Identification and delineation of areas flood hazard using high accuracy of DEM data

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Abstract. Flood incidents that often occur in Karawang regency need to be mitigated. These expectations exist on technologies that can predict, anticipate and reduce disaster risks. Flood modeling techniques using Digital Elevation Model (DEM) data can be applied in mitigation activities. High accuracy DEM data used in modeling, will result in better flooding flood models. The result of high accuracy DEM data processing will yield information about surface morphology which can be used to identify indication of flood hazard area. The purpose of this study was to identify and describe flood hazard areas by identifying wetland areas using DEM data and Landsat-8 images. TerraSAR-X high-resolution data is used to detect wetlands from landscapes, while land cover is identified by Landsat image data. The Topography Wetness Index (TWI) method is used to detect and identify wetland areas with basic DEM data, while for land cover analysis using Tasseled Cap Transformation (TCT) method. The result of TWI modeling yields information about potential land of flood. Overlay TWI map with land cover map that produces information that in Karawang regency the most vulnerable areas occur flooding in rice fields. The spatial accuracy of the flood hazard area in this study was 87%.

1. Introduction

Landforms has an important role for the study of flooding, because the land form is one of the vessels where the process of running water comes from the input of rain to the sea. Areas that are highly affected by the flood are areas with flat and sloping reliefs. Indicators of flood-prone landforms are floodplains, marine terraces, swamps and rear swamps [1], geomorphologically dangerous flooded areas characterized by a concave or flat morphology of landforms and their morphoaransemen, which are associated with rivers, with meander flow patterns and or braided. The location and location of the landform can be used as one of the potentially flood-potent and mapped areas [2]. Landforms in the coastal areas of Karawang regency are alluvial plains, areas with landforms of alluvial plains, alluvial valleys, river bends, and swamps that are susceptible to flooding because they are low areas or basins. The research location in Karawang regency was chosen because it met the criteria as flood hazard areas, located in coastal areas with slope characteristics <2% and had an average rainfall of ≥ 200 mm including in flood hazard class [3]. The characteristics of the flood hazard areas can be identified by the form of land that is the result of geomorphological phenomena, and the form of land may indicate a basin as a wetland area. The development of information technology raises the challenge in the distribution of spatial information of flood hazard areas that can be determined more quickly, precisely and accurately. Utilization of DEM and Landsat-8 Image data is expected to provide efficiency in the identification and delineation activities of flood hazard areas.

DEM data used in this research is TerraSAR-X Image 2011 with high accuracy of 1 m. TerraSAR-X image has a high spatial resolution so it can be an alternative in generating DEM data accurately, the utilization of DEM is expected to result in more accurate landform analysis. The high spatial resolution of the TerraSAR-X sensor provides access to surface heterogeneity on a better scale [4]. The approach in determining the drainage network for wetland identification is simpler, and directly obtains an interconnected runoff flow network. This approach is considered a better approach because it relies on the runoff analogy to establish the flow path [5]. Topographic Wetness Index (TWI) analysis method can give an illustration of an area having potential flood hazard or have a high chance of flooding.

The Landsat-8 image of October 2015 is a multispectral image that can provide the earth surface physical information, for the purpose of identifying wetland area using wetness parameter. The Tasseled Cap Transformation (TCT) method is a mathematical model formula for calculating brightness, greenness, and wetness [6], which will generate new digital value information from digital numbers in each band (band 1 to band 5 and band 7) on the Landsat image [7]. The use of spectral value transformation as an object sharpening effort in digital data satellite imagery that will generate new digital value information. Transformation of spectral values can be divided into two, namely (1) sharpen information, (2) summarize information from the number of channels that exist [8].

The purpose of this study was to identify flood hazard areas using high-resolution DEM data with Topographic Wetness Index (TWI) method. This method generates derived data from DEM data, using flow accumulation and slope functions to display potentially flooded basin areas [9]. Flood hazard map are generated from the TWI map overlay with a history of flood events and The Tasseled Cap Transformation (TCT) map. Image data processing in this study using software ILWIS 3.85 which is downloaded for free.

