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Application of GIS technology to establish a drainage density hierarchical map for flood hazard zoning in Lam river basin

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ABSTRACT

In recent years, flood in the Lam river basin occurs more often with a higher level of losses in human's lives, property. Preventing and reducing the damage caused by flood has been an urgent issue researched by lots of organizations and scientists all over the world a well as in Vietnam. To find a proper solution to prevent flooding, it is necessary to analyze and research factors affecting the flood directly such as rainfall, slope, soil, land use, drainage density, etc.. It would be easier if these factors show up on maps with corresponding levels of risk. This paper will present the method for the building of the drainage density hierarchical map with the input data used as the digital elevation model and the map of river systems in the Lam river basin. The calculation results show that the river network density of the Lam River is 0.59 km/ km2, which is approximately equal to 0.67 km/ km2 in the central rivers. Based on the drainage density hierarchical map, users can get accurate and detailed information about the river network density as well as the degree of flood hazard because of this factor in the specific basins. This will be useful for flood hazard zoning and flood warning in the study area.

1. Introduction

River system shows the results of topographic separation under the influence of flow. As one of the nine major river systems of Vietnam, the Lam river system has two large tributaries, Ca River and La River. The Ca River originates from Xieng Khouang province (Laos), has a height of over 2,000 m, flows in the North - East - South direction with La River at Truong Xa and empties into the East Sea at Cua Hoi. The river flowed from Truong Xa to the East Sea is called the Lam river. The main characteristics of rivers in the Lam river system originate from high mountains in the Truong Son range (Kieu T.D, Thanh L.D, 2011). Rivers and streams in this basin have large slopes and the midland transiting between mountainous and lowland areas is narrow so when there is heavy rain, floods are concentrated quickly. Moreover, regulation of the flood is not good, leading to the quick concentration of

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floodwater in the delta combining with heavy rains in downstream often causes a flood in a vast area (Kieu, 2015).

Regarding the number of streams in a particular drainage basin, the concept of drainage density will be used, this is an important property of a river network. This concept represents the diversity of the water resource in a basin. Drainage density defines the extent to which streams dissect a topography. The key feature quantified by drainage density is thus the channel head, or stream source (Glenn and et al., 1998). This element describes the degree of drainage network development and was recognized by many authors to be significantly effective in the formation of flood flows (Gardiner and Gregory, 1982).

The drainage density plays a major role in concentrating flood flow in the basin, in other words, the higher the drainage density, the higher the risk of flood flow, ie the greater the flood risk (Pallard, 2009; Rimba, 2017; Sain and Kaushik, 2012). In addition, this factor also affects the amount of water draining out of the basin (Glenn and et al., 1998). According to Niranjan B., the higher the flow velocity, the denser the river network hence increasing the drainage density flood flow (Niranjan, 2016). Besides, the soils with high permeability and high density of vegetation have low drainage density, in contrast, arid areas or areas with impervious surfaces (eg rocky mountains) and sparse vegetation cover have high river network density (Glenn and et al., 1998; Golshan and et al., 2016).

The integration of drainage density and other criteria such as rainfall, soil, and cover has attracted many scientists' attention and been considered as the cause of flood (Anwar, 2011; Di Lazzaro et al., 2014; Ogden et al., 2011). To have flood risk analysis data and establish the flood risk zoning map, drainage density values, and corresponding risk levels should be shown on the map. This study was conducted to handle data of drainage density - a factor affecting flood to serve the flood hazard zoning in the Lam river basin.

2. The method

One of the physical characteristics of the basin that influence flood magnitude is drainage density. Drainage density is a classical descriptor of catchment morphology which is known to control the formation of river flows (Pallard and et al., 2009). Drainage density was defined by Horton as the ratio of the total length of streams in a watershed over its contributing area. It describes the degree of drainage network development and it is computed by the equation (Horton, 1945):

$$k = \frac{L\ (km)}{F\ (km^2)} \quad (1)$$

Where: k: Drainage density; L: The total length of rivers and streams in the basin; F: The area of the basin; L and F must be measured in the same units. In this study, the unit was km/km^2

Figure 1 is a Flow chart depicting the process of establishing a drainage density map. This study uses DEM elevation model data and river system map of the Lam basin combining Spatial Analysis Tools in ArcGIS 10.2 software to determine the area of sub - basins, length of river and stream system and from there the drainage density index will be determined.

