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Effect of noises removal and spatial resolutions of Digital Surface Model (DSM) in flood inundation model

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Abstract. Digital Elevation Model (DEM) is an important component in flood inundation modelling as a part of flood risk analysis. However, Digital Surface Model (DSM) which still contains noises of artefacts is more common to be available than DEM. Then DSM misleads the inundation extent. This study will evaluate a measure to obtain a bare-earth surface (DEM) by developing and applying a workflow to remove the noises from DSM using simple tools available in the GIS computer software. The output of the method will then be used as input for flood inundation modelling of Semarang City in Indonesia. In addition to the main data set of TerraSAR-X DSM provided by Indonesia Geospatial Information Agency (*Badan Informasi Geospasial* or *BIG*), two sets of open source digital elevation data from Shuttle Radar Topography Mission (SRTM) and Advanced Spaceborne Thermal Emission (ASTER) are included in this study. The three data sets are processed and quantitatively compared. The results show that the applied noise removal method must be traded off with the lower resolution. Hence, the level of detail of particular flood inundation modelling will determine the required DEM resolution. Different study purposes will lead to different appropriate DEM resolutions to be used.

1. Introduction

Despite its long time existence and various measures to tackle it, flood is still intensively discussed these days. The history of measures to overcome the flood has covered many different methods. It ranges from flood impact reduction through flood defense as hard method to more comprehensive flood risk reduction approach (e.g. [1-5]). Flood risk reduction involves several different concepts including flood risk analysis as a part of flood risk assessment and flood risk management [6]. In flood risk analysis, the general process requires evaluation and assessment, planning and design, over the steps. In relation to that, the need for numerous data is always presence. However, the fact is normally challengingly opposite to the ideal condition. Data-limited or data-poor at different levels is a common condition. While the flood risk analysis must be continued, then it has to be conducted under such environment.

Measures are conducted to minimize the data-poor condition (e.g. [7-9]) and improve the flood risk assessment process (e.g. [10, 11]). Among a number of required data which are poorly available, some of them can be improved through particular methods. Specifically related to flood risk modelling, it is the elevation model. Despite its importance, Digital Elevation Model of bare earth or ground surface, equally named as Digital Terrain Model (DTM), are limitedly available. These days, DEM is no longer completely unavailable since a number of sources provides open data free of charge worldwide. However, its quality is frequently lower than the requirement. Specifically, the main DEM used in this study is obtained in relatively high horizontal resolution of 9-meter grid from TerraSAR-X, but it is a DSM and not a DTM [12]. Hence, it contains noise that must be removed in order to obtain a bare-earth of ground surface terrain which is relevant to flood inundation modelling. Using the currently available Geographic Information Systems (GIS) software in the market, a workflow can be developed to remove the noise, i.e. the non-terrain related objects or artefacts, based on built-in features of toolbox and toolset. This study aims to analyze the results of the implemented procedure over three different sets of data for three different return period of floods. Simultaneously, it also evaluates their respective resolutions, both horizontal and vertical ones.

The specific study area of this study is Semarang City, the capital of Central Java Province in Indonesia (figure 1). Semarang City stretches from 6°57’ to 7°7’S and 110°16’ to 110°30’E. Twenty one main rivers and canals flow from south to the Java Sea in the north of the city [13]. Thirteen predominant rivers and canals are involved in this study. At the downstream area, in west-east direction, two of them in the most western area, i.e. Plumbon River and Bringin River; three rivers and canal in the middle area, i.e. West Flood Canal, Semarang River, and Baru River; also three rivers and canal in the most eastern area, i.e. East Flood Canal, Sringin River, and Babon River. In the upstream area, three tributaries of the middle rivers are Kreo River, Kripik River, and Garang River; while two tributaries of the eastern rivers are Penggaron River and Dolok River. Most of the rivers are originated from Mount Ungaran at the south out of the city. This situation divides the city into two main terrains, i.e. low land area in the northern side of the city as far as ca. 3-5 km from the shoreline and hilly area in the southern area of the city. The average annual rainfall in the city ranges from 1600 to 2600 mm for approximately half a year, mainly in October to April with the peak in December to February. The average temperature is 28°C and the average humidity ranges from 75% to 80%.

2. Quantitative flood risk analysis

The general minimum scope of result in flood risk analysis is a quantified estimation of flood damage. In order to achieve that goal, it has to go through several main steps, i.e. flood inundation mapping, land cover or land use identification and mapping, development of potential stage (depth) vs. damage relation either in form of equations or curves. This study deals with only the first step.

