JOURNAL OF APPLIED GEOSPATIAL INFORMATION

Vol 2 No 2 2018

http://jurnal.polibatam.ac.id/index.php/JAGI
ISSN Online: 2579-3608

Inundation Model Using UAV-derived Digital Elevation Data and PCRaster Dynamic Model in An Excessive Rainfall Event

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Received: November 23, 2018
Accepted: December 27, 2018
Published: December 28, 2018

Abstract

Extreme weather reportedly occurred on 28th November 2017 caused by a cyclone called Cempaka. Categorized as extreme weather since this event triggered an excessive rainfall reaching 246.8 mm in a 24-hour. Consequently, some areas in Yogyakarta Special Region are inundated. This research attempts to model the inundation of excessive rainfall using GIS software, PCRaster. The study area is concentrated in Selopamioro and Sriharjo, where Opak and Oyo rivers meet. Elevation model and rainfall data are used as the principal data to model the inundation. Elevation model is derived from the Unmanned Aerial Vehicle (UAV) image, while, the rainfall data of a-24-hour hourly data from the Meteorological Agency is also used as an input. The elevation model works as a flow direction model and the rainfall amount plays as the flowing material. The original states of water of the river are not considered, thus the study merely describes how the certain amount of rainfall adds to the level height of terrain and modeled for 24 hours. The result maps are the area that experience of a-24-hour high intensity of rainfall. The study depicts the additional water level caused by rainfall and the concentration of excessive rainfall in the study area. This information is beneficial in order to alarm a similar future event.

Keywords: UAV, Geographic Information System (GIS), Excessive Rainfall, Model

1. Introduction

Intergovernmental Panel on Climate Change states that there has been the change of climate at an extreme level (Sillmann et al., 2017). Extreme weather is one of the consequences due to this change. High rainfall intensity classified as extreme had occurred on 28th November 2017 recorded at 286 mm in a day (Rini, 2017). According to ANTARA (2017), the official news bureau, Board for Disaster Management in Regency level states that the event had caused loss of approximately 50 billion rupiah.

This research as follows up of the previous research conducted by Aji et al. (2018) which attempts to map the inundation in the same location which is based on the interpolation of inundation depth point and delineation of the inundation area both using participatory mapping for the data acquisition. Marfai et al (2015) confirm that participatory mapping is an effective way in terms of disaster management in order to map the damage and loss following a disaster event.

In recent times, the image obtained from UAV (Unmanned Aerial Vehicle) has been applied for mapping. The advantage of using UAV data is the possibility to obtain orthophoto and DEM data in an efficient and effective way in terms of cost, need, and processing (Rokhmana, 2006; Rosaji, 2013). In addition, the advantage of data acquisition in terms of product is both orthophoto and DEM data in high resolution. The image processing of UAV using GCP (Ground Control Point) results in orthophoto at more detailed spatial resolution than 0.25 m and DEM data with vertical resolution 0.2 -3.2 m (Gindraux et al., 2017; Handayani et al., 2017; Rokhmana & Utomo, 2016; Santise et al., 2014;). This resolution can meet for big scale mapping 1:2,500 to 1:10,000.

Efficient flood modeling is a beneficial tool for crucial flood prediction and water resource administration for sustainable urban development. (Zhang & Pan, 2014).

This research attempts to map the estimated inundated area in Selopamioro and Sriharjo Village, Imogiri District, Bantul Regency caused by an excessive rainfall event modeled using PCRaster and UAV (Unmanned Aerial Vehicle) – derived Digital Elevation Model data.

1.1 Hydrological aspect of Excessive Rainfall

The concept of excessive rainfall according to Mutreja (1986) is the total of rainfall after reduced by the evaporation, interception, infiltration, and filling surface detention. Asdak (2007) mentions that the overland flow event occurs in the same concept as mentioned. Therefore, in this research, the aspect of the rainfall excess is modeled as the form in overland flow. In case of an extreme event with very high rainfall intensity, interception, evapotranspiration, and infiltration are sometimes ignored.