2.1. Methods of determining basin boundaries:

A drainage basin is an area of land where precipitation collects and drains off into a common outlet, such as into a river, bay, or other bodies of water. The drainage basin includes all the surface water from rain runoff, snowmelt, and nearby streams that run downslope towards the shared outlet, as well as the groundwater underneath the earth's surface (University of Wisconsin - Stevens Point, 2004).

A major geometrical characteristic of any drainage basin is its area, delimited by the water divide linking the highest points at the boundary with neighboring basins and extending down to the final section of the mainstream.

In each basin may include many smaller basins (called sub - basins). The watershed boundary is a closed line drawn along the watershed line from the outlet point of the basin (Ministry of Agriculture and Rural Development, 2012).

Currently, there are two main methods to determine river basins: traditional method (using paper maps) and automatic method. The map using the method is quite simple, low cost (Dung D.D, 2009). The person who draws the boundaries

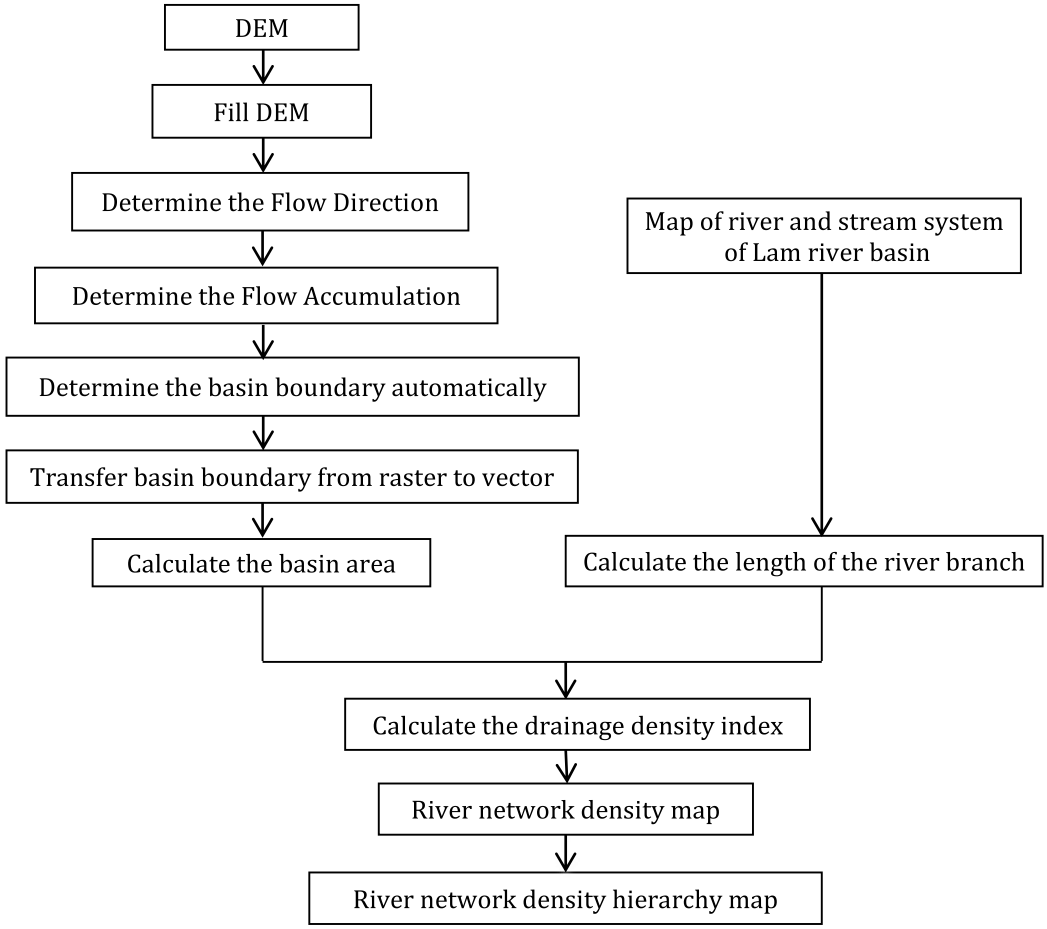

Figure 1. The process of establishing a drainage density hierarchy map.

uses topographic features on the map to determine where a divide is located. Also, the basin can be generalized on paper maps. However, it will take time to delineate the basin and calculate the]catchment area. Besides, determining basin boundaries bases on many subjective factors when conducting work on the map as well as the qualification and experience of the makers, so its accuracy is not high. But with the introduction of computers, things become much easier. Now, one can generate preliminary watershed boundaries in a fraction of the time needed for the traditional method through modern tools.

