Geographic Information System and Remote Sensing Approach with Hydrologic Rational Model for Flood Event Analysis in Jakarta

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Abstract. Rapid development in Jakarta which generates more impervious surface has reduced the amount of rainfall infiltration into soil layer and increases run-off. In some events, continuous high rainfall intensity could create sudden flood in Jakarta City. This article used rainfall data of Jakarta during 10 February 2015 to compute rainfall intensity and then interpolate it with ordinary kriging technique. Spatial distribution of rainfall intensity then overlaid with run-off coefficient based on certain land use type of the study area. Peak run-off within each cell resulted from hydrologic rational model then summed for the whole study area to generate total peak run-off. For this study area, land use types consisted of 51.9 % industrial, 37.57% parks, and 10.54% residential with estimated total peak run-off 6.04 m³/sec, 0.39 m³/sec, and 0.31 m³/sec, respectively.

Keywords: Run-off, Impervious surface, Flooding, Jakarta

1. Introduction
Nowadays, there are changing views about Geographic Information System (GIS) definition which not only seen as a computerized system but also as integrated software and hardware used to develop and analyze data for problem solving [1].

Recently, GIS platform has been used to integrate spatial database (Digital Elevation Mode (DEM), land use type, soil map, rainfall, slope, and drainage area) to calculate peak run-off with hydrological rational model [2]. Moreover, locations with high risk flood can be assessed by analyzing areas which have total peak run-off estimation based on rational model which was combined with arithmetic overlay [3]. On 9-10 February 2015 there was massive flood event in Jakarta Province, where two days of heavy precipitation from 9 – 10 February 2015 was classified as very exceptional [4].

Therefore, to give more detail about flood event analysis on 9-10 February 2015, this article uses both GIS & remote sensing approach with hydrological rational model to observe peak run-off spatial distribution on specific location in Jakarta Province, Indonesia.

1.1. Study Area
Study area is located in Grogol Petamburan sub-district as a part of West Jakarta Municipality, with population of 223,604 people in 2016 [5].
This unit of analysis is also positioned between two major rivers flow in Jakarta Province, Pesanggrahan and Ciliwung River. Based on GIS assisted geometry calculation, total area of this spatial unit is 1.53 sq km (Figure 1).

![Figure 1. Study area](image)

**Figure 1.** Study area

2. Methods
To describe each step to gain result of peak run-off spatial analysis from GIS and hydrologic rational integration, a framework has been made in Figure 2.

![Figure 2. Framework for integrated GIS & remote sensing approach with hydrologic rational model](image)

**Figure 2.** Framework for integrated GIS & remote sensing approach with hydrologic rational model
2.1. Data
In order to compute rainfall intensity, rainfall data were downloaded from Indonesian Meteorology and Geo-physics Agency website [6] which provided report about the flood event of Jakarta Province within 8-10 February 2015.

In addition, flood locations were downloaded from website of Indonesian Natural Disaster and Mitigation National Agency [7]. This map then digitized to become spatial database of flood locations. Furthermore, to analyze the land use type within flood location, Google Earth images dated 25 August 2015 were downloaded.

Table 1. Data used

| Name                                   | Data type     | Data processing with GIS or remote sensing technique |
|----------------------------------------|---------------|------------------------------------------------------|
| Rainfall data 8-10 February 2015       | spreadsheet   | Query selection by attributes                        |
| Flood locations                        | map           | Digitize                                             |
| Google Earth images 25 August 2015     | RGB images    | Unsupervised image classification                     |

2.2. Geographic Information System
In this article, kriging plays an important role, where it interpolates rainfall intensity value based on several rainfall stations.

Once it gets the cell with specific information of rainfall intensity for every pixel, it can be multiplied with run-off coefficient. Moreover, with the help of raster calculator function of ArcGIS software, the value of in every cell can generate the peak run-off information. Another important function of GIS used in this study is masking capability where it could detach selected raster cell of study area from the classified raster cells.

2.2.1. Ordinary kriging (OK). Ordinary kriging was used to interpolate rainfall intensity data of 10 February 2015. OK works by using constant mean (µ), while the objective of using ordinary kriging is to make interpolation smoother based on data trend [8]. OK has been applied successfully to interpolate rainfall data both yearly and monthly in Sri Lanka though minimum values were overestimated and maximum values underestimated [9].