2.1. Flood inundation mapping

Flood inundation mapping here means estimated flood inundation extent. The most common method to generate it is by hydrodynamic modelling. This study employs SOBEK Rural ver.2.15 developed by Deltares for that purpose. Generally, a number of basic 1-dimentional (1D) data required to be available are the schematic system consists of the rivers and canals network and cross sections at minimum two locations per reach (i.e. one upstream and one downstream points), boundary condition at the upstream and downstream points, e.g. discharges or water levels in either constant values or function of time. In addition to those data, supplementary data might be involved, for example, hydraulics structures and their necessary parameters. Other than 1D data, the 2D data of (digital) elevation models or maps of the study area terrain are essential.

2.2. Digital elevation model

Digital Elevation Model (DEM) meant here in relation to the earlier mentioned flood inundation model is Digital Terrain Model (DTM). It provides the elevation of ground surface from which the depth of inundation or flood water level is measured. The best quality DEM with regard to accuracy is developed from a comprehensive ground survey which is high cost when it must cover a large area of study due to its physical contact with the recorded object and consequently, more time consumption. Hence, DEM developed from aerial images acquired through active remote sensing technologies and photogrammetric process of images taken by satellite equipped with either radio sensor (RaDAR) or light sensor (LiDAR), even promising Unmanned Aerial Vehicle (UAV) or Unmanned Aerial Aircraft (UAA) which also popularly known as "drone".