There is a lot of software that can determine basins automatically such as Mapinfo, Arcgis, etc. But the most popular one is ArcGIS. The SWAT or Hydrology Tools in ArcGIS software can be used to automatically localize the basin boundaries. This paper presents the process of determining a basin automatically using the Hydrology Tools, including the following steps:

Step 1. DEM acquisition

The first input required for watershed determining is DEM. Digital Elevation Models (DEMs) are a type of raster GIS layer. In a DEM, each cell of the raster GIS layer has a value corresponding to its elevation. There are several ways by which a DEM can be obtained. One way is to digitize elevation contours on a topographic map and then perform interpolation of elevation using digitized elevation contours. A DEM can also be created automatically from aerial photos, satellite images. The SRTM (Shuttle Radar Topography Mission) also provides ready - made DEMs. Whatever method is used, the spatial resolution of a DEM can be crucial in the generation of accurate stream sediment sample catchment basins. A DEM can be used for automatic determination of stream networks instead of digitizing streams from a topographic map (Martz and Garbrecht, 1993). This study uses DEM built from topographic maps of the study area.

Step 2. Fill DEM

A filled DEM or elevation raster is void of depressions. Depression is a cell or cells in an elevation raster that is surrounded by higher elevation values, and thus represents an area of internal drainage. Although some depressions are real, such as quarries or glaciated potholes, it may be an imperfection in the DEM. Therefore, depression must be removed by using the Fill function in the Hydrology of ArcGIS. After adjusting, DEM can divide the basin and calculate the parameters more accurately.

Step 3. Determine the flow direction

A flow direction raster shows the direction water will flow out of each cell of a filled elevation raster. A widely used method for deriving flow direction is the D8 method, used by ArcGIS. In D8 method, assigns a cell's flow direction to the one of its eight surrounding cells that has the steepest distance - weighted gradient as Figure 2. This process is repeated for all points in the basin. This is an intermediate product to create a cumulative flow map.

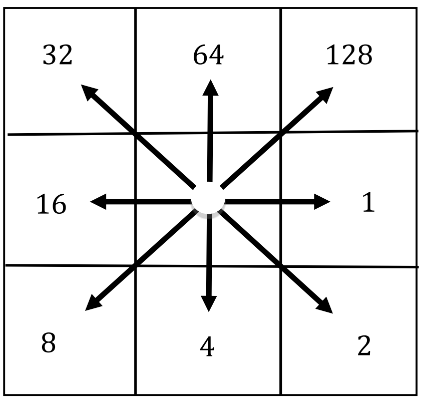

Figure 2. Flow direction in the 8 flow direction model (1 - East; 2 - South East; 4 - South; 8 - South West; 16 - West; 32 - North West; 64 - North; 128 - North East).

Step 4. Determine the flow accumulation

A flow accumulation raster tabulates for each cell the number of cells that will flow to it. The tabulation is based on the flow direction raster. This is the basis for determining the basin automatically using the "Flow accumulation" function in ArcGIS.

Step 5. Determine the boundary of sub - basin

Before defining the basin boundary, it is necessary to add a pour_points point layer to the database layer. Then converting properties of pour_points to raster, from which the basin boundary is determined automatically (Yanli, 2011).

2.2. Determine the basin area automatically

The watershed boundary defined in the above step is raster, hence it needs to be converted to vector form and then using the Calculate Geometry tool to calculate the catchment area. This method has overcome the disadvantages of the traditional method is that fast calculation speed with higher accuracy.

2.3. Determine the length of the river tributaries in the sub - catchments

From the map of the Lam river basin system, the length of the river tributaries in the sub - basins can be calculated. Before calculating the length, it is necessary to determine the main river which is the longest river in the area. This river is made up of many different segments extending from the upstream to the end of the downstream. It is necessary to select objects and export them to a new object that is the longest tributary. Then, creating Length field, using the Calculate Geometry tool to calculate the length of each river tributary in km.

