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Height Above Nearest Drainage (HAND) as a Model for Rapid Flood Inundation Mapping Based on Remote Sensing and Geographic Information Systems in the Kapuas Sintang Sub Watershed

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Abstract: This study aims to map the flood inundation and the extent of the inundation in the study area using the HAND model. The data used in this study is DEM. The DEM is used to generate a hydrologic framework, including flow accumulation, drainage network, flow direction, elevation, and flow distance. The method used in this study is the HAND descriptor. The analysis in this study used spatial hydrological analysis and hypsometric analysis using zonal statistical tables in ArcGIS. Based on the results of the analysis of height above the nearest drainage it is known that the Kapuas Sintang sub-watershed has five classes of inundation, namely very high inundation, high inundation, moderate inundation, low inundation, and no inundation. Very high, high, and moderate inundation classes are spread over three sub-districts, namely Sintang, Dedai, and Tempunak sections. Sintang District has the widest distribution, followed by Dedai District and Tempunak District is the narrowest. Prediction of inundation area and flood area with HAND can be used to improve the new mapping model without involving additional data sources. The HAND model is a nice and simple tool that is useful for inundation studies as well as in inundation area prediction.

Keywords: Geographical information system, Height above nearest drainage, Inundation; Model; Rapid flood; Remote sensing

Introduction

Flooding disasters are a global problem around the world that is becoming more significant and severe (Hu & Demir, 2021; Lee et al., 2020). Flood is one of the most destructive natural disasters and phenomena that happen both in rural and urban areas (Gianotti et al., 2018; Hlodversdottir et al., 2015; Li et al., 2020b; Morris et al., 2016; Zhou et al., 2019). Flood disasters cause colossal losses including monetary losses, population deaths (Li et al., 2020b; Sayama et al., 2015), and social, economic, and educational.

Therefore, rapid estimation of inundated areas is critical during a flooding event to effectively manage response operations. Accurate information on areas affected by floodwater to prioritize relief efforts and plan mitigation measures against damage is indispensable (Rosser et al., 2017). It is important to model and predict the inundation extent of floods, which is critical information for flood mitigation (Bhola et al., 2018; Hu & Demir, 2021; Tadesse & Fröhle, 2020), preparedness (Arrighi et al., 2019; Hu & Demir, 2021), and planning and response efforts (Bhatt et al., 2017; Hu & Demir, 2021). Accurate predictions of flood inundation extent can facilitate understanding the potential flood risk and damage (Singh et al., 2017; Yildirim & Demir, 2019), and support flood mitigation and planning (Hu & Demir, 2021; Yildirim & Demir, 2021).

Floods are difficult to predict, due to many factors (Xiang & Demir, 2020). Factors that cause flooding among others high rainfall (Hu & Demir, 2021; Sholihah et al., 2020) runoff, stream behavio (Tariq et al., 2022),

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and other issues that affect flooding significantly (Hu & Demir, 2021). For these reasons, flood prediction has highly complex (Hu & Demir, 2021; Mosavi et al., 2018), because it has to involve a lot of parameters that cause flooding.

One of the information about flood disasters is flood inundation maps. Flood inundation maps can be used in flood risk information (Hu & Demir, 2021; Lamichhane & Sharma, 2017; Sermet & Demir, 2019b) and novel communication systems about flooding (Sermet & Demir, 2019a) in an area. Flood inundation maps are a critical resource for mitigating damages from flooding and are integrated into the collaborative decision-making process (Li et al., 2020b; Sermet, Demir, et al., 2020; Xu et al., 2020).

There are many models to predict flood inundation ranging from highly complex distributed models to relatively simplified conceptual models. Some models used are based on a model that fuses remote sensing, social media (Seo et al., 2019), and topographic data sources (Rosser et al., 2017), observations (Sermet, Villanueva, et al., 2020), methods employ mathematical equations to model the complex physical processes involved in hydrological events. Although these models show promise in their ability to predict in a wide range of scenarios flood inundation, the requirement of intensive computation, large amounts of complex data, and the need for expert parameter calibration (Mosavi et al., 2018; Teng et al., 2017; Tewari et al., 2021) make it difficult to apply in real-time modelling.

