2007 floods, but increased the depth and duration on some areas.

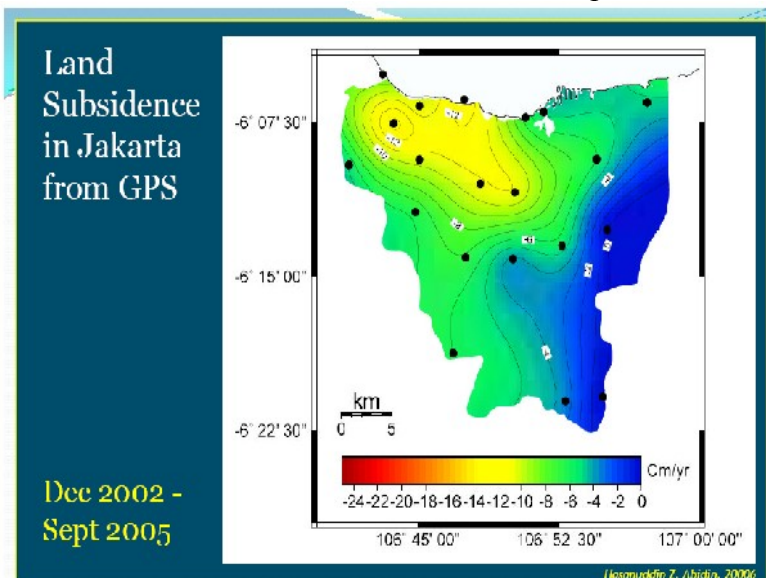


Figure 6: Recorded subsidence in Jakarta [Hasanuddin Z. Abidin, 2006].

A worrying prospect is that subsidence is still ongoing and, according to recent measurements, the rate increases. Figure 7 pictures the scenario for Jakarta in 2025, when a new peak of 18.6 years cycle will happen.

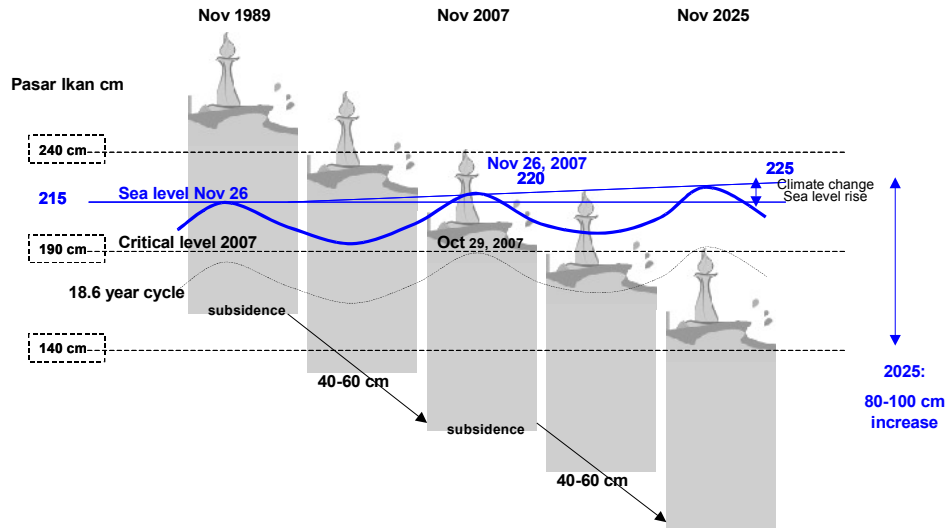


Figure 7 Tides and subsidence

Over the next 18.6 years North Jakarta continues to subside at least 50 cm (which is still a conservative estimate). During the first 9 years, flooding from the sea will continue on a regular basis, but be similar or less to the floods of November 2007. Then, from 2016, Jakarta continues to go down, while the tide levels rise again. By 2025 maximum spring tide will rise at least 80-100 cm above the current sea defence, causing disastrous floods in North Jakarta.

Apart from flooding, the effects of subsidence will be considerable. Large parts of Jakarta will face drainage problems and more and bigger pumps are required. Groundwater will become more saline, subsequently causing problems for the large number of households that depends on groundwater for daily water supply.

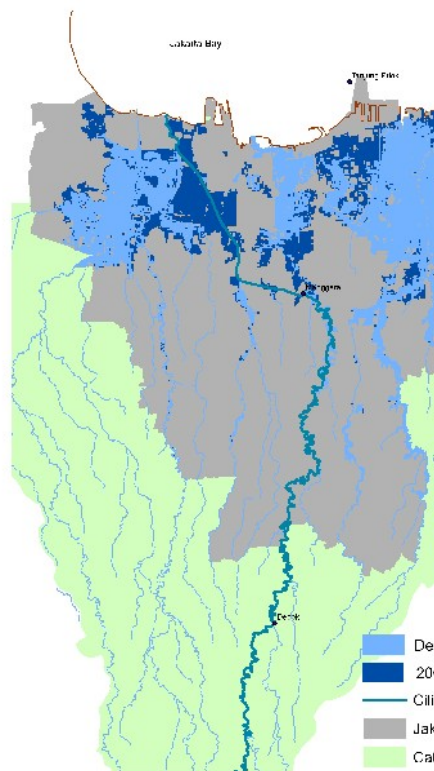
Research is ongoing to find the decisive causes for the subsidence. It is most likely that groundwater extraction is the main driving force. Research is ongoing to assess how subsidence continues in the future, and to forecast how long it will continue

Conclusions

- Sea water levels were not significantly high during the 2007 flood events and did not contribute to the flood.
- Subsidence (1) causes the Jakarta sea defence to sink below critical levels and (2) has major impact on the quality of live in the city.
- From 2016 flooding from the sea will occur more often, resulting into disastrous floods in 2025.

Causes - maintenance

The FHM Framework was set up with the most up-to-date dataset. Results of the inundation pattern were similar as to what happened in 2007.



Analyses were done to assess what would have happened in case regular maintenance was carried out (i.e. in case cross sections are in accordance with the design). The results are shown in Figure 8.

The (underlying) dark blue shows the extent of the flood in 2007, as calculated by the FHM framework. The lighter blue shows the extent in case the whole system was in accordance with the design.

In 2007, the floods affected the lives of 2.6 million people in Jakarta. In case all canals were in accordance with the original design, 1.6 million people would have been affected.

The conclusion is that about 40 % reduction in flood risk could be reached in case maintenance was carried out regularly.

Figure 8: Flood Extent Map for 2007 and design condition.

Measures

The results of the FHM Framework triggered authorities to implement, or speed up implementation of, measures to mitigate flooding in Jakarta, such as:

- Construction of a temporary sea defence wall in North Jakarta.
- Speeded up construction of the elevated toll road to the airport, in order to safeguard its accessibility.
- Starting pilot projects to restore the canals to its original design and to show the possibilities of dredging in an urban environment.

The World Bank launched the JEDI project: Jakarta Emergency Dredging Initiative. The project aims to restore the majority of Jakarta's canals to original design.

Road ahead

Though the activities mentioned above will mitigate flooding from the sea in the short term and mitigate floods as in 2007 on the longer term, the prospect for the northern part of Jakarta remains troublesome. Doing nothing is not an option. Fortunately, there is a growing awareness that actions have to be taken. The FHM Framework is a unique and comprehensive instrument to assess various options such

as large-scale polder construction in the North or the creation of an inner-lake just North of the city in Jakarta Bay. Stakeholders will be challenged to decide about the future of the North Jakarta.

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