1.2 Digital Elevation Data

According to type and the source of the data, Digital Elevation Model (DEM) can be categorized into Digital Surface Model (DSM) and Digital Terrain Model (DTM). DTM represents the height of the surface of the earth, on the other hand, DSM represents true surfaces including objects on the surface (e.g. buildings, woodland) (Kasser and Egels, 2002; Jensen, 2007; in Aber et al., 2010). In general, the data used in the model is DTM. UAV data results in DSM data, therefore DSM to DTM extraction is performed.

1.3 GIS and Dynamic Model

Geographic Information System (GIS) is computer-assisted systems for the capture, storage, retrieval, analysis and display of spatial data (Clarke, 1986). Over GIS, the real world is modeled. The type of models: a static and dynamic model. The dynamic model is a model processes and new attributes are computed as a function of attribute changes over time (The PCRaster Research and Development Team (a), 2018).

1.3 PCRaster

PCRaster is a software package that has capability to perform dynamic modelling. Here are several elements of PCRaster as mentioned in The PCRaster Research and Development Team (b), (2018):

a. A Geographical Information System which consists of a set of computer tools for storing, manipulating, analyzing and retrieving geographic information.
b. Raster-based system.
c. The data contains data type information based on the attribute data.
d. Data type checking mechanism is provided.
e. Open database.
f. Classical GIS function.
g. Integrated cartographic and dynamic modelling.

PCRaster command, tools and the example of modelling and further commands function are provided in the website http://pcraster.geo.uu.nl.

2. Research Methods

2.1 Digital Elevation Data from UAV

The elevation data used for the model is the Digital Terrain Model (DTM). DSM to DTM extraction is performed by using the principle of eliminating points on the earth surface, for instance, landcover then to perform interpolation. One of the methods is semiautomatic to eliminate the height point is applying DTM Filter Slope-based/ maximum local slope (MLS) (Serifoglu et al., 2016). In principle, MLS eliminate height based on the slope difference that is calculated over the closest neighboring pixel. The outcome is bare earth as interpolation data to result in DTM. In this research, the slope and distance use is 30º and 18, respectively.

2.2 Modelling Using PCRaster

In order to perform the model, the input data should be converted into PCRaster format, *.map raster format. Conversion data tool, export, and import data tools have been provided in the package. Every operation is done using the command, therefore, it needs to read carefully the software documentation on the provided website (http://pcraster.geo.uu.nl). Data should be prepared and verified before performing the model based on the data type. The main outline in order to perform this model are:

a. Data preparation

Prior data conversion, new map file *.map is created as a blank map and clone map. This new map contains information i.e the coordinate system, data type, the number of row and pixel and cell size. Therefore, during the data conversion, this map will represent as clone map, which the new converted map will follow the information of the clone map as a reference map. Hence, every data type needs a different clone map as a reference. Most ASCII file requires to remove the header, therefore the information in the text file would be pixel value only.

As the input data, UAV-derived DEM data in raster format then converted to ASCII format. The DEM ASCII format is converted into PCRaster format (*.map) with the scalar data type. The number of columns, rows, no data value, cell size should be checked, and prior the conversion, the header in ASCII format should be omitted. The conversion will follow the cloned map as previously mentioned. DEM data used in this model is generated to local drain direction as a function of elevation data. DEM data refers to DTM (Digital Terrain Model) with pixel size is 5 m.

Rainfall data (Table 1) obtained from Meteorological Burau, is 24-hour data recorded on 27 of November 2017 as the input data. The rainfall data is the data recorded in Sleman area which is different from the location of the study area (According the official is 246,8 in a day). This limitation due to the availability of hourly data in the research area. It is assumed that rainfall intensity in the research area has less discrepancy to the one in Sleman area. This data is called as time series data in PCRaster and addressing the rainfall intensity of the referred station but represented separately as *.tss. Rainfall station has a nominal data type with *.map extension.

Table 1 Rainfall Intensity for 24-hour

Timestep	Rainfall (mm)	Timestep	Rainfall (mm)
1	7.4	13	1.8
2	8.3	14	19.2

Timestep	Rainfall (mm)	Timestep	Rainfall (mm)
3	18.8	15	13
4	20.5	16	27
5	8.6	17	19.1
6	16.4	18	14.9
7	19.8	19	10
8	12.9	20	4.7
9	4.6	21	8.5
10	0.9	22	4.7
11	0	23	3.7
12	0.8	24	1.2

The output of the model will have the same area, therefore, one of the maps will be considered as the mask area.