2. Method

2.1. Location and Time of Study

The research location in Karawang regency, located in the northern part of West Java Province, with geography position between 107º02 '- 107º40' East and 5º56 '- 6º34' South. The research and data processing activities were conducted from August 2016 to March 2017. Data analysis was conducted at the Geospatial Information Agency. Hypsography of study location is located at an altitude of 0 meters up to 80 meters above sea level, climatologically monthly rainfall data obtained from [10] and The Tropical Rainfall Measuring Mission [11] Karawang regency shows that bulk rain at low intensity levels.

2.2. Materials and tools

The materials used in this study consisted of the image and history of flood events presented in Table 1.

Table 1. Materials used in the study.

No.	Materials	Specification
1.	DEM/DTM TerraSAR-X years 2011, Otrhorectification	Elevation accuracy, 1 m
2.	Citra Landsat-8, recording of OctoberOctober 2015	Resolution 30 m
3.	Map of flood events Year 2015- BIG	Scale 1:60,000
4.	History of Floods – Agriculture Department of Karawang Regency	2016
5.	Topographic map – BIG	Scale 1:25,000

The tool used for spatial data processing is a set of computers with Microsoft Office 2010 software, Global Mapper V.10, ER Mapper 7, Ilwis 3.85 and ArcGIS 10.2.

2.3. Data analysis procedure

This research is done through several stages. Research stages generally consist of: (a) the preparation and data collection phase, (b) the data processing interpretation stage, (c) the field check stage, (d) the data analysis stage, and I the presentation stage of the results. The expected output of this study is the identification of flood hazard areas, with the classification of high levels of luminance, medium luminosity and low luminosity. The software used to process spatial data is Global Mapper 10, ER Mapper 7, Ilwis 3.85 and ArcGIS 10.1.

2. *Perparation*

At this stage, a review of the literature on study areas and literature related to research topics, TerraSAR-X data collection, Topographic map and Landsat-8 imagery was performed.

b. Processing and interpretation

b.1. Flood hazard mapping with Topographic wetness index (TWI)

Topographic Wetness Index (TWI) is a wetness index that can be used as an indicator of an area that has the potential for flooding. Topographic Wetness Index (TWI) is derived data generated from DEM data in a steady state –steady state – using flow accumulation and slope functions [12]. Wetness index is a key variable that controls hydrological and biogeochemical processes [13].

The accuracy of the TWI results relies heavily on the topographic surface, using high-resolution DEM data allowing the implementation of more detailed modeling. Therefore, the use of TerraSAR-X DEM data is necessary to develop the TWI method to be able to delineate more precise flood hazard areas [14]. TerraSAR-X signals have sensitivity to wet areas, thus there is an increase in wet area information. The results of the analysis will show the degree of wetness in an area and give an indication as the flood hazard area.

To DEM data is done Shaded Relief / Hillshade process with the intention to present a relief image of a region on raster data which is still in 2-D format (two dimension) by giving 3-D (three dimension) impression. Appropriate luminance and shading techniques will result in a 3-D display of DEM data. The availability of high-resolution DEM data will improve the detail of topographic surface reliefs that are the primary data for TWI modeling. The formula of the TWI method (Formula 1), developed by [15], in a run-off model and a topographic wetness index that has no units. The Topographic Wetness Index is a wetness index determined from the previously calculated surface variables with the following equation:

$$\text{Formula TWI} = ln\frac{\alpha}{tan\ \beta} \qquad (1)$$

Where α = *Flow Accumulation* and tan β are slopes.

The TWI model describes water trends accumulated at certain points with slopes that indicate the effect of gravity on water movement [8]. A location that has a sloping slope will have a high TWI index value, thus potentially high water puddle. Conversely, a location that has a steep slope will have a low TWI index value, resulting in a low potency of water puddles. The data processing begins with DEM data recovery with the Fill Sink function, a process of eliminating depression or sink which is a condition where there is a striking elevation difference with very small coverage. For hydrological study the condition of this sink can interfere with the calculation, so it needs to be removed first sink. One of the keys in obtaining derivatives of surface hydrological characteristics is by obtaining flow direction on each raster data cell [16]. Because in the basic concept, flow direction is determined from a high value to a lower value [8].