2.3. Rainfall intensity
To predict rainfall intensity, this article uses Mononobe equation [10]:

\[ I_t = \frac{R_{24}}{24} \left( \frac{24}{t} \right)^m \]  

where
\( I_t \) = Rainfall intensity (mm/hour)
\( R_{24} \) = 24-hour rainfall duration t
\( m \) = 2/3

2.4. Hydrologic rational model
To compute hydrological rational model with per-pixel analysis, Equation (2) [2,3] was used:

\[ Q_p = C \times I \times A \]  

where
\( Q_p \) = Peak run-off (m³/sec)
\( C \) = Run-off coefficient
\[ I = \text{Rainfall intensity (mm)} \]
\[ A = \text{Drainage area (in this case pixel unit at spatial resolution 1.6 m x 1.6 m)} \]

2.5. *Image processing*

To acquire land use type in the study area, image processing were performed by employing these steps;

- Download high resolution image from Google Earth dated 25 August 2015.
- Image geometric correction by using orde-3 polynomial method.
- Unsupervised classification using ISODATA clustering to get 3 land use type namely; industrial, residential, and parks.

2.6. *Run-off coefficient*

Run-off coefficient is needed for every pixel in land use type which was generated from unsupervised image classification from Google Earth image. In addition, this article uses run-off coefficient in Table 2.

| Land use type                          | C (median) |
|----------------------------------------|------------|
| Industrial heavy areas                 | 0.75       |
| Residential, multi units-detached      | 0.50       |
| Parks                                  | 0.125      |

3. *Result and discussion*

Using Equation (1), rainfall intensity from 12 stations can be predicted (Table 3). Furthermore, it can be observed from Table 3 that the highest rainfall intensity occurred in Tanjung Priok rainfall station while the lowest was in Soekarno-Hatta Airport.

| Number | Rainfall stations                          | Rainfall intensity (mm/hour) |
|--------|-------------------------------------------|------------------------------|
| 1      | Pintu Air Pulogadung                      | 22.07                        |
| 2      | Jembatan Panus, Depok Jawa Barat          | 8.44                         |
| 3      | Stasiun Meteorologi Kelas I Soekarno-Hatta Cengkareng | 0.73                      |
| 4      | BMKG Citeko                               | 3.16                         |
| 5      | BMKG Jl. Angkasa No.2                     | 16.07                        |
| 6      | Stasiun Klimatologi Bogor                 | 7.22                         |
| 7      | Stasiun Meteorologi Maritim Tanjung Priok | 29.29                        |
| 8      | Pintu air Kali Pesanggrahan Kedoya        | 17.28                        |
| 9      | Pintu air manggarai                       | 17.36                        |
| 10     | Pintu air cideng                          | 17.04                        |
| 11     | Pintu air Sunter                          | 9.41                         |
| 12     | Pintu air karet                           | 14.44                        |
| 13     | Angke hulu                                | 5.11                         |
| 14     | Krukut hulu                               | 7.30                         |
| 15     | Pintu pesanggrahan depok                  | 17.36                        |
| 16     | Pasar Teluk Gong                          | 16.39                        |
| 17     | Waduk Kebon Melati                        | 14.68                        |
| 18     | Rorotan                                   | 21.18                        |
| 19     | Ragunan Zoo                               | 6.41                         |
| 20     | Presidential Palace                       | 7.87                         |
3.1. Rainfall intensity interpolation with ordinary kriging

Rainfall intensity interpolation using OK is displayed in Figure 3 (A), where higher rainfall intensity can be observed close to the northeast of Jakarta Province.

In addition, it can be visually observed from Figure 3 (B) that most flooded areas were located in the north-eastern part of Jakarta Province.

![Figure 3](image)

**Figure 3.** (A) Rainfall intensity spatial distribution using OK, (B) spatial distribution of flood event February 2015 (data processing from [6] [7])

3.2. Peak run-off spatial distribution

In terms of spatial analysis, spatial distribution of peak run-off is displayed in Figure 4. Most of the study area was dominated by industrial land use type with approximately an area extent of 0.79 sq km (51.91%), which resulted in estimated peak run-off 0.028 m³/hour/pixel.
Moreover, the smallest land use type was residential with an area extent of 0.16 sq km, and predicted peak run-off 0.09 m$^3$/hour/pixel. Surprisingly, this area also had parks around 0.58 sq km (37.57%) which was located in the eastern part. For further analysis, the study area which is surrounded by two major rivers, Pesanggrahan and Ciliwung River, make it unfavorable since the water level from those rivers might also exceeded riverbanks. Therefore, for further study the distance from river could be included in the analysis not only limited to spatial hydrology analysis.

In terms of estimated total peak run-off from the study area, the biggest came from industrial land use type with approximately 6.04 m$^3$/sec, followed by residential (0.39 m$^3$/sec) and parks (0.31 m$^3$/sec), respectively (Figure 5).

4. **Conclusion**

By combining both GIS and remote sensing with rational hydrological model, this study has managed to reach its objectives that is to display information about peak run-off spatial analysis. The biggest total peak run-off came from the eastern part of the study area where it was dominated by industrial land use, while the smallest total peak run-off mostly resulted from the western part.
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