Observed points are included in the model. These observed points are the same observed point of the participatory mapping in terms of the location which contain the depth of the inundation. The purpose is to obtain the excess rainfall value as the same location as the sampled inundation point. Those are the main data used in this model. This model results in new data such as ldd (local drainage network), rainfall zone, and the value of the simulated rainfall over ldd.

b. Store all the data in one database
All the data that is included in the model should be stored in the same location (Figure 1) in order the model to execute.

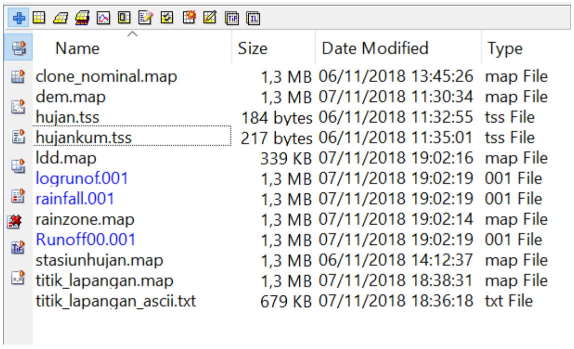

Figure 1. Database

c. Start the simulation
The main result of the model is rainfall zone, local drain direction, and accumulation of the excessive rainfall (written as runoff in the script).

The explanation of all the commands used in the model is provided on the PCRaster website. Figure 2 Shows the script used in order to run the model.

```
# model for simulation of runoff
# 24 timesteps of 1 hour => modelling for one day
binding
RainStations=stasiunhujan.map; # map with location of rainstation
RainTimeSeries=hujan.tss; # timeseries with rain
RainZones=rainzone.map; # reported rainfall area
SurfaceWater=rainfall; # reported stack of maps with rain
Dem=dem.map; # digital terrain map
Ldd=ldd.map; # reported local drain direction map
LogRunOff=logrunof; # reported stack of maps of log runoff
Observed_point=titik_lapangan.map;

areamap
stasiunhujan.map;

timer
1 24 1;

initial
# coverage of meteorological stations (the nearest)
report RainZones=spreadzone(RainStations,0,1);
# generate the local drain direction map on basis of UAV data
report Ldd=lddcreate(Dem,1e31,1e31,1e31,1e31);

dynamic
# calculate and report maps with rainfall at each timestep (mm/hour)
report SurfaceWater=timeinputscalar(RainTimeSeries,RainZones);
# compute runoff
report Runoff=accuflux(Ldd,SurfaceWater);
# output inundation at each timestep
report Inundation=timeoutput(Observed_point, Runoff);
```