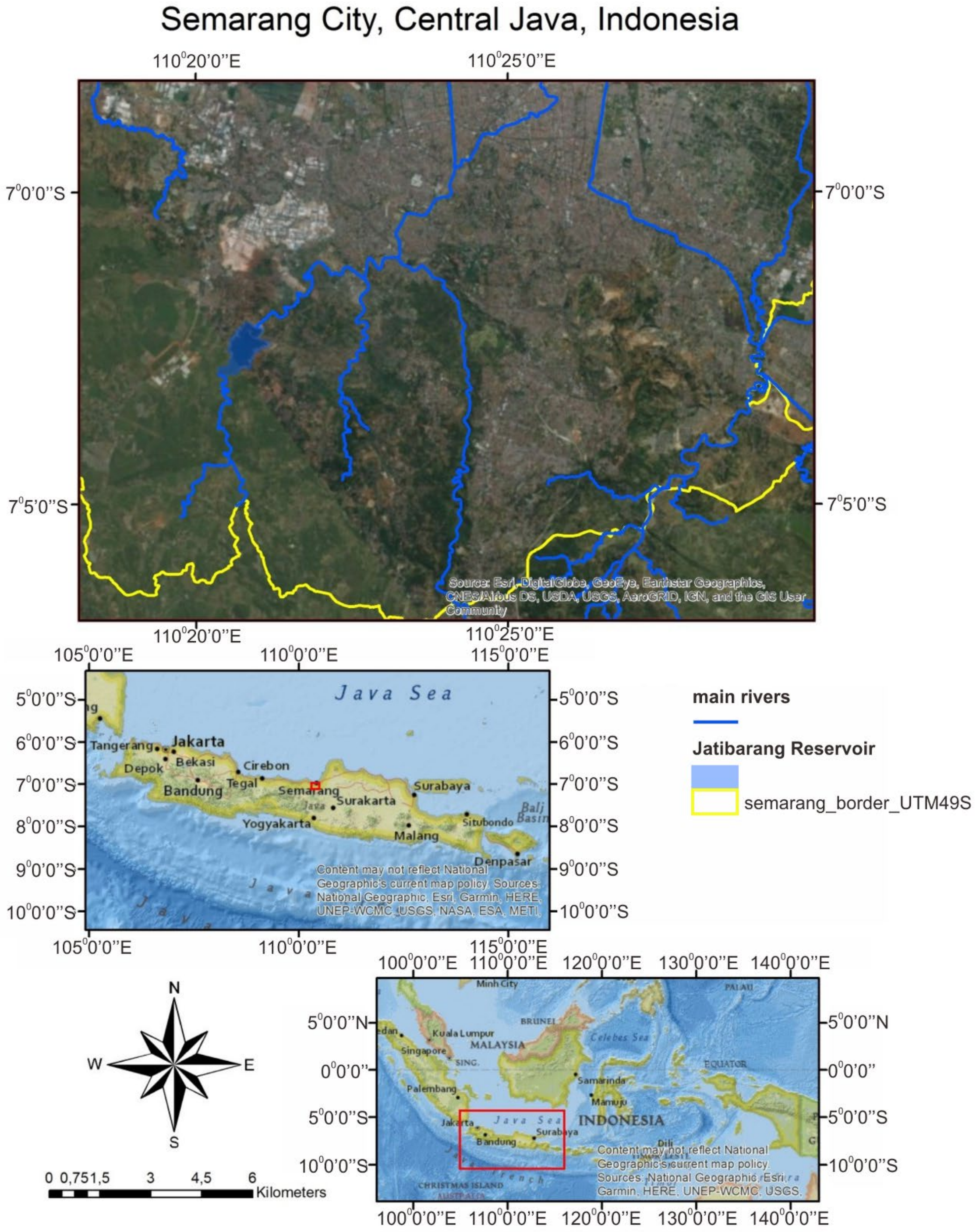

Figure 1. Study area.

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2.3. Data-limited issue

Data-poor or data-limited is a common issue presents in many study areas, including Semarang City. With regard to flood inundation model in Section 2.1, most of the 1D data are historic. Their absence or unavailability is not easily retrieved, replaced, or regenerated. It is excluded from the scope of this study. Regarding the 2D data, based on the recent national government policy of One Data and including One Map, request for obtaining geographic data such as DEM must be addressed to the Indonesia Geospatial Information Agency or *Badan Informasi Geospasial* (*BIG*). Local governments are not allowed to release any digital geographic local data although of their administrative area. They are positioned as the data supplier to the central government.

BIG Indonesia purchases the DEMs from TerraSAR-X and releases them without any further post process. For non-academic or non-research or commercial purposes, users must purchase it from *BIG*. It can actually be obtained free of charge as well. However, the one used in this study is the one provided by *BIG*. Its metadata is presented in table 1. For any maps of Indonesia, the vertical datum used as reference is based on Earth Gravitational Model 2008 (EGM2008).

2.4. Open source data

A number of open source digital elevation data are available online free of charge. Two most notable among them utilized in this study are Shuttle Radar Topography Mission (SRTM) and Advanced Spaceborne Thermal Emission (ASTER). Those data can come in different raster formats such as .hgt (early SRTM), .tif, and .bil. In summary for this study, table 1 presents the metadata of those open source data sets together with TerraSAR-X from *BIG*.

Associated to each necessity, several sets of different procedures of preparation are conducted upon the data sets. For instance, assigning suitable spatial reference and coordinate systems. It is conducted using suitable tools of “Define Projection”, “Project Raster”, “Mosaic To New Raster” (with “*Blend*” operator), and “Extract by Mask”. Correspond to the study area of Semarang City in Indonesia, the suitable Projected Coordinate Systems to apply is WGS 1984 UTM Zone 49S. The new mosaicked raster is then extracted by the area considered in the flood inundation model. It covers the whole catchment area or river basin contributing to the flood occurs in Semarang City. In this case, it reaches the most upstream of river basin originated in Mount Ungaran located at the south of the city.

Table 1. Original metadata of utilized data sets.

Data set	SRTM 1 Arc-Second Global	ASTER GLOBAL DEM	TerraSAR-X
Entity ID	SRTM1S07E110V3 SRTM1S08E110V3	ASTGDEMV2_0S07E110 ASTGDEMV2_0S087E110	1408-54, 1408-63, 1409-22, 1409-31
File name	s07_e110_1arc_v3.tif s08_e110_1arc_v3.tif	ASTGTM2_S07E110_dem.tif ASTGTM2_S087E110_dem.tif	1408-54_E110_S07_DEM.bil 1408-63_E110_S07_DEM.bil 1409-22_E110_S06_DEM.bil 1409-31_E110_S06_DEM.bil
Resolution	1-ARC (30m x 30m)	1 ARC-SECOND (30m x 30m)	0.3 arcsec (9m x 9m)
Acquisition date	11 Feb 2000	17 Oct 2011	2011
Published date	23 Sep 2014	16 Nov 2011	n.a.
File date	30 Dec 2014	16 Mar 2011	20 Aug 2012, 25 Aug 2012, 14 Sep 2012, 22 Aug 2012
Source	earthexplorer.usgs.gov	earthexplorer.usgs.gov	Indonesia Geospatial Information Agency (*BIG = Badan Informasi Geospasial*)
No. of bands	1	1	1
Cell size (X, Y)	0,00027777778, 0,00027777778	0,00027777778, 0,00027777778	9, 9
Format	TIFF	TIFF	BIL
Pixel type	signed integer	signed integer	signed integer
Pixel depth	16 Bit	16 Bit	16 Bit
XY coord. syst.	GCS_WGS_1984	GCS_WGS_1984	unknown
Angular unit	Degree	Degree	
Datum	D_WGS_1984	D_WGS_1984	