Based on that condition need for easy-to-implement models led to the development of simplified conceptual models. The model is in the form of digital data (Li et al., 2020a; McGrath et al., 2018), making them the preferable choice in rapid mapping. One of the simplified conceptual models is Height Above Nearest Drainage (HAND) (Tewari et al., 2021). HAND is an information plan directly derived from DEM, involving two other products also extracted from DEM, namely the flow directions and the drainage network (Dantas & Paz, 2021).

To estimate flood inundation areas based on HAND, that is a certain height of this flood is assumed, that all points of the layer that present attributes lower than the established flood height are considered flooded (Nobre et al., 2016). This method identifies flood areas assuming, therefore, that the water level equally rises along the entire river course, maintaining the unevenness along with the drainage network that is, the water level rises parallel to the bottom of the river course.

Some of the HAND models have been used by researchers, purely to test the ability of HAND, but some are compared with several other models with different methods for estimating flood inundation. Different models and methods in real terms certainly produce different results. Therefore, in this study, the authors wanted to test the ability of the analyst model to use HAND with the Hypsometric method, which was also derived directly from the same DEM of the study area. Hypsometric is used to obtain the relationship between height and area in a watershed, basin, or water catchment area so that the ability to map flood inundation with the HAND model will be known which is also compared with the Hypsometric analysis.

The peak of the flood incident in the Sintang sub-district occurred on November 16, 2021. The floods were affected by heavy rains which occurred from November 11 2021 to November 15, 2021. Who died? The floods also damaged 77 electrical substations and submerged 88 houses of worship, nine offices, and a hospital. The community has not worked for more than 3 weeks because the floods have not receded (Cipta, 2021).

The flood incident in Sintang was repeated again in 2022. This time the flood submerged various existing infrastructure in the area, such as 1,000 residential units, seven educational facilities, seven worship facilities and fifteen public facilities. Floods with a water level reaching 1.5 to 2 meters on 14 October 2022 have submerged community settlements, places of education, houses of worship, markets and a number of roads in the local area for more than one week (Wuysang, 2022).

There are several benefits provided by HAND can provide in flood inundation prediction, due to its simplified conceptual models, practically HAND runs at a very fast time. This means that stakeholders involved or interested in flood planning can easily make changes to a DEM to simulate adding barriers and then run the algorithm to determine how these changes affect flood inundation extents. Automatically this can lead to more effective flood protection planning since previously because HAND can make it simpler and practical. This study aims to map the flood inundation and the extent of the inundation in the study area.

Method

Study Area

The research area is in the Kapuas sub-watershed, located at 111020'0″ E-111056'0″ E and 009'30″ S-0020'0″ N. The Kapuas sub-watershed is in the Sintang District, Sungai Tebelian, Dedai, Kayan Hilir, Kelam Permai, Binjai Hulu, parts of Ketungau Hilir and Sepauk districts. The area of the Kapuas sub-watershed is 207,088.32 ha (2,070.8832 Km^2). Within the Kapuas sub-watershed also flow two large rivers, namely the Kapuasriver and the Melawi River. Other small rivers that flow in it are the Kebiang and Lebang rivers. For more details, the site area can be seen in Figure 1.