Figure 2. PCRaster Script of Rainfall Excess Model

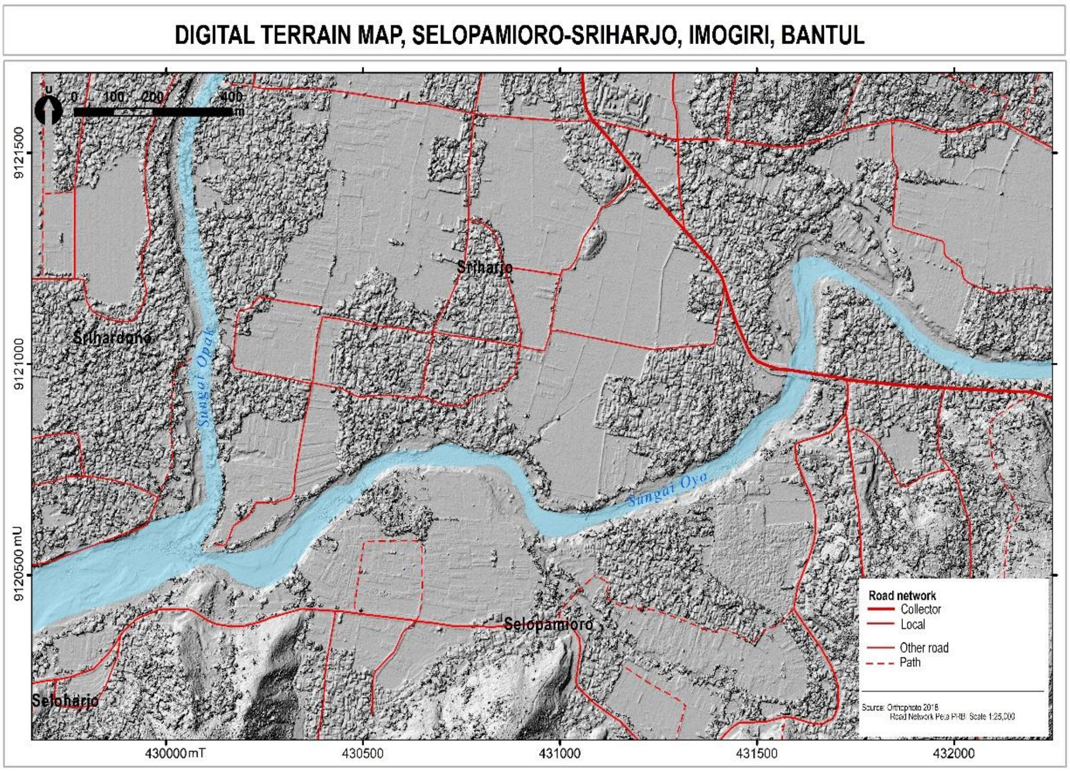

Figure 3. Digital Surface Map

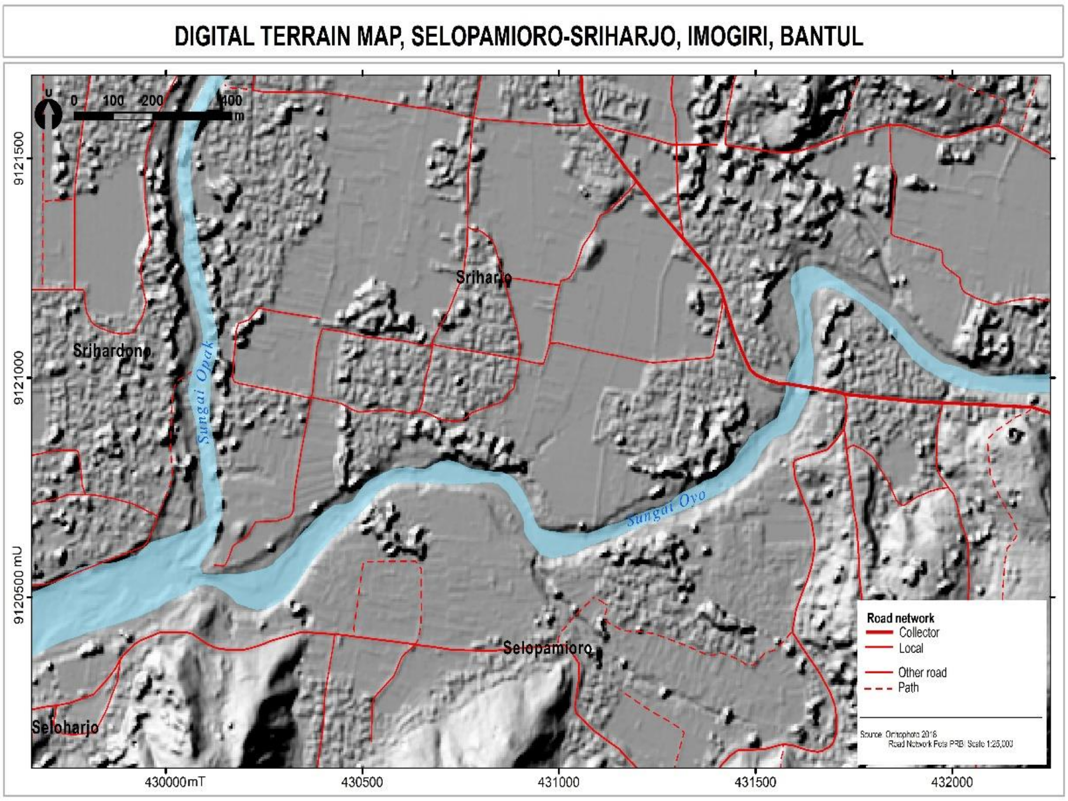