The flow accumulation function is applied in modeling the amount of accumulated flow of water present in a particular region. As a result there will be an accumulated water value which is also identical to the actual river network in the field. Flow Accumulation serves to calculate the number of upstream areas or the countless stream of cells flowing into each cell. Theoretically, the process of river extraction is done by collecting pixels that have the same flow direction and accumulation trends and their adjacent locations [17]. Stream Networks is a function of making a network of rivers in a particular region. The information used is the flow accumulation described by determining the value of flow accumulation that is considered as a river based on the extraction and collection of pixels that have the same flow and accumulation tendency toward the adjacent location.

TWI in this research resulted from the processing of raster data using software Ilwis 3.85. The wetness index is grouped at each interval of 5 index scales, the high wet index value being indicative of the wetland region. The wetness index value on the index 15 scale is assumed to be the boundary of the flood hazard area. Implementation of boundary delineation of flood areas, done by vectorization method (raster to vector conversion) and or visual interpretation. In general delineation results need to be generalized or simplified by maintaining the general characteristics of the map. The methods include selection, simplification, merging, and magnification. Selection is done for objects that need to be removed and / or combined because they do not meet geometry specifications or do not fit into the classification of elements that can be displayed on the map scale. Selection is done by removing and / or aggregating segments of polygon at least 0.5 mm x 0.5 mm [18].

b.2. Mapping of flood hazard areas in paddy fields

Utilization of Landsat-8 Imagery, analyzed by The Tasseled Cap Transformation (TCT) method, as one method of identification of wetland area by transforming spectral value. The TCT method as an attempt to perform digital data object sharpening of Landsat satellite imagery will produce new spectral values or new information [20]. Land surface objects have varied spectral responses on wet / waterlogged and dry / unfertilized water.

The math calculation model of The Tasseled Cap Transformation (TCT) according to [15] is as follows (Formula 2),

$$\begin{aligned} &i1*0.1511+i2*0.1973+i3*0.3283+i4*0.3407+i5*-0.7117+i6*-0.4559 \quad (\textit{wetness}) \\ &i1*-0.2941+i2*-0.2430+i3*-0.5424+i4*0.7276+i5*0.0713+i6*-0.1608 \quad (\textit{greenness}) \\ &i1*0.3029+i2*0.2786+i3*0.4733+i4*0.5599+i5*0.5080+i6*0.1872 \quad (\textit{brightness}) \end{aligned} \tag{2}$$

Of the three above formulas of concern in this study is wetness, this formula indicates the area associated with the presence of water. The highest digital value indicates as the water surface area and the lowest as a dry area. Water gives the appearance of white or bright, and the appearance of the black indicates gray scale, Table 2. Is the new digital value of the classification wetness level. The software used in the processing of Tasseled Cap Transformation (TCT) Landsat-8 image is ERDAS-7.

Table 2. New digital figures showing the wetness of TCT analysis results.

Class	Digital value of TCT	Land cover
1	192 - 253	Wet areas, rice fields, ponds
2	160 - 191	Plantations with high and rare plants
3	76 - 159	Open area, gardens with rare plants
4	0 - 75	Fields, rice fields run out of harvest, open areas for construction

b.3. Delineate the distribution of flood areas

Mapping of flood hazard areas resulted from incorporation of hazard area map maps with historical data of flood events. Flood hazard maps of TWI results in overlay with historical data of flooding on paddy fields consisting of frequency of flood events, height of inundation, and duration of inundation (Figure 1). How to combine flood incident report data into the map is to add flood data as an administrative district map attribute. This map is then combined with a flood hazard map for flood risk analysis.

The criteria for the height of the flood waters in the wetlands will be very concerned with the height of the plant, the height of the rice plant 70 to 120 cm. Therefore, the criteria of flooded puddles with a height of > 70 cm indicate that paddy fields have high potential flood hazard. The application of the above criteria consider the condition of rice crops that when submerged in floods for a week will die [16], and if the rice fields are often submerged for several days under cropping conditions will cause crop damage and also decrease yield [21].