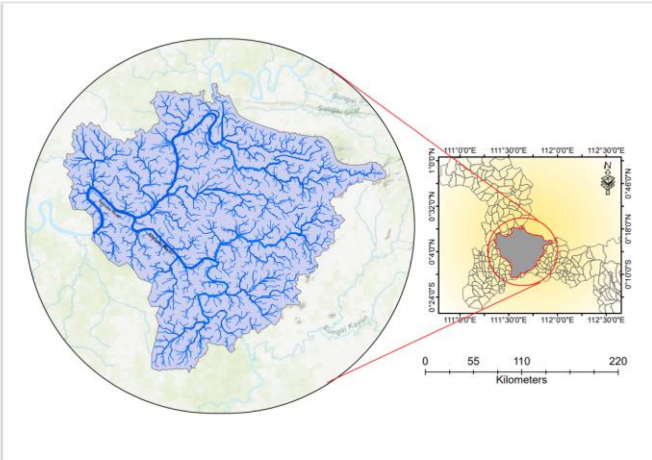


Figure 1. Study area

The Data and Method

To generate a HAND model for the study area required data is DEM with a resolution of 10 meters. DEM was used as one of the inputs collected from the ALOS PALSAR data source. DEM was used to generate a hydrologic framework, including flow accumulation, drainage networks, flow direction (Dantas & Paz, 2021), sub-watershed boundaries, elevation (Buto & Anderson, 2020), and flow distance. The method used in this study is the HAND descriptor. The analysis in this study used spatial hydrological analysis and hypsometric analysis using the zonal statistics table in ArcGIS.

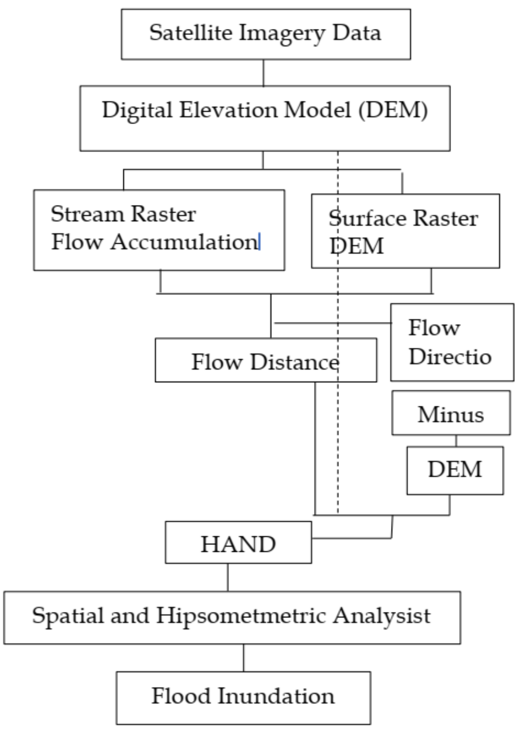


Figure 2. Research flow

There are several steps to produce a HAND raster, namely: each object is described as a unit that has three parameters, namely the outlet (point), catchment area (polygon), and flow direction (polyline) (Johnson et al., 2019). The next step is to create an accumulation of streams in raster format. Flow accumulation with DEM in the form of a surface raster is used to make the flow distance. The next step is to calculate the HAND value with the minus tool in math analysis in ArcGIS. Based on these steps, the water level can be calculated by subtracting the HAND value from the reclassified raster which contains the water level for each pixel. The stages of the research flow can be seen in Figure 2.

Result and Discussion

The HAND model does not require physical parameters like soil characteristics, geology, and land use. Therefore, flood predictions made by the HAND model cannot reflect the influences of soil characteristics or the water-soil interactions, geology, and land use. However, this did not prevent the HAND from becoming one of the most popular flood extents predicting tools (Li et al., 2020b).

The raster digital topography or Digital elevation model is the only input data needed to generate the HAND model and its derived contours. The results of image analysis of the Kapuas Sintang sub-watershed made from the DEM, which shows the topographical height above sea level (a) and by making hypsometrics the average height and depth above sea level (b) can be seen in Fig 3 and Fig 4.

