Mapping flooded risk area in East Java Indonesia using remote sensing data

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Abstract. Flooded risk area describes the potential ease of an area to experiencing flooding. Several natural factors such as intensity, duration, and distribution of rainfall, land use / land cover, slope of the area, and soil type can affect the risk of flooding. This study aims to create the flooding risk map level of an area. Those parameters which affect the risk level are classified to be marked and weighted. The equation called Kingma algorithm is then applied to the weighted parameters to get the risk level value. The results are then classified and mapped into 3 classes of risk level that are safe, risky, and highly risk. This study showed that the highly risk areas are located in the flat area, low infiltration soil, and high intensity of rainfall. In contrast, the steep slope areas with high infiltration level of soil and still have a lot of vegetation growing.

1. Introduction
Flooding is an event where land which is usually dry or non-swampy areas becomes flooded [1]. This caused by several parameters including the high rainfall [2] and topography area in the form of lowlands to sunken, and low ability of soil infiltration, which causes the soil is no longer able to absorb water [1]. Floods usually occur in the lowlands, namely the downstream area. These flood events always occur repeatedly which results in the carrying of sediment material deposited in certain places, thus causing the occurrence of new lands formed by flooding. The shape of the land formed by the flood includes, among others: natural embankments, floodplains, back swamps, deep curved charred and former rivers [3].

East Java is a province located at the eastern end of the island of Java. East Java Province is located between 111°, 0′-114°4′, 4′ East Longitude and 7°, 12°-8°, 48′ South Latitude [4]. The excessive rainfall intensity will cause problems that result in disasters such as floods, landslides and others. Floods in East Java occurred 86 times in 2018, and 96 in 2019 [5]. To avoid the large losses incurred due to flooding, it is needed to provide the flooding risk area in East Java. This information is generated based on the flood vulnerability which is defined as a condition that describes whether or not an area is affected by flooding based on natural factors that affect flooding including meteorological factors (rainfall intensity, rainfall distribution, frequency and duration of rainfall) and characteristics of watersheds (land’s slope, soil type and land use) [6].

To figure the flood-prone areas, this study used remote sensing technology, which is defined as science and art to obtain information from an object, area, phenomenon through data analysis obtained using a device without direct contact to the object, area, or phenomenon studied. The device in this
manner is a sensing device (sensor). The sensors used in remote sensing are artificial sensors (sensors which are designed and produced by mankind for some purpose such as optical sensor in digital cameras [7]. Technology and data remote sensing can accommodate the need for mapping flood-prone areas for larger areas and are obtained free of charge. Free data remote sensing that is available for free with high temporal resolution is also available as well as Landsat-8 and DEM SRTM data. Landsat-8 is a satellite built in April 2008 which is a collaborative mission between NASA and USGS (US Geological Survey) with the division of responsibilities respectively. The provision of Landsat-8, instruments, launchers and elements of mission operations of the Earth Station System are part of NASA's responsibility [8].

Flooding area had been detected remotely using satellite optical data [9, 10], Radar data [11, 12], and DEM [13]. DEM (Digital Elevation Model) is a 3-dimensional shape of the earth's surface that provides data on various earth surface morphologies such as slope, slope aspects, land height and watershed area [14]. SRTM (Shuttle Radar Topography Mission) is a satellite vehicle equipped with a wave generator synthetic Aperture Radar Interferometry (InSAR) which was launched in 2000. SRTM data is a remote sensing product that produces DEM with 30 meter and 90 meter spatial resolution [15].

Previous study related to flood vulnerability has been conducted and discussed the analysis of flood prone areas [16]. The research was conducted in Kebumen District, Kebumen Regency of Central Java province of Indonesia. The study was a descriptive quantitative using Geographic Information System (GIS) technology. The data utilized are rainfall, land cover, altitude, slope and land system. The model used was Composite Mapping Analysis (CMA) to find the weight of each data which is then used as a determinant value in the level of flood hazard. The results of the study showed that the greatest causes of flooding in Kebumen District were rainfall and also its altitude. In line with previous studies, this manuscript aims to obtain a map of flood vulnerability in the area of East Java Province based on rainfall data, land cover data processed from Landsat-8 imagery, DEM SRTM data and soil types.

2. Methods

2.1. Study Area and Datasets
The study area was focused in East Java province of Indonesia. This province lays in 111°0'-114°4' E and 7°,12'-8°48' S. Occurring flood in East Java province was recorded 86 times in 2018 and 96 times in 2019, so mapping flooded risk area in this province is considered important to do. The data used in this study are rainfall data for six months recorded by Meteorology Climatology and Geophysics Agency (BMKG), satellite data i.e. SRTM and Landsat-8 OLI/TIRS downloaded from the earth explorer website and soil type map data from the Ina geospasial website. Indonesian district boundary administration acquired from www.info-geospasial.com was also utilised in this study to describe the flooded risk area locations.