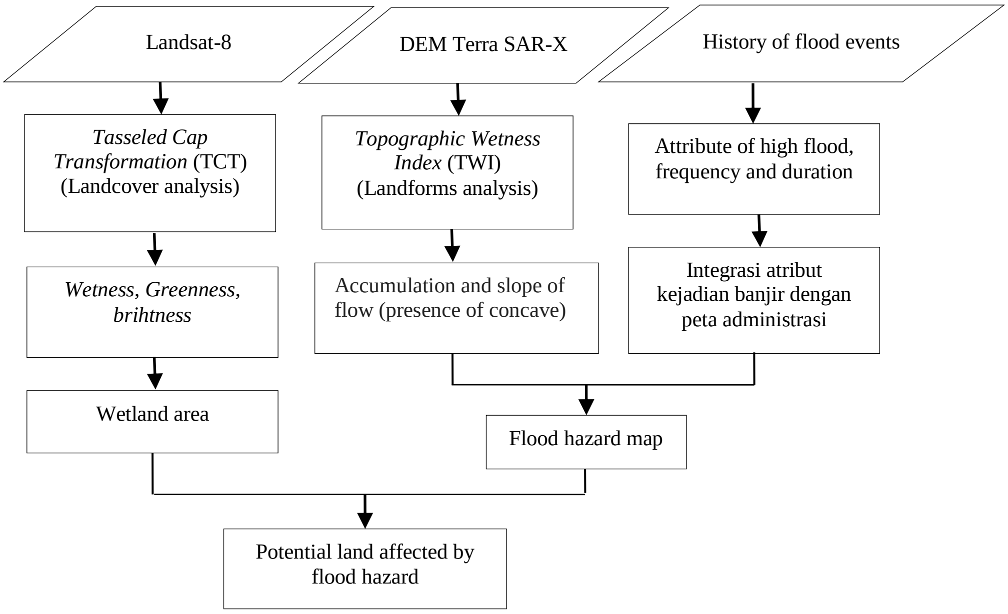

Figure 1. Flow chart for the preparation of flood hazard maps.

c. Field survey

The survey was conducted for primary data collection and secondary data as well as validation of TWI analysis result map, so it can be known the errors or deficiencies. The determination of the field was done randomly (purposive random sampling) and the flood event history was obtained from the [20] of Karawang Regency (Table 2).

d. Data analysisi, validation and presentation

The flood hazard areas were analyzed by overlaying between the TWI maps and the historical map of flood events in the district unit units. Potential of flood distribution is analyzed by overlaying between TWI maps and TCT maps. Subsequently validated using maps of flood events published by Geospatial Information Agency (2015). Test the accuracy of flood hazard analysis results with overlay method between TWI map with Flood Map of Year 2015 and TCT Map. The accuracy test using a wide parameter with a sample of 3 (three) locations, accuracy is presented in percentage with broad baseline reference on TWI Map.

3. Result and discussion

Flood hazard mapping with Topographic wetness index (TWI)

Index calculation with input fill sink and flow accumulation DEM produce wetness index (Figure 2). The TWI analysis is arranged sequentially with the Stream Networks analysis, arranging a network of streams that exist in a given region using flow accumulation information. Flow accumulation is explained by determining the value of flow accumulation considered as a river.

The red color on (Figure 2) has a high Index value more than 25 (>25). This region has a sloping slope so that the potential for high water puddle, green color has index value 15 in this study as an indication of boundary of the inundation area. The blue color indicates a location that has a steep slope and has a low TWI index value, potentially low water inundation occur.