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3. DSM noises removal and resolution conversion

Among a number of available options of current GIS software, ArcGIS Desktop 15.0 developed by Environmental Systems Research Institute (ESRI) is used in this study. It comes with various handy tools for achieving the goal and two of them mainly utilized in this study are "**Aggregate**" and "**Resample**". Those two toolsets change the horizontal resolution. In addition to the horizontal resolution conversion, a workflow of vertical resolution conversion is also executed to change the integer to floating formats of the data sets. It mainly uses "**Raster to Point**" toolset and "**Interpolation**" toolbox with one of the chosen methods. Any raster results of noise removal and resolution conversion workflows are then converted into ASCII format, i.e. .asc files, to be suitable inputs for the flood inundation modelling using SOBEK Rural ver.2.15.

3.1. Noise removal with reduced horizontal resolution: "Aggregate" toolset

"**Aggregate**" is one of the "**Generalization**" toolsets in "**Spatial Analyst Tools**" used for generating a reduced-resolution (coarser) version of a raster. It works by taking either the statistics of "*Sum*", "*Minimum*", "*Maximum*", "*Mean*" or "*Median*" value of original cells as input and assigned it as the value of new cells. If the value of input cells is integer, the new cells will be integer as well, as long as the statistics picked up for the process is not the "*Mean*". The floating input cells or a "*Mean*" statistics will always provide floating output cells. "**Aggregate**" often requires "**Resample**" toolset to follow if the final intended resolution is not a multiple of the original resolution.

In this study, this toolset is utilized to remove noises (building, trees, etc.) from DSM by choosing the "*Minimum*". The resolution of the new raster is always consequently lower and determined by specifying a cell factor parameter set in the geoprocessing analysis environments. Generally, the larger the cell factor applied, the more noise removed. Figure 2 illustrates a "factor 3" applied to a raster of 9x9 grid and results a new 3x3 grid [14]. The smaller grid size of original raster, the more options of and larger cell factor can be applied to obtain a particular new grid size or resolution. For instance, towards a 100-meter new resolution raster from a 9-meter resolution original raster, cell factor 2 to 9 are applicable. While for the same new resolution from a 30-meter resolution, only cell factor 2 and 3 are applicable.

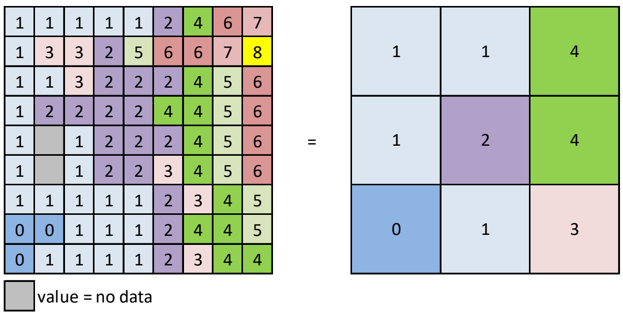

Figure 2. Aggregation of a 9x9 grid raster with "factor 3" based on "*Minimum*" values. Source:desktop.arcgis.com/en/arcmap/10.5/tools/spatial-analyst-toolbox/aggregate.htm [3]

3.2. Horizontal resolution change: "Resample" toolset

"**Resample**" is one of the "**Raster Processing**" toolsets in "**Data Management Tools**" used for changing the data set spatial (horizontal) resolution through one of several possible options of technique, either "*Nearest*", "*Majority*", "*Bilinear*" or "*Cubic*". The lower left corner coordinate of the output raster data set is kept the same to the one of the input raster data set. Slightly different from "**Aggregate**", "**Resample**" can all the time be a standalone toolset to result a particular final intended resolution.