3. Results

The DEM used in this study has a resolution of 30 m shown in Figure 3. However, it is necessary to adjust the DEM by processing unusual elevation data (grid cells having unusually higher or lower elevation value compared to surrounding data).

The used method is the interpolation of numerical values from values around that cell. Elevation of the adjusted DEM is correct so dividing the basin and calculating the parameters will be more accurate. Figure 4 is the result of this processing step.

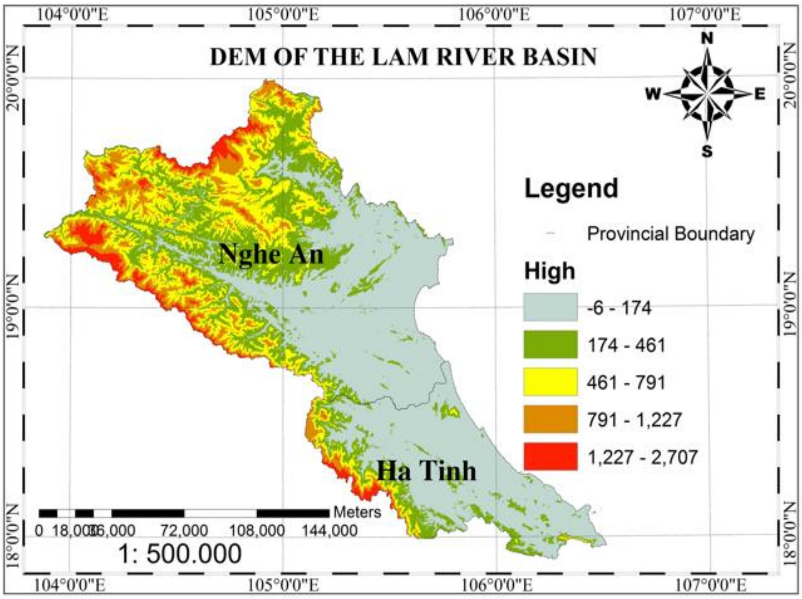

Figure 3. DEM of Lam river basin.

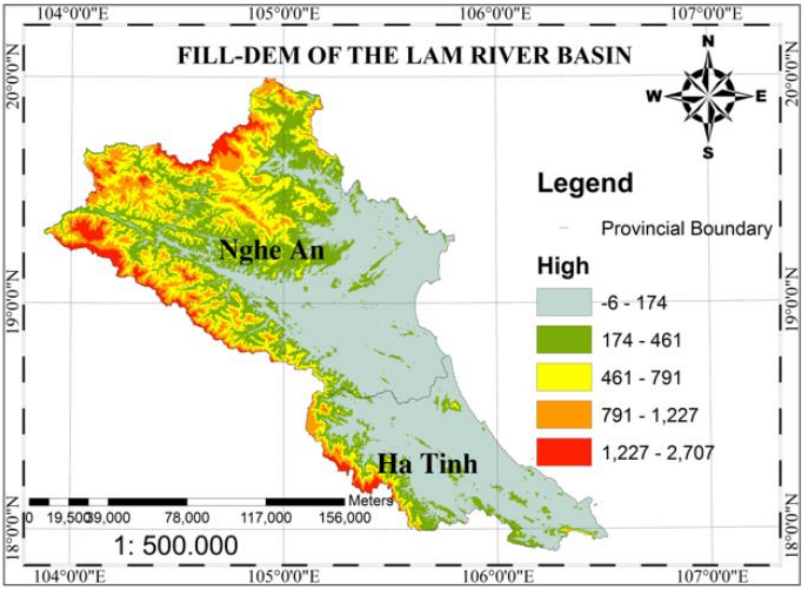

Figure 4. Fill DEM of Lam river basin.

This area defines 634 pour - points which are stored in files that show their coordinates. The raster boundary of sub - basins automatically determined is shown in Figure 5.

Converting raster boundary to vertex from which calculating sub - catchment area. The drainage density index is calculated based on the total length of the river and stream system (Fig. 6) for each sub - basin and the corresponding catchment area.

The value of the drainage density index shown on the Exel file in Table 1.