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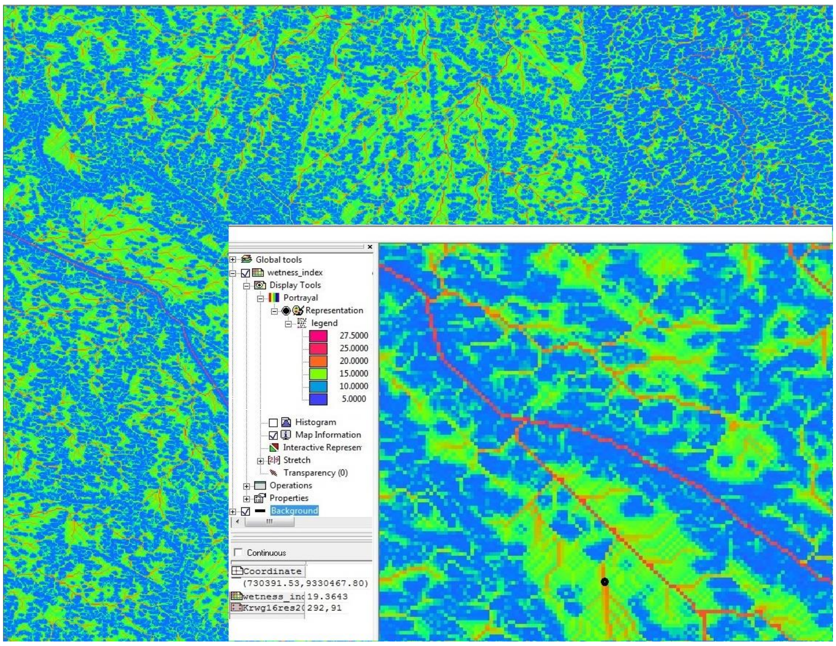


Figure 2. Wetness Index (WI>15 indicating wetlands).

Delineation of boundary areas indicating the danger of flooding is done through visual interpretation that shows the distribution of flood hazard areas (Figure 3). This condition is in accordance with the opinion of [21] that the main factors affecting the flood hazard in the field are flat topography, low elevation and soil type with fine texture.

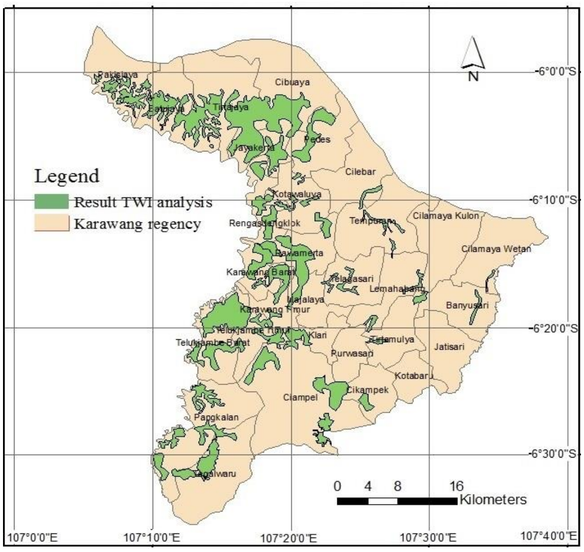
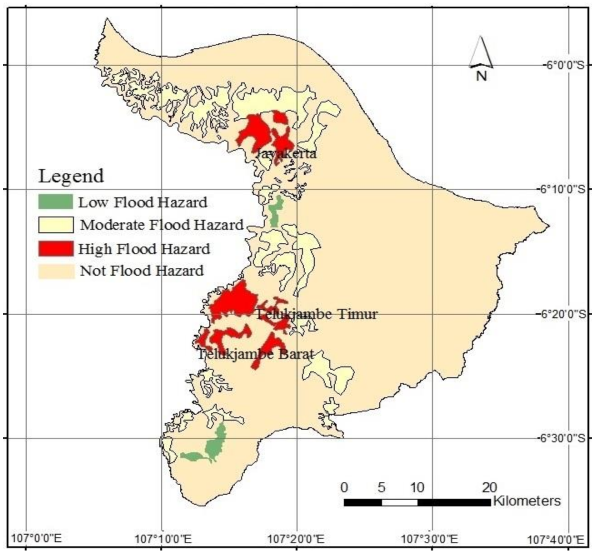


Figure 3. Topographic wetnees index map.