In this study, for suitability and practicality reasons, "*Nearest*" technique is picked up. It is the fastest resampling technique and suitable for discrete data including integer elevations of the data sets in this study. For different data sets of SRTM, ASTER, and TerraSAR-X, all of them are intended to have an equal comparable 100-meter resolutions, either directly from the original raster files or the output raster files of "**Aggregate**" utilization.

3.3. Vertical resolution change: integer to floating conversion workflow
The workflow consists of two main components, i.e. "**Raster to Point**" toolsets and then one of the chosen methods from the "**Interpolation**" toolbox. Several deterministic interpolation methods are available, i.e. "*IDW*", "*Natural Neighbor*", "*Spline*", and "*Trend*". They all use particular mathematical formulas to obtain certain preferred surface smoothness while applying general concept of interpolation, i.e. values assignment at locations based on surrounding values. Also, there is one geostatistical interpolation method, namely "*Kriging*" which is based on statistical models as well as statistical relationship among surrounding points (or also known as "autocorrelation"). When contour lines are available as the input data, then a method can be chosen either from "*Topo to Raster*" or "*Topo to Raster by File*" options.

In this study, all the three employed datasets come in integer vertical resolution so that they are all converted into floating format through the aforementioned workflow. The chosen interpolation method is "*IDW*" which stands for Inversed Distance Weighting. It basically works in an averaging process with the points closer to the estimated cell are given higher weight.

4. Flood inundation extent
As mentioned earlier in Section 3, any raster results of noise removal and/or spatial resolution conversion are then converted into ASCII format (to be .asc files) and used as 2D grid input in flood inundation model simulations using SOBEK Rural ver.2.15. Flood inundation extent is the simulation output and presented as a map in ASCII format. A particular 2D map employed in a simulation of a particular flood scenario is considered as a particular case. For each case, a corresponding flood inundation depth map is generated as a file whose generic name format is "*dm1maxd0*". This file can be easily open in ArcGIS or MS Excel for further quantitative analysis.

The "*d1maxd0*" file contains grid values of inundation depth at each grid for associated DSM or DTM input map. A certain volume of particular inundation condition is obtained by multiplying each inundation depth value with the grid area and summarizing the total. Hence, for each case, it results respective inundation volume value which can be plotted in graphs and quantitatively analyzed.

The original TerraSAR-X raster (of 9-meter horizontal resolution) as the main map in this study is processed in eight different ways, i.e. 1) resampled to 100-meter resolution (coded as "**no removal**"), 2) aggregated with cell factor 5 to be 45-meter resolution and then resampled to 100-m resolution (coded as "**factor 5 removal**"), 3) aggregated with cell factor 11 to be 99-meter resolution and then resampled to 100-m resolution, (coded as "**factor 11 removal**"), 4) converted into point shapefile, IDW-interpolated to 100-meter resolution (coded as "**no removal**"), 5) aggregated with cell factor 5 to be 45-meter resolution, converted into point shapefile, and then IDW-interpolated to 100-meter resolution (coded as "**factor 5 removal**"), 6) aggregated with cell factor 11 to be 99-meter resolution, and then IDW-interpolated to 100-meter resolution (coded as "**factor 11 removal**"), 7) resampled to 50-meter resolution (coded as "**no removal**"), and 8) aggregated with cell factor 5 to be 45-meter resolution and then resampled to 50-m resolution (coded as "**factor 5 removal**").

Additional data sets of SRTM and ASTER which are originally of 30-meter horizontal resolution are processed in four ways, i.e. 1) resampled to 100-meter resolution (coded as "**no removal**"), 2) aggregated with cell factor 3 to be 90-meter resolution and then resampled to 100-m resolution (coded as "**factor 3 removal**"), 3) converted into point shapefile, IDW-interpolated to 100-meter resolution (coded as "**no removal**"), and 4) aggregated with cell factor 3 to be 90-meter resolution, converted into point shapefile, and then IDW-interpolated to 100-meter resolution (coded as "**factor 3 removal**").

4.1. Effect of noise removal
Figure 3 shows the results correspond to the first six processed TerraSAR-X maps (numbered as 1 to 6 in section 4) while figure 4 shows the results correspond to the last two processed TerraSAR-X images (numbered as 7 and 8 in section 4). Figure 5 shows the results correspond to open source data sets of SRTM and ASTER.