Figure 4. Digital Terrain Map

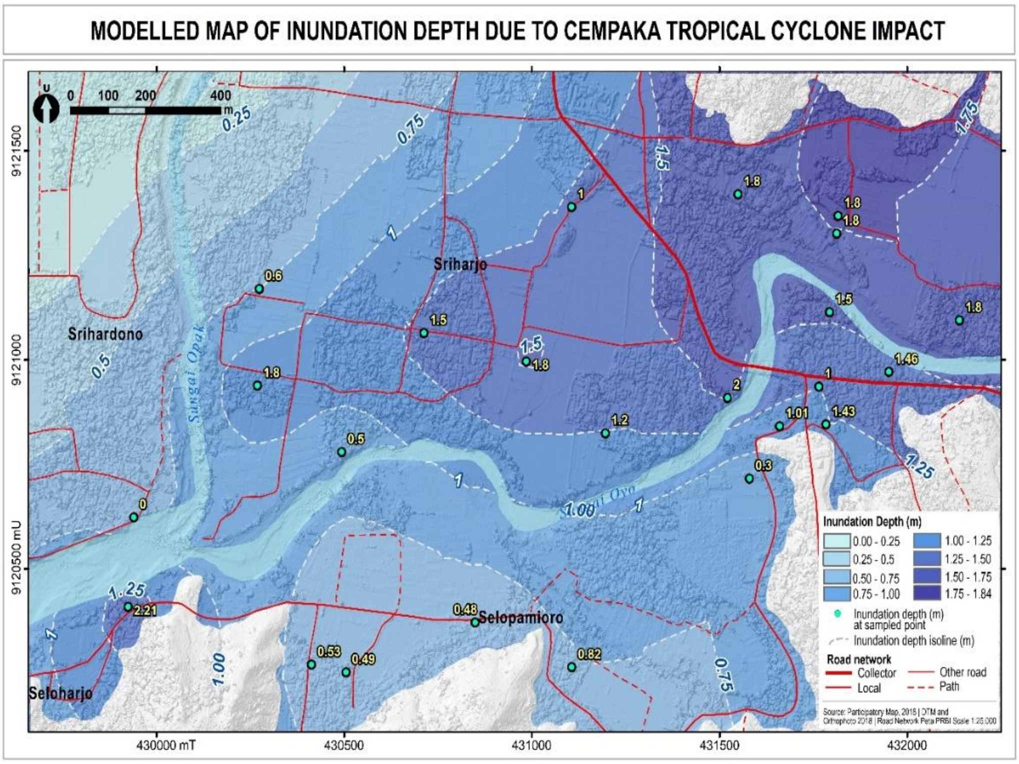

Figure 5. Modelled Map of Inundation based On Field Data (Participatory) (Source: Aji et al, 2018)