Figur 4. Flood hazard map.

Mapping of flood hazard areas in paddy fields

Data of flood occurrence frequency, height of puddle and duration of flood of rice field obtained from Agriculture Department of Forestry Plantation and Animal Husbandry of Karawang regency (Table 2). Height of puddle, central and southern regions have high grade with high puddle more than 70 cm (>70 cm), while for the north dominated by water level of puddle less than 70 cm (<70 cm) in medium category. High criteria for flooding more than 70 cm (>70 cm) indicate that the research area has high flood potential, especially in paddy field areas. Floods that occur annually, potentially become areas with high flood hazard if the average height of flood water more than 70 cm (>70 cm) and long puddle more than 7 days (>7days). The research area based on the criteria of flood hazard has high flood hazard potential due to fluvial land form in the northern region, in the middle of high flood hazard potential due to the flood plain located at the longitudinal bar of Citarum river and Cibeet river (Figure 4).

Table 3. Reports of flood events in rice fields during the planting season 2008/2009 -2013/2015.

No	Districts	Frequency	High flood average (cm)	Flood duration	Flood criteria
1.	Cikampek	1	60	6	low
2.	Rengasdengklok	1	70	7	low
3.	Tirtajaya	1	65	16	low
4.	West Karawang	2	100	15	medium
5.	East Karawang	2	100	15	medium
6.	Klari	2	100	5	medium
7.	Pangkalan	2	150	5	Medium
8.	Cilebar	2	70	16	Medium
9.	West Cilamaya	2	60	16	Medium
10.	East Cilamaya	2	60	16	Medium
11.	Ciampel	3	150	10	Medium
12.	Cibuaya	3	50	16	Medium
13.	Tempuran	3	70	15	Medium
14.	Jayakerta	4	80	16	High
15.	Rawamerta	4	70	15	medium
16.	East Telukjambe	5	100	15	High
17.	West Telukjambe	5	150	15	High
18.	Pakisjaya	4	70	16	medium
19.	Batujaya	5	60	16	medium
20.	Pedes	4	60	16	medium

Processed from data : [22]

Rainfall

The monthly rainfall data from The Tropical Rainfall Measuring Mission (TRMM) is presented in Table 3. Rainfall in Karawang regency at the low classification level because the monthly average is less than 100 mm, referring to the rainfall classification level criteria from the Bogor Climatology Station 2015. Flood incident in Karawang regency is not only caused by local rainfall which is extreme but also from flood of Citarum River, Cibeet River and other river that pass in Karawang regency because of high rainfall in upstream area.

Table 4. Average monthly rainfall in Karawang regency.

Month	Average monthly rainfall in the year (mm)						
	2010	2011	2012	2013	2014	2015	2016
January	16	6	8	18	24	13	7
February	8	5	7	8	20	15	17
March	8	5	5	8	12	8	10
April	5	6	8	8	9	6	9
May	5	5	4	8	5	4	5
June	7	4	2	3	4	1	7
July	5	1	0	9	6	0	3
August	5	0	0	1	0	0	5
September	9	0	0	0	0	0	7
October	10	3	2	3	0	0	9
November	8	8	8	6	8	10	8
Desember	6	6	10	15	8	8	3

Source: [23]

Delineation of flood area distribution with The Tasseled Cap Transformation (TCT)

Land surface objects have varying spectral responses to wet areas or inundated and dry or not waterlogged. The TCT method as an attempt to refine the digital data object of satellite imagery produces new information. The wetland area is indicated by white color, while the dry land area is dark (Figure 5).