The calculation results show that the drainage density of the Lam River is 0.59 km/ km^2, which is approximately equal to that of the rivers in the central area 0.67 km / km^2. Upstream area of the La river, the drainage density is from 0.85 km / km^2 (Ngan Pho river) to 0.90 km / km^2 (Ngan Sau river) while the upstream of the Hieu river is 0.74 km / km^2 and the upstream Ca river is 0.58 km / km^2. The higher drainage densities result in increased runoff flow, so Ngan Sau and Ngan Pho rivers have the greatest flood risk, followed by the Hieu River and the lowest is the

Ca River mainstream. The level of flood risk depends on the drainage density index.

In this study, the drainage density in the area is divided into five levels and based on four levels in the study (Kieu T.D, 2015). With different values of drainage density, the risk of flood formation in rivers will be different. The drainage density plays an important role in the concentration of flood flows in the basin, Higher drainage density resulted in higher chances of having a flood (Elkhrachy, 2015; Saini and Kaushik, 2012; Sulaiman, 2015).

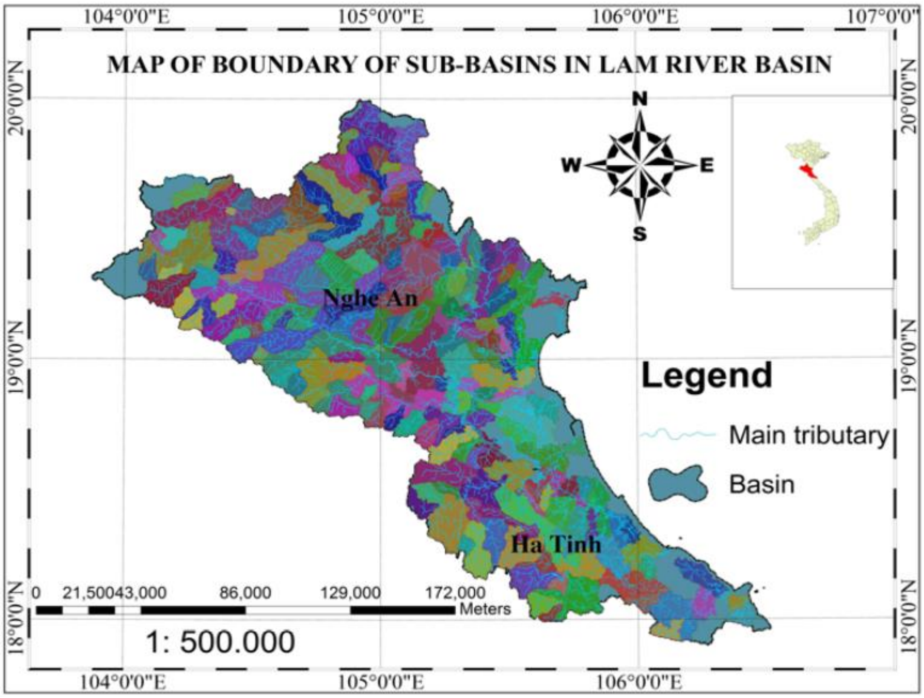

Figure 5. Map of the boundary of sub - basins in Lam river basin.