2.2. Processing Data
The flood-prone areas is determined according to the pixel values of flood risk which is calculated mathematically using the equation written by Kingma Kingma [17]. The flood risk’s pixel values are then classified into several classes of risk categories regarding to the number of parameters considered in the calculation process. This study used 4 parameters (rainfall, land use, land slope, and soil type) in the flood risk calculation as written in Table 1 up to Table 4.

| Category          | Daily rainfall (mm/hour) | Index |
|-------------------|--------------------------|-------|
| Very heavy rain   | >100                      | 5     |
| Heavy rain        | 51-100                    | 4     |
| Moderate rain     | 21-50                     | 3     |
| Light rain        | 5-20                      | 2     |
| Very light rain / drizzle | <5            | 1     |

Source: [18]
Table 2. The classification of land use.

| Land Use Type                  | Index |
|------------------------------|-------|
| Forest / Dense vegetation    | 1     |
| Bush                         | 2     |
| Fields / plantations         | 3     |
| Rice field / Swamp           | 4     |
| Settlement / urban area      | 5     |

Source: [19]

Table 3. The classification of land slope.

| Slope (%) | Category              | Index |
|-----------|-----------------------|-------|
| 0-8       | Flat surface          | 5     |
| >8-15     | Ramps / Sloping land  | 4     |
| >15-25    | Quite steep           | 3     |
| >25-45    | Steep                 | 2     |
| >45       | Very steep            | 1     |

Source: [18]

Table 4. The classification of soil type.

| Soil Type                                    | Infiltration  | Index |
|----------------------------------------------|---------------|-------|
| Aluvial, Planosol, Grey Hidromorf, Laterite  | Not sensitive | 5     |
| Latosol                                      | Quite sensitive | 4    |
| Brown forest soil, Mediteran soil            | Mid sensitive | 3     |
| Andosol, Lateric, Grumosol, Podsol, Podsolic| Sensitive     | 2     |
| Regosol, Litosol, Organosol, Renzina         | Very sensitive | 1     |

Source: [20]

The processing data was divided into three steps that are parameters classification and mapping, calculating the risk area values, and classification and mapping flooded risk area. The four parameters which are involved in this study are classified based on Table 1 – Table 4. The classification results are then mapped and overlaid with district administration’s border to see the distribution of each parameter. Each class of the classified those four parameters i.e. rainfall classification, land slope classification, land use classification, and soil type classification was marked by the weight index as a reference values to be calculated using equation (1) to determine the flooded risk area values [17].

\[ K = a \times X_{(CH)} + b \times X_{(Lu)} + c \times X_{(Ls)} + d \times X_{(So)} \]  

(1)

Note:
\( K \) : Flood Risk value  
\( X_{(CH)} \): Rainfall index  
\( X_{(Lu)} \): Land use index  
\( X_{(Ls)} \): Land slope index  
\( X_{(So)} \): Soil Type  
\( a, b, c, d \) : Weight constant of each variable

All the flood risk values over the East Java province are then classified into several classes and the number of classes is determined using Strugges equation as written in equation (2) below.

\[ K = 1 + 3.3 \log N \]  

(2)

where:
\( K \) : the number of classes
To see the distribution of flooded risk area within East Java province, the map of those resulted three classes risk area is overlaid to the district border administration.

### 3. Results and Discussion

#### 3.1. Rainfall

The rainfall data obtained from BMKG are classified regarding to the table 1 and it showed that the average values of rainfall data in East Java categorized as light rain and very light rain only (see Table 5). It is also given the rain score as a reference value for flood risk area calculation.

| Daily rainfall (mm/hour) | Category          | Weight constant (a) | Rainfall Index ($X_{CH}$) | Rain Score (a * $X_{CH}$) |
|--------------------------|-------------------|---------------------|---------------------------|---------------------------|
| 5-20                     | Light rain        | 5                   | 2                         | 10                        |
| <5                       | Very Light rain   | 5                   | 1                         | 5                         |

The value of each rainfall class is figure out into the map to describe the average rainfall distribution as shown in Figure 1. The figure shows that four districts in the east part of East Java province have very light rainfall and the other districts have light rainfall.