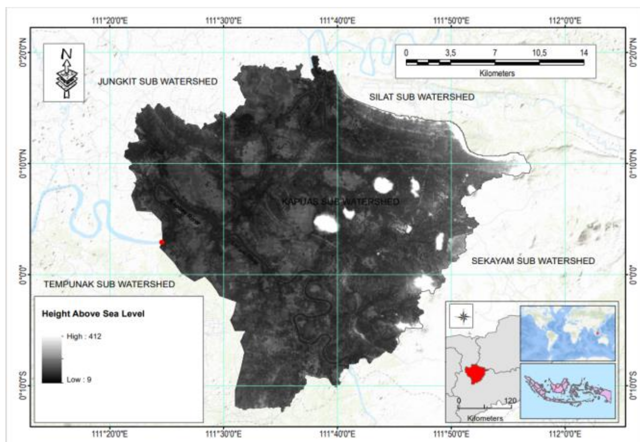


Figure 3. Height above sea-level topographic

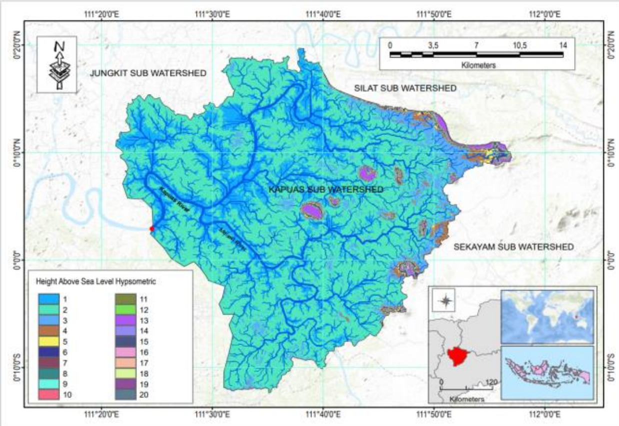


Figure 4. Height above sea-level hypsometric map

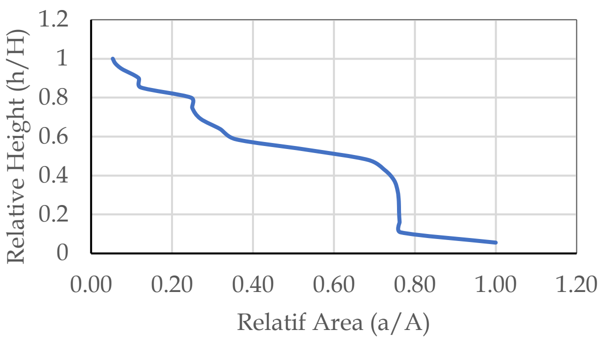
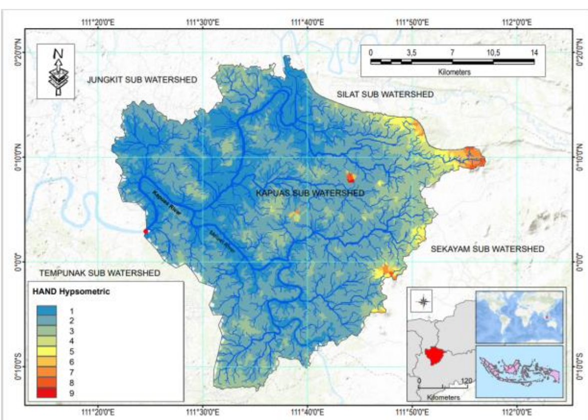
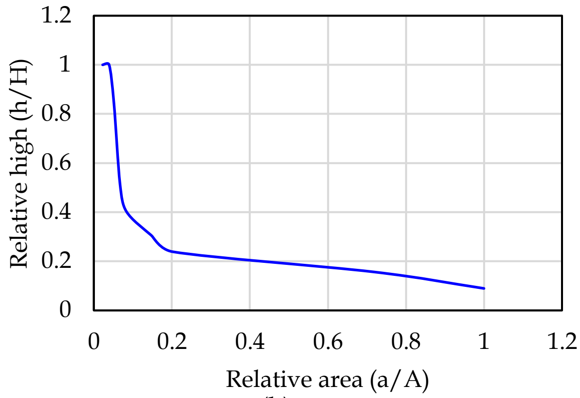


Figure 5. Height above sea level hypsometric curve

The first approach to mapping flood inundation is a topographical hypsometric model of Elevation above sea level, using DEM data and flowline data sets, pairing the relative elevation of a place and the relative area of an area. On a hypsometric map, the height above sea level shows the bodies of water in the river channel and on both sides of the river that has the same level. In this context before the creation of HAND. On the hypsometric curve, sea level height indicates that the wider the area, the lower the water inundation that occurs (Liu et al., 2016).