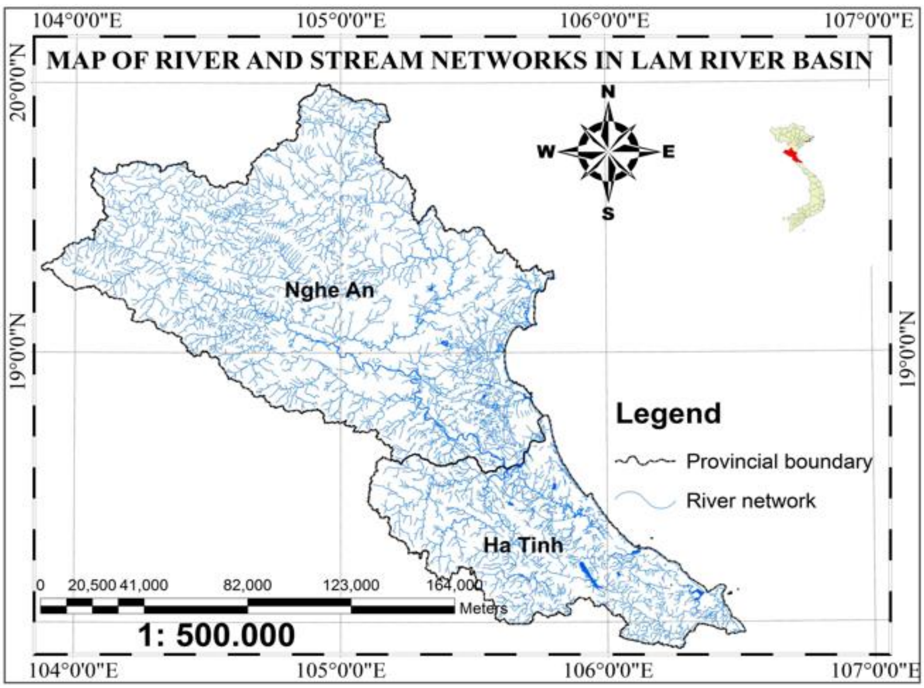

Figure 6. Map of river and stream networks in Lam river basin.

Drainage density hierarchy in Table 2 is based on the level of flood hazard, in which the thickest river density will be assigned high hazard level corresponding to the highest score and as the river density decrease, hazard level, and score will decrease as well. Higher drainage density resulted in higher chances of having a flood. The above calculated values are shown on the drainage density map as in Figure 7 according to the 5 levels divided in Table 2.

From the drainage density map, flood hazard hierarchy based on the influence of the drainage density index corresponding to 5 risk levels shows in Figure 8. The method of establishing this map quickly results in the drainage density index for flood management and zoning in the Lam river basin.

This method is highly effective compared to the manual method used before. Based on this map, users have detailed and accurate information about river network density of specific basins

Table 1. Results of calculation of drainage density index.

FID	ID	GRID CODE	Area (km^2)	Length (km)	Drainage Density (km/km^2)	FID	ID	GRID CODE	Area (km^2)	Length (km)	Drainage Density (km/km^2)
0	1	0	69.794	58.747	0.842	20	21	20	57.566	65.05	1.130
1	2	1	46.823	33.04	0.706	21	22	21	130.108	74.568	0.573
2	3	2	152.702	75.284	0.493	22	23	22	33.738	9.41	0.279
3	4	3	101.568	47.031	0.463	23	24	23	89.848	64.25	0.715
4	5	4	232.371	147.632	0.635	24	25	24	170.870	92.382	0.541
5	6	5	73.739	63.948	0.867	25	26	25	260.730	164.014	0.629
6	7	6	75.217	48.902	0.650	26	27	26	47.490	26.254	0.553
7	8	7	129.856	64.262	0.495	27	28	27	140.762	58.385	0.415
8	9	8	54.068	23	0.425	28	29	28	32.334	13.194	0.408
9	10	9	33.850	21.855	0.646	29	30	29	47.126	20.025	0.425
10	11	10	153.444	65.498	0.427	30	31	30	70.111	46.648	0.665
11	12	11	184.855	119.93	0.649	31	32	31	168.942	73.846	0.437
12	13	12	50.750	66.129	1.303	32	33	32	18.179	13.496	0.742
13	14	13	83.602	34.899	0.417	33	34	33	97.839	43.477	0.444
14	15	14	106.097	76.419	0.720	34	35	34	30.761	27.587	0.897
15	16	15	35.695	27.967	0.784	35	36	35	146.888	70.726	0.481
16	17	16	52.057	13.319	0.256	36	37	36	4.961	4.619	0.931
17	18	17	20.236	18.414	0.910	37	38	37	180.515	70.1	0.388
18	19	18	94.198	71.038	0.754	38	39	38	40.178	21.103	0.525
19	20	19	47.365	30.286	0.639	39	40	39	277.692	148.953	0.536

Table 2. Drainage Density Hierarchy.

No.	Drainage Density (km/km^2)	Mark	Level of flood risk
1	D < 0.5	1	Very Low Hazard
2	D = 0.5 - 1.0	3	Low Hazard
3	D = 1.0 - 1.5	5	Moderate Hazard
4	D = 1.5 - 2.0	7	High Hazard
5	D > 2.0	9	Very High Hazard