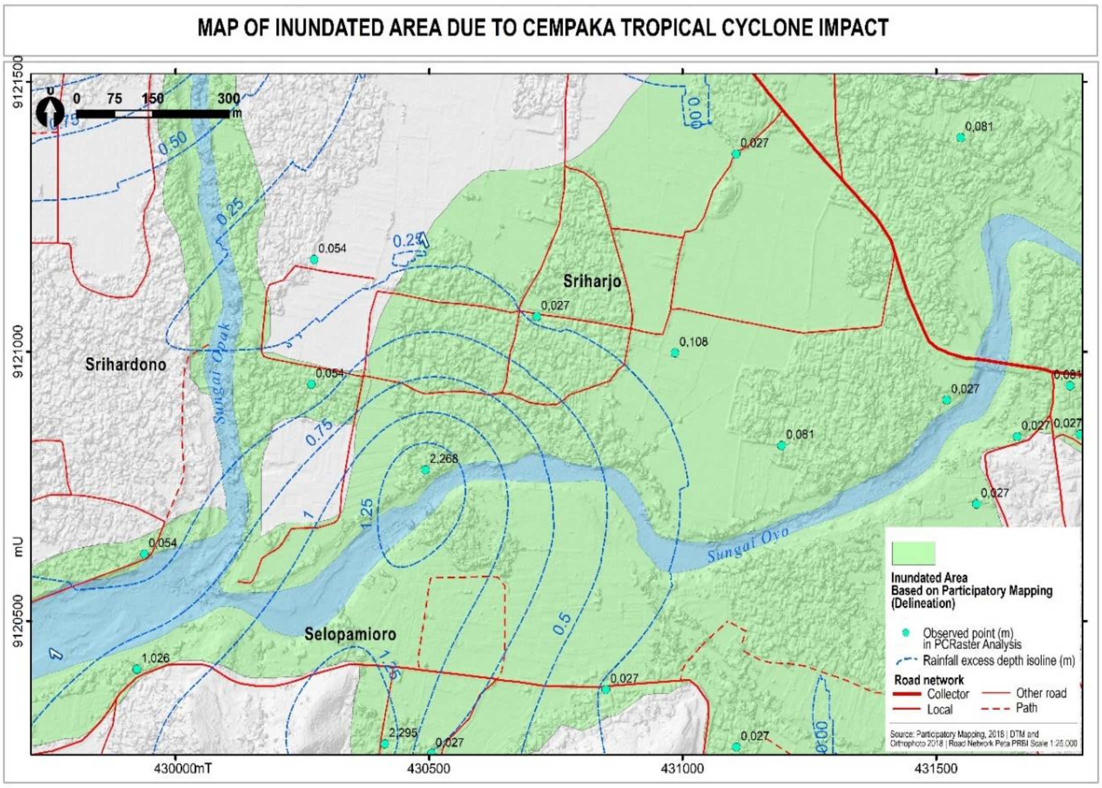

Figure 6. Inundation Map based on Participatory Mapping Method using Direct Delineation (Source: Aji et al, 2018)