![Figure 1. The map of rainfall classes in East Java 2019.](image-url)

#### 3.2. Land Use

The map of land use was produced based on Landsat-8 OLI/TIRS data acquired from earth explorer USGS website. The Landsat data was classified into 5 classes of land use as shown in Table 6 using supervised classification method.
Table 6. Results of the classification of land use.

| Category            | Weight constant (b) | Land use Index ($X_{Lu}$) | Land use Score ($b \times X_{Lu}$) |
|---------------------|---------------------|---------------------------|----------------------------------|
| Settlement / Housing| 2                   | 5                         | 10                               |
| Rice field          | 2                   | 4                         | 8                                |
| Bare land / bush    | 2                   | 3                         | 6                                |
| Forest / trees      | 2                   | 2                         | 4                                |
| Water body / sea    | 2                   | 1                         | 2                                |

The map of land use classification and its distributions in East Java province is displayed in Figure 2. The figure shows that the most area in East Java was classified as forest (green colour) and settlement (light brown). Rice fields shown in dark green colour is still appear a lot among the settlement area. The districts which have a lot of forest are Banyuwangi, Situbondo, Bondowoso, Bojonegoro, Nganjuk, Madiun, Ngawi, Sumenep, Jember, Malang, Trenggalek, Pacitan dan Pamekasan. It indicates that those districts still have a lot of vegetated area and potentially safe from flood’s hazard. Meanwhile the settlement areas are found mostly in the town such as Surabaya, Pasuruan, Probolinggo, Malang city etc.

Figure 2. The map of the land use in East Java 2019.

3.3. Land Slope
Land slope was generated from DEM SRTM data. The DEM SRTM data was processed to produce contour map. Land slope was calculated based on contour map by dividing the difference of adjacent land elevation to the distance between those two contour lines. The land slope values are then classified according Table 3. It was found that the land slope in East Java province can be categorized in 5 classes as shown in Table 7 below.
Table 7. Results of land slope classification score.

| Land slope (%) | Category            | Weight constant (c) | Land slope Index ($X_{Ls}$) | Land slope Score ($c * X_{Ls}$) |
|----------------|---------------------|---------------------|-----------------------------|---------------------------------|
| 0-8            | Flat surface        | 3                   | 5                           | 15                              |
| 8-15           | Ramps / Sloping land| 3                   | 4                           | 12                              |
| 15-25          | Quite Steep         | 3                   | 3                           | 9                               |
| 25-45          | Steep               | 3                   | 2                           | 6                               |
| > 45           | Very steep          | 3                   | 1                           | 3                               |

The map of land slope distribution written in Table 7 is shown in the colour map as displayed in Figure 3. The grade of the slope class indicated by land slope index is then multiplied by the weight constant of the slope, i.e. 3, and the result is given in the last column of Table 7. These values are then inputted to the equation 1 to get the risk values. Because of equation 1 is linear, it is obviously that flat surface with slope 0-8% has the biggest contribution to the risk level (the most potential to be flooded) compare to the opposite land slope which is very steep land slope (>45%).

![Figure 3. The map of the land slopes in East Java 2019.](image)

3.4. Soil Type
The classification results of soil types can be divided into 5 classes according to their sensitivity level of infiltration or water absorption. The classification was built according to the soil type data retrieved from the Ina Geoportal websites within East Java province. The classification results and their index and scores are written in Table 8.
Table 8. Classification of soil types result.

| Category                                      | Weight constant (d) | Soil type Index \(X_{So}\) | Soil type Score \((d * X_{So})\) |
|-----------------------------------------------|---------------------|-----------------------------|----------------------------------|
| Alluvial, Planosol, Gray Hydromorph, Laterite| 2                   | 5                           | 10                               |
| Latosol                                       | 2                   | 4                           | 8                                |
| Brown forest soil, Mediterranean soil         | 2                   | 3                           | 6                                |
| Andosol, Lateric, Grumasol, Podsol, Podsolic | 2                   | 2                           | 4                                |
| Regosol, Litosol, Organosol, Renzina          | 2                   | 1                           | 2                                |

Data in Table 8 showed that soil types which have the highest scores are the soil types that are difficult to absorb water and oppositely the soil types which have the lowest scores are the soil types that is easily absorb the rain water and lead to the safe condition from flood. The alluvial, planosol, gray hydromorph, and laterite soil types have a lowest sensitivity level that is not easy to absorb water. Therefore the areas that have those type of soil s are prone to deal with flood in the rain season because the rainwater will remain in the areas for long time before the water is passed to the sub-surface. Thus these soil types are given the highest score to the flood risk determination algorithm.