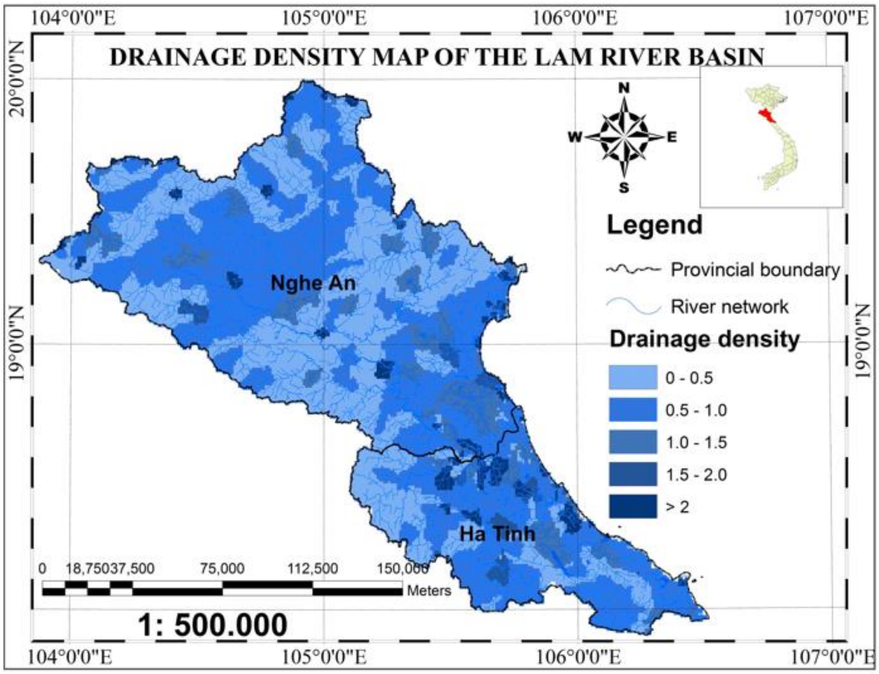

Figure 7. Drainage density Map of Lam River Basin

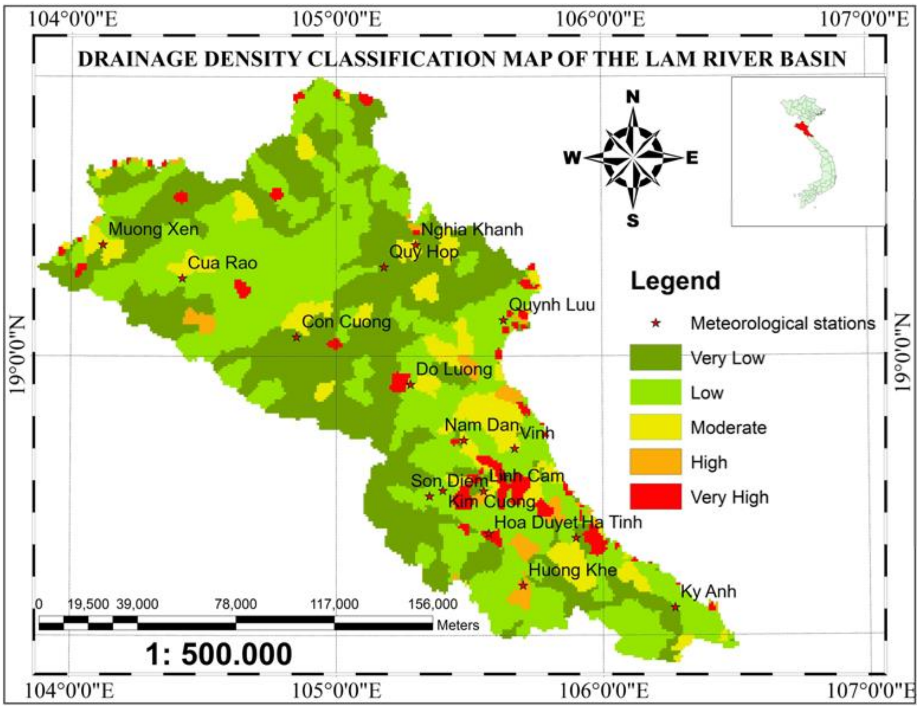

Figure 8. Drainage density hierarchy Map of Lam River Basin.

4. Discussion

Criteria that affect the flood hazard can be determined through the reasons that caused floods. The main reasons for a flood can be divided into several main categories: natural factors, socio - economic factors, infrastructure factors. Choosing these factors depends on the physical geographical condition, research method, the possibility of data collection. Each element will have different levels of influence depending on the specific conditions of each particular basin. Drainage density is one of the main criteria in the physical geographical group affected flood. Many studies have shown that impact of drainage density factor on flood risk in high and medium level in many river basins such as Lam river basin (Minh and Dung, 2017), Huong river basin (Phuong et al., 2015), Vu Gia river basin (Tu et al., 2013). etc. Therefore, the establishment of this map is necessary and indispensable when studying flood risk zoning.