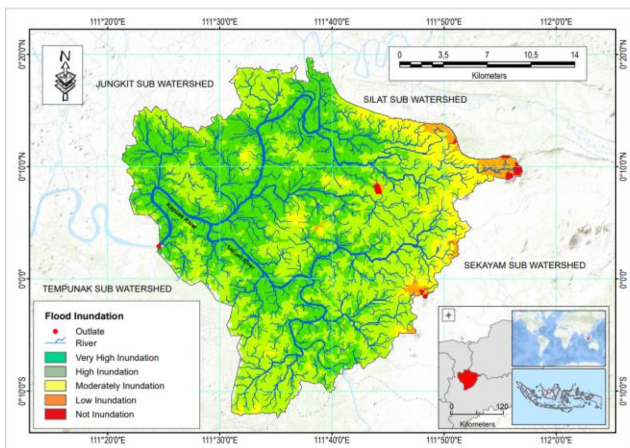
(a)



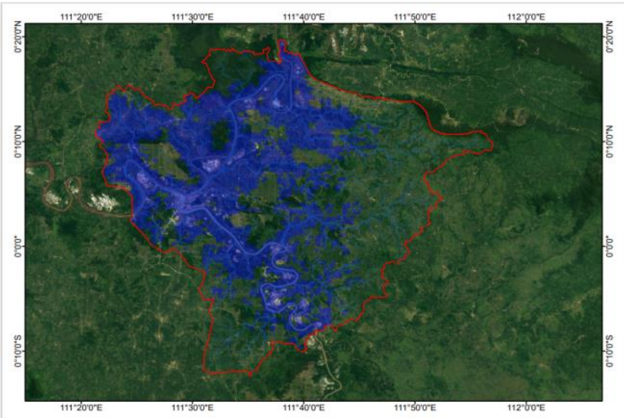
(b)

Figure 6. (a) Height above nearest drainage Hypsometric map, (b) Height above nearest drainage hypsometric curve

The second approach uses the concept directly from the HAND model. In this analysis the HAND value of each grid represents the relative height of a point above its nearest drainage pixel in the mainstream, by comparing the given water depth with the HAND value of each grid, we can separate inundated pixels from non-flooded pixels (Li et al., 2020b). According to the concept of the HAND value, if a pixel has a HAND value less than the normalized water depth, it is considered to be inundated. Normalized water depth is the normalized depth to the main grid whose HAND value is 0 (Liu et al., 2016; McGrath et al., 2018; Nobre et al., 2016). The author uses the water depth near the outlet position. As the outlet is located near the very downstream part of the study area, the water depth there does not require detailed normalization.



(a)



(b)

Figure 7. (a) Height above nearest drainage map. (b) Satellite image Kapuas watershed and overlaid with very high flood inundation map

In figure (a), based on the results of the Height above nearest drainage analysis, it is known that the study area has five classes of inundation, namely very high inundation, high inundation, moderate inundation, low inundation and no inundation. When compared with the hypsometric map of altitude, the mapping model with Height above nearest drainage has a wider distribution of inundation. This shows that predicting flood inundation using the Height above nearest nearest drainage model is very popular and effective (Li et al., 2020a).

The very high inundation, high inundation and moderate inundation classes are spread over three sub-districts, namely Sintang, Dedai and Part of Tempunak sub-districts. Sintang sub-district has the widest distribution, followed by Dedai sub-district and the narrowest is in Tempunak sub-district. Figure 6 (b) shows the results of the HAND analysis overlaid with images taken from Google Earth, and the distribution of flood inundation can be observed, which is shown in blue.

Conclusion

HAND is a new model and approach for flood hazard mapping developed and validated based on Digital Elevation Model (DEM) data. Prediction of inundation area and flood area with HAND (Height Above Nearest Drainage) can be used to improve the new mapping model without involving additional data sources. The HAND model, is a nice and simple tool that is useful for inundation studies as well as in inundation area prediction. This method is also very useful in watersheds that do not have detailed bathymetry or other calibration data. HAND calculations use the original DEM or modified DEM with depression removal process. However this has an impact on the results related to the flood area, especially for low flood elevations. It is therefore advisable to consider DEM without depression. The reason is that DEM without depression leads to a flattening of the longitudinal flood profile along the river, which is related to the realities on the ground. Estimation of flood area based on HAND is coherent with the morphology of the basin expressed in the longitudinal topography of the river profile.

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Author Contributions

This research contributes to mapping and providing fastly flood inundation data on topographical conditions that are difficult to reach in the field.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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