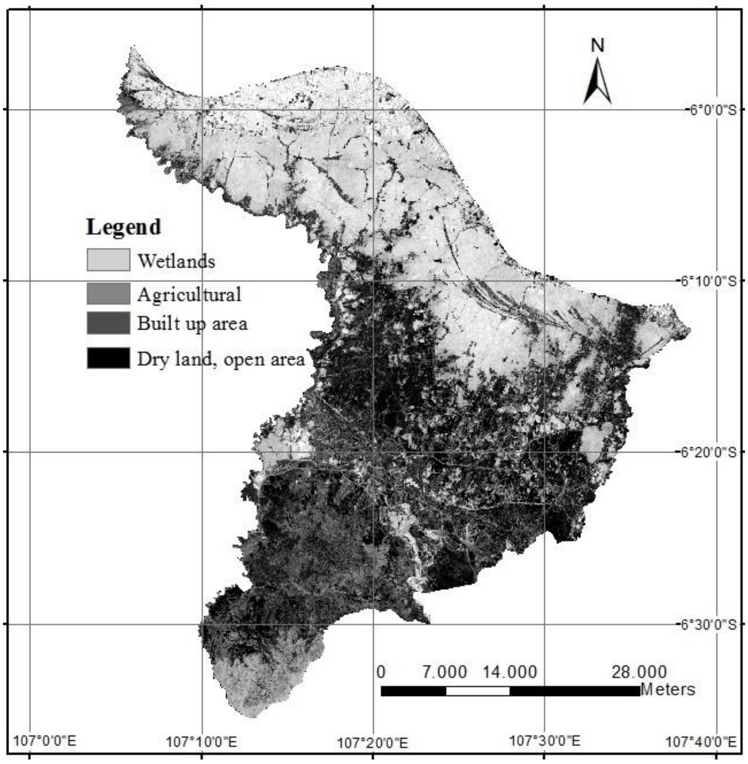


Figure 5. The Tasseled Cap Transformation.

Flood hazard areas with an area of 28,366 ha in Karawang regency mostly flooded rice fields. Results Overlay TCT map with TWI map (Figure 6) shows the distribution of flood hazard areas. Areas with high flood hazard covering 7,489 ha (7.61%), medium flood hazard covering 19,188 ha (19.49%) and low flood hazard covering 1,689 ha (1.72%). Potential flood hazard with long inundation more than 7 days and high water inundation over 70 cm can lead to crop failure.

Validation

Flood hazard analysis results in validation by overlaying between TWI maps and map of flood events of 2015 published by Geospatial Information Agency (Figure 7).

The overlay results show that the flood area is relatively the same as the map of flood event 2015 published by Geospatial Information Agency. The flood hazard area is calculated using TWI map with an area of 28,366 ha, while the calculation result of the map of flood incident that occurred in 2015 with an area of 25,168 ha. The accuracy test uses the broad parameter presented in Table 4. with an average of 87% accuracy.

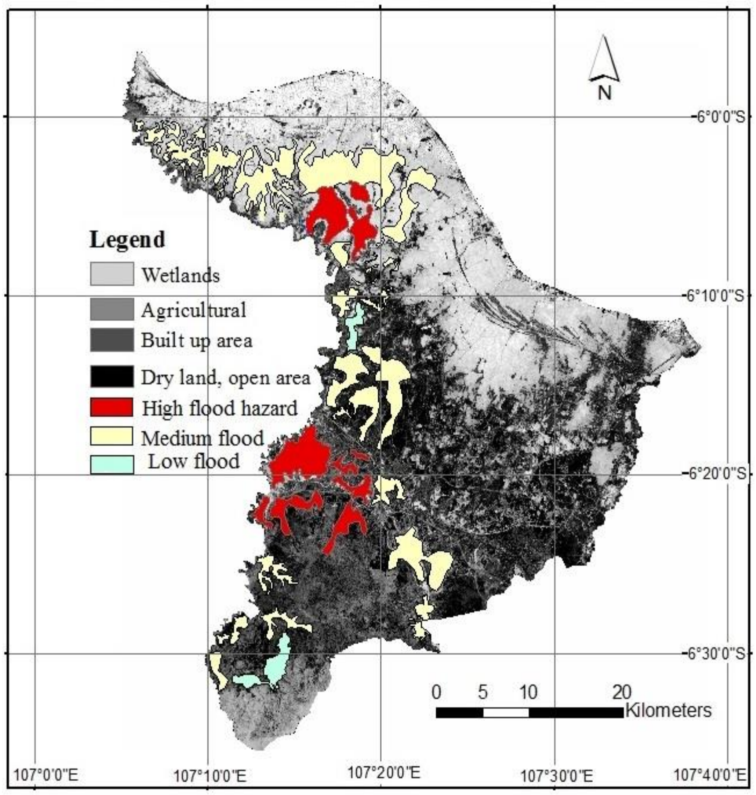


Figure 6. Overlay TWI dengan TCT.