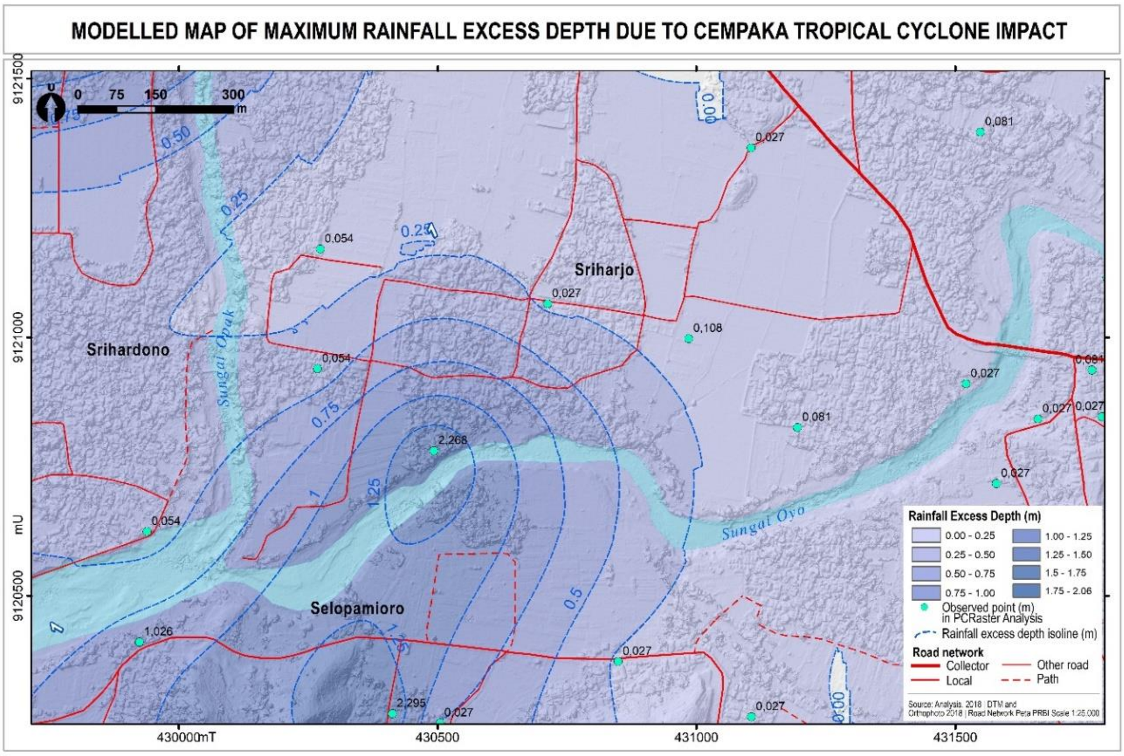

Figure 7. Modelled Map (Source: Interpolation of PCRaster-derived Data

3. Results and Discussion

3.1 Digital Terrain Model

Digital Terrain Model (DTM) resulting from the MLS method is shown in Figure 4. The DSM is shown in Figure 3. According to the visual observation of the results, DTM extraction result shows that landcover is not completely removed. This method is applied with several attempts by changing the slope and distance value in order to give the better result. However, this result is considered the best result for the model. Landcover in the study area is dominated with rural-type landcover, manifested by clustered rural-type housing, community forest type cover which consists of stands, and paddy field.

Upon extraction, landcover persists, however, looks smoother. Both of the maps are represented in the hillside. The perspective of the hillside representation causes some area looks higher in the DTM compare to one in DSM. Certain area for instance housing/ rural residential area looks smoother. However, natural features, for instance, hill and valley, considered have better result since the landcover is eliminated from the surface and looks smoother. It is suggested to put more effort to use this method and applied locally in order to have the better result. The DTM result for this operation is resampled into 5 m cell size. This considers that landcover feature still persists and contributes to unrealistic local drain direction result that will be used as an input model in the PCRaster.

3.2 Inundation Map

Previous research by Aji et al (2018) results modeled inundation map based on inundation depth points interpolation using participatory mapping as shown in Figure 5. The results show that the highest inundation depth is 2.21 m. The map shows that the deepest inundation is concentrated in the eastern part of the study area.

Figure 6 shows the delineation of the inundated area using participatory mapping. This map is based on the direct delineation of village official and community in the study area. This map does not show the inundation depth, yet the inundated area only. This map is overlaid with isoline of a 24-hour excessive rainfall depth. Figure 7 shows the excessive rainfall map depth. This map is modeled with observed points of excessive rainfall extracted from PCRaster simulation which has the same location as points of inundation depth points based on the participatory mapping. This map addresses the concentration of area where the rainfall flows through the terrain. It shows that the rainfall excess is concentrated in the vicinity of the meeting point of Oyo and Opak river. The map shown in Figure 7 does not imply the depth of the inundation, in terms of considering water comes from the upstream area, as study location is not based on the watershed/ basin.

The rainfall excess depth points based on PCRaster is interpolated using the kriging method. The interpolated points values are selected based on the maximum rainfall excess depth. The result shows that 1 of 30 points does not show realistic value, therefore, the points that interpolated are 29 points only.

Figure 7 Shows that the concentration of excess rainfall is in the vicinity of meeting point between Opak and Oyo River, on the contrary, the most impacted area based on the depth according to participatory mapping is in the eastern part of the area. According to the results, imply that Figure 7 shows the contribution of rainfall during the disaster event only, in terms of magnitude. However, external factor, for instance, the scope of the study in terms of watershed unit analysis and runoff from the upstream area is ignored.

This research depicts the contribution of such rainfall intensity in the certain type of disaster only, which may give the future reference in the future when the same rainfall intensity occurs. Hence, future research in regards to watershed analysis in the area is the need. Moreover, vulnerability analysis is needed in order to prepare such future events.

4. Conclusion

Digital Terrain Model extraction using MLS method in study area still shows several landcover features for instance clustered housing and vegetation stands, yet the texture looks smoother. Natural features, hill, and valley results more satisfying result as the bare earth is perceivable.

The model of excessive rainfall map shows that the concentration of excessive rainfall depth is in the western part of the study/ mapped area, in the vicinity of Opak and Oyo river meeting point. Yet, the most impacted area based on the depth according to participatory mapping is in the eastern part. Therefore, the scope and unit analysis need to be expanded and consider other factors for instance the runoff from the upstream.

Acknowledgements

Authors thank to Universitas Gadjah Mada who has financed this research and also Laboratory of Geographic Information System and Laboratory of Remote Sensing Department of Geo-Technology which have to give support in order to finish this research. Writers would also thanks to Desa Selopamioro and Desa Sriharjo as the research conducted in the location. We are open to critics and suggestions for this paper.

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