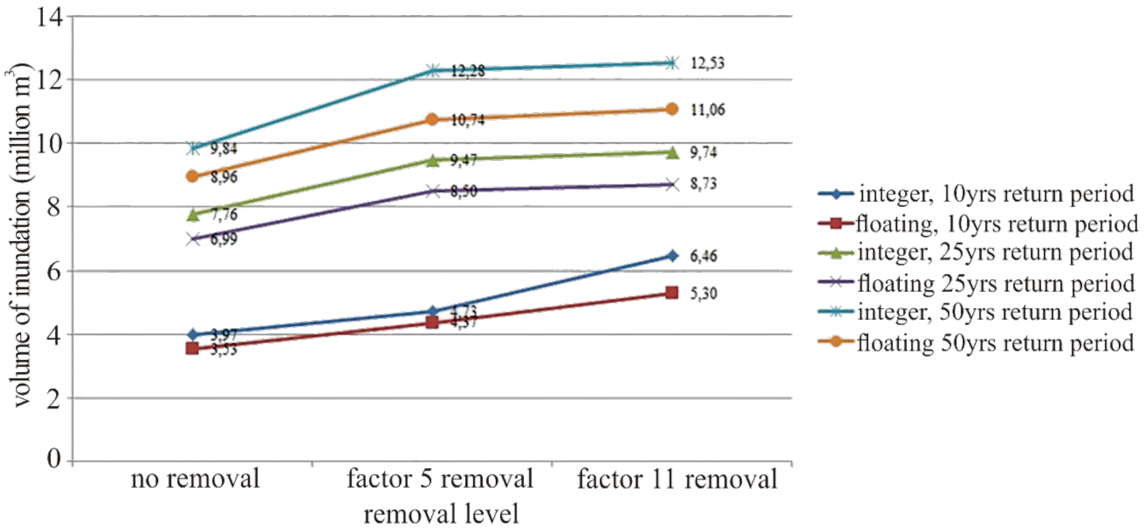

Figure 3. Effect of noise removals from TerraSAR-X images (100-meter horizontal resolution) on volume of inundation for different return periods of flood.

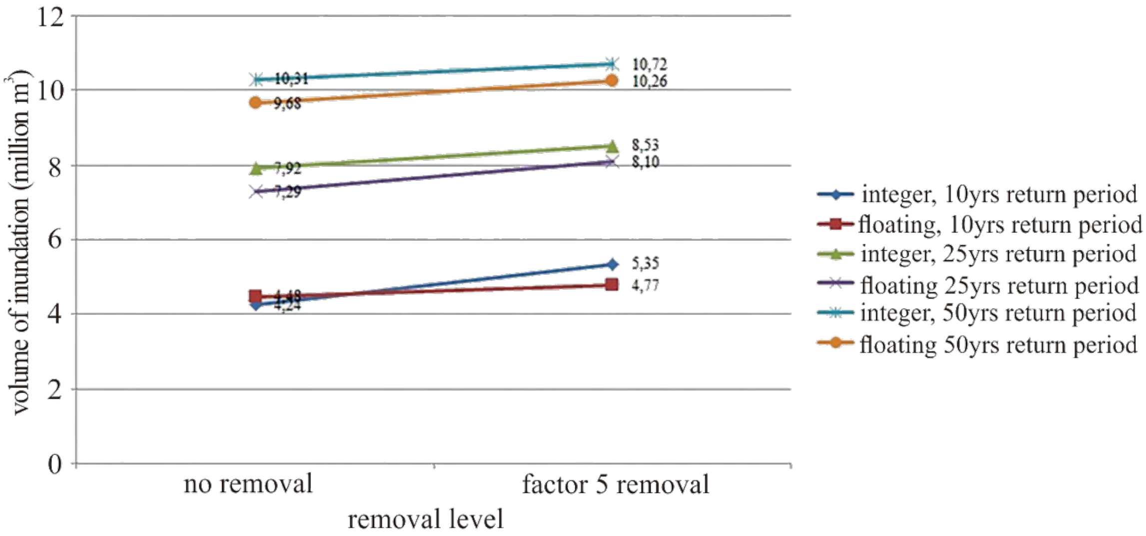

Figure 4. Effect of noise removals from TerraSAR-X images (50-meter horizontal resolution) on volume of inundation for different return periods of flood.