Figure 4. The map of soil types in East Java 2019.

3.5. Flood Hazard Map

Once all the involved parameter data are acquired, classified, and scored, the step of risk level calculation can be performed refer to the equation (1). This study found that the risk level values in East Java province of Indonesia are in between 14 and 45. The result values are then classified into flood hazard categories as seen in Table 9.
Table 9. Results of the calculation flood vulnerability value.

| Description of flood hazard          | The flood level value |
|--------------------------------------|-----------------------|
| Very risky or very vulnerable        | 35-45                 |
| Flooded Prone                       | 25-35                 |
| Safe from flood hazard               | 14-24                 |

Table 9 shows that the classification results of flood level in East Java have 3 categories that are very risky, prone and safe. The distribution of each category is displayed in Figure 5. The figure shows very risky are in dark brown colour, flooded prone area with brown colour, and the last category i.e. safe area from flooded is figured with light brown colour. The very risky areas are mostly observed in the dense population city such as Surabaya, Pasuruan and Malang or in the areas that near to the coast such as Pacitan, Trenggalek, and Blitar.

![Figure 5. The map of flood risk area in East Java 2019.](image)

4. Conclusion
Based on the study results that have been conducted, it can be concluded that the flood hazard map was done using rainfall data, remote sensing data from Landsat-8 imagery and DEM SRTM, as well as maps of soil types. Map of flood vulnerability in East Java has 3 level of flooded risk areas namely very risky or very vulnerable, flooded prone, and safe from flooded hazard.

References
[1] Seyhan E 1990 Dasar – Dasar Hidrologi (Yogyakarta: Gadjah Mada University Press)
[2] Cahyono BE, Fears P and McAtee B 2013 Asian J. Appl Sci 1 31-7
[3] Haryani NS 2017 Proc. of Seminar Nasional Penginderaan Jauh LAPAN Jakarta
[4] DLH-Jatim 2018 Informasi Kinerja Pengelolahan Lingkungan Hidup Daerah Provinsi Jawa Timur (Surabaya: Dinas Lingkungan Hidup Provinsi Jawa Timur)
[5] BNPB 2019 *Laporan 5*: Badan Nasional Penanggulangan Bencana (BNPB); accessed on 5 August 2019. Available from: https://bnpb.cloud.dibi/laporan5.

[6] Suherlan 2001 *Zonasi Tingkat Kerentangan Banjir Kabupaten Bandung Menggunakan Sistemi Informasi Geografis*. Available rom: URL.

[7] Lillesand MY and Kiefer WR 1994 *Remote Sensing and Image Interpretation* 3rd ed (New York: John Wiley & Sons Inc)

[8] NASA 2008 *Landsat-8/LDCM (Landsat Continuity Mission)* accessed on 5 August 2019. Available from: http://directory.eoportal.org/get_announcement.php?an_id_10001248

[9] Kordelas GA, Manakos I, Aragonés D, Díaz-Delgado R and Bustamante J 2018 *Remote Sens* 10(910) 1-23

[10] Rao P, Jiang W, D YH, Chen Z and Jia K 2018 *Remote Sens* 10(1025) 1-20

[11] Huang W, DeVries B, Huang C, Lang MW, Jones JW, Creed IF and Carrol ML 2018 *Remote Sens* 10(797) 1-18

[12] Chini M, Pelich R, Pulvirenti L, Pierdicca N, Hostache R and Matgen P 2019 *Remote Sens* 11(107) 1-20

[13] Mashaly J and Ghoneim E 2018 *Remote Sensi* 10(1204) 1-18

[14] Zhou Q and Liu X 2004 *Photogramm. Eng. Rem. Sens* 7(8) 957-62

[15] Zyl JJV 2001 *Acta Astron* 48(5) 559-65

[16] Nugroho HD 2018 *Analisi Daerah Rawan Bencana Banjir di Kecamatan Kebumen Kabupaten Kebumen Jawa Tengah* [Skripsi] (Jakarta: UIN Syarief Hidayatullah)

[17] Kingma NC 1991 *Natural Hazard: Geomorphological aspect of Flood hazard*. Available rom: URL.

[18] Matondang JP, Kahar S and Sasmito B 2013 *Jurnal Geodesi UNDIP* (2) 103-13

[19] Darmawan M and Theml S 2008 *Katalog Methodologi Penyusunan Peta Geo Hazard dengan GIS*. Available rom: URL.

[20] Asdak C 2004 *Hidrologi dan Pengelolaan Daerah Aliran Sungai* (Yogyakarta: Gadjah Mada University Press)