The research results show that high and very high drainage density i.e. high and very high flood hazard concentrates in Ha Tinh province, especially the Hoa Duyet and Linh Cam hydrological stations. In addition, this index in Nam Dan and Do Luong hydrological stations is medium and low respectively. This result can be verified by alarm level and corresponding risk level at 5 hydrological stations in the Lam river basin with three historical flood events: October 16 - 18, 2010 (Table 3); October 15 - 16, 2013 (Table 4); and October 15 - 16, 2016 (Table 5).

The verification results show that there is a similarity between drainage density and risk level at hydrological stations: Hoa Duyet, Linh Cam, Nam Dan, and Do Luong. This result can be combined with other hierarchy maps such as rainfall hierarchy map, sloe hierarchy map, soil hierarchy map, land cover hierarchy map, etc. to establish a flood risk zoning map of the study area.

5. Conclusion

The river network has a great influence on flow formation and the flow characteristics and it is also the cause of flood in the basin. Lam river basin, with quite a complex terrain and high slope, the drainage density there is quite complicated. This creates specific characteristics of the flood in each river tributary as well as causes local and

Table 3. Water level, Alarm level and Drainage density level at Hydrological stations in flood event October 16 - 18, 2010. (Source: Ha Tinh Committee for Flood and Storm Control).

No.	River	Hydrological station	Water level (m)	Alarm level	Hazard level	Drainage density level
1	Ngan Pho	Son Diem	13.00	Over alarm level 3 (0.78 m)	Very high	Low
2	Ngan Sau	Hoa Duyet	12.37	Over alarm level 3 (1.87 m)	Very high	Very high
3	La	Linh Cam	7.28	Over alarm level 3 (0.78 m)	Very high	High
4	Ca	Nam Đan	6.2	Over alarm level 1 (0.8 m)	Medium	Medium

Table 4. Water level, Alarm level and Drainage density level at Hydrological stations in flood event October 15 - 16, 2013. (Source: Ha Tinh Committee for Flood and Storm Control).

No.	River	Hydrological station	Water level (m)	Alarm level	Hazard level	Drainage density level
1	Ca	Do Luong	13.19	Below alarm level 1 (1.31 m)	Low	Low
2	Ngan Pho	Son Diem	14.62	Over alarm level 3 (1.62 m)	Very high	Low
3	Ngan Sau	Hoa Duyet	11.26	Over alarm level 3 (0.76 m)	Very high	Very high
4	La	Linh Cam	5.74	Over alarm level 2 (0.24m)	High	High
5	Ca	Nam Dan	6.50	Below alarm level 2 (0.4 m)	Medium	Medium

Table 5. Water level, Alarm level and Drainage density level at Hydrological stations in flood event October 15 - 16, 2016. (Source: Ha Tinh Committee for Flood and Storm Control).

No.	River	Hydrological station	Water level (m)	Alarm level	Hazard level	Drainage density level
1	Ca	Do Luong	13,00	Below alarm level 1 (1.12 m)	Low	Low
2	Ngan pho	Son Diem	12,8	Below alarm level 3 (0.2 m)	Cao	Low
3	Ngan Sau	Hoa Duyet	10,91	Over alarm level 3 (0.41 m)	Very high	Very high
4	La	Linh Cam	5,5	Alarm level 2	High	High
5	Ca	Nam Đan	5.66	Over alarm level 1 (0.26 m)	Medium	Medium

extraordinary characteristics of flood formation in the basin. High drainage density means a large river tributary system, so flood risk will be high. The value of the drainage density index obtained from the study shows that the high flood risk more concentrated in Ha Tinh province. These results were verified by three historical floods of three years 2010, 2013, 2016 indicating the similarities between the levels of drainage density and the flood risk that occurred at the Linh Cam and Hoa Duyet, Nam Dan, Do Luong hydrological stations. Therefore, it is necessary to study and analyze the drainage density of the Lam river basin in detail, from which the characteristics and levels of flood in each tributary can be delineated, minimizing the flood risk, as well as damage that flood brought.

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