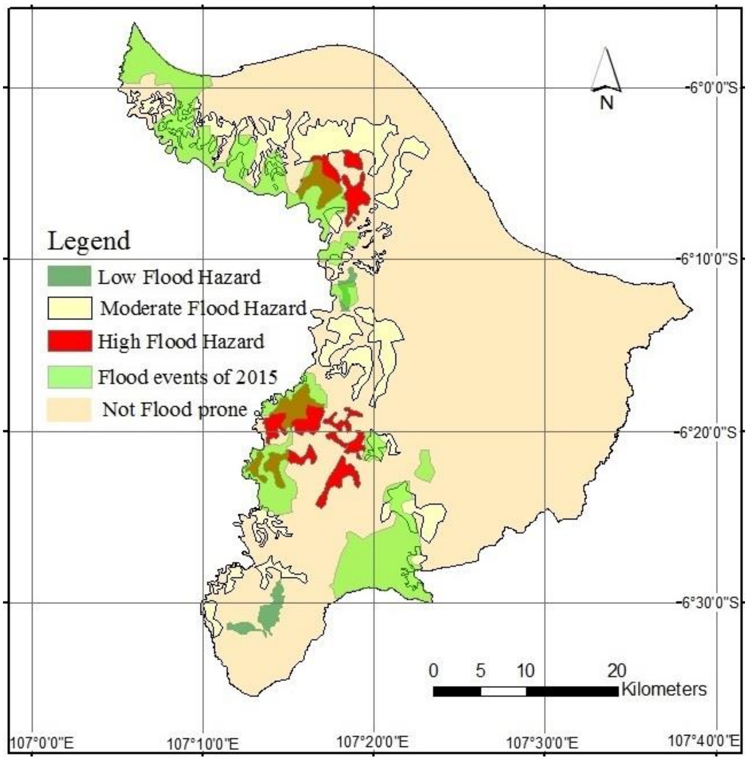


Figure 7. Map validation.

Table 5. Map test accuracy.

TWI (ha)	TCT (ha)	BIG (ha)	Accuracy %	Sample area
28,366	-	25,168	87%	Entire region
2,234	2,128	2,166	95%	Karangligar
2,857	2,695	6,813	94%	Ciampel/Cikampek
3,591	2,216	2,893	71%	Pangkalan
	Average		87%	

4. Conclusions

Flood hazard area mapping using high resolution DEM data and Topography Wetness Index (TWI) method is successful and gives good results. The wetness index is grouped at each of 5 index intervals, with the humidity index 15 being the boundary of the flood hazard area. The flood hazard areas resulting from TWI map analysis with a history of flood events indicate that there are areas with high flood hazard levels. High flood areas are indicated that the frequency of floods occurs more than once every year with depths of more than 70 cm and inundation more than 7 days. Some northern areas that are fluvial / lowland plains have high flood potential in paddy fields. In the middle of areas with high flood hazard are floodplains, encounter of Citarum river with Cibeet river, this area is paddy field. To recognize the Tasseled Cap Transformation (TCT) wetlands the Landsat-8 data was able to identify wetland and dryland cover. Delineation of flood spreading for TCT land cover analysis with TWI shows the distribution of flood areas that occurred in Karawang regency in paddy fields. Monthly rainfall in Karawang regency including low less than 100 mm / month, more flood events caused by the overflow of rivers due to high rainfall in the upstream area. Spatial studies indicate that high flood hazard is indicated in paddy fields with 7,489 ha of rice field, wetland with flood hazard is indicated with area of 19,188 ha and low flood hazard with 1,689 ha. The accuracy of spatial analysis in this study was 87%.

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