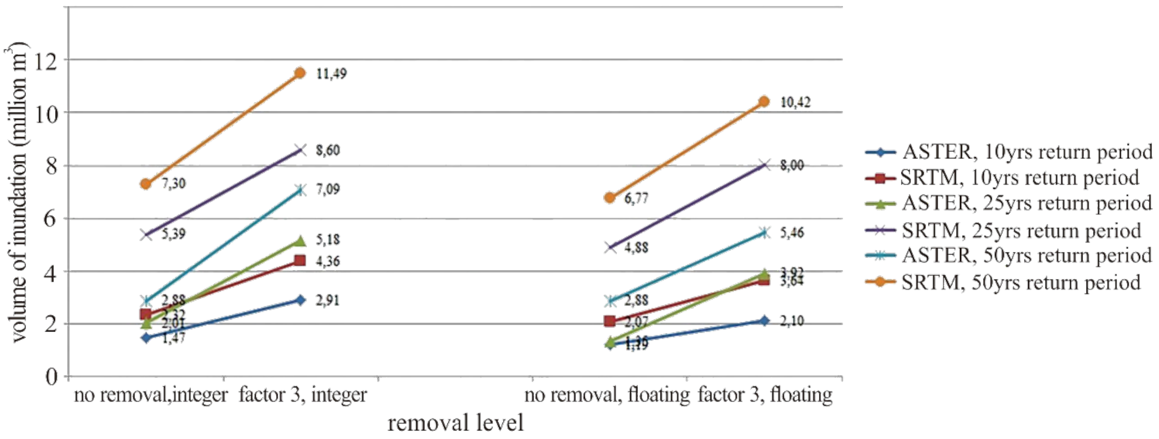

Figure 5. Effect of noise removals from SRTM and ASTER images (100-meter hor.res.) on volume of inundation for different return periods of flood.

Expectedly, figure 3, figure 4, and figure 5 show that noise removal leads to increased inundation volume from "no removal" towards higher removal factor. This applies consistently upon all data sets, despite different factor applied to TerraSAR-X images (i.e. factor 5) compared with factor 3 applied to SRTM and ASTER images. Comparing figure 3 and figure 4, it can be seen that lower resolution of 100-meter is more sensitive to the noise removal effect. Figure 5 reflects a certain considerable differences of inundation volumes between SRTM and ASTER data sets. In general, SRTM's inundation volumes are larger than those of ASTER by 0.7-4.4 millions m^3 (for integer format) and 0.8-4.9 millions m^3 (for floating format). This has been a long and continuous discussion in previous studies which is not included here. Involving figure 3 to this analysis, it reflects that TerraSAR-X's inundation volumes are even the highest one among the three. These difference is challenging due to the absence of data set for validation purpose. It is relatively fortunate that previous study conducted partially upon the middle rivers subsystem (West Flood Canal, Semarang River, Baru River, Kreo River, Kripik River, and Garang River) is available and its inundation depths confirm the TerraSAR-X's in this study [15].

4.2. Effect of spatial resolutions
Analysis upon the effect of resolution is inseparable from the analysis of noise removal effect.

4.2.1. Effect of horizontal resolution. Comparing figure 3 and 4, it can be seen that most of the curves of 100-meter (or lower) resolution is steeper than the 50-meter resolution, in spite of the equal factor of 5. In other words, it can be said that generally, lower resolution is more sensitive to the noise removal effect.

4.2.2. Effect of vertical resolution. Comparing figure 3 to figure 4 and figure 5-left to 5-right, in general the integer curves are on the top of the floating curves. It suggests that maps in integer format is more potential to overestimate the flood inundation than the floating one. In addition to this, figure 5 shows that the integer curves are steeper (of 1.4-4.2 millions m^3) than the floating ones (of 0.9-3.7 millions m^3). This implies that integer format is more sensitive than the floating one with regard to noise removal effect.

5. Conclusion
Despite the expected results, it is still unclear what the appropriate noise removal level is and how it can be determined. Whereas, it is important in order to avoid either under- or over- noise removal that consequently causes under- or over- flood risk estimation at the end of the whole flood risk analysis process. Flood risk analyzer must be aware and take this well into consideration in order to appropriately

implement the studied and applied workflow to particular (lower) scale of flood risk analysis; whether a larger area of coverage and/or a rougher estimation are accepted in the work. The overall results communally imply that the resulted inundation volume is influenced by a number of interrelated aspects. Hence, there is possibility that the studied factors here (noise removal and spatial resolution) are not stand-alone, but interrelated with other aspects, e.g. flood scenario, including return period and flood risk systems.

Acknowledgments
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