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Rerearch paper

Evaluation of soil erosion risk in Da Nang City using remote sensing and GIS technology

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Abstract: Soil erosion is a naturally occurring process in mountainous areas that affects all landforms. Located in Central of Vietnam, in the tropical monsoon climate Da Nang City is characterized by more than 70 percentage of area with hilly and mountainous topography. This study is objective apply the Universal Soil Loss Equation (ULSE) model developed by Wischmeier and Smith (1978) integrating with remote sensing data and Geographical Information System (GIS) tool to evaluate soil erosion risk in Da Nang City, Vietnam. Rainfall erosivity (R), slope length–steepness (LS), soil erodibility (K), cover management (C), and conversation practice (P) were used to generate soil erosion map of Da Nang City. In this research, Open–Source Geographical Resources Analysis Support System (GRASS) GIS and QGIS tools were used for developing potential soil erosion map for study area. This study has revealed that the erosion in the Da Nang City has been changed compared to the potential erosion map. The high erosion levels (above 50 tons/ha /year) and the low erosion level (less than 5 tons/ha/year) have decreased; erosion at medium levels increased significantly. Thus, after adding the vegetation cover, the amount of soil loss changes to the direction of decreasing. Especially, in Hoa Vang District, the area of potential erosion at highest level is 37752.02 hectares; accounting for 52.3% and but in the average level is 37335.8 hectares, 51.7% respectively. This indicates the positive effects of vegetation cover on reducing soil erosion.

Keywords: Soil erosion; Da Nang City; USLE; Remote sensing, GIS.

1. Introduction

Soil erosion processes is influenced by a whole complex of factors, the emergence and development of modern exogenous processes is influenced by topographic, tectonics, structural lithological conditions, climate, soil and vegetation cover and human activities [1]. There have been many approaches and different methods in research of soil erosion [2–6]. It can be capable of analyzing space in a short time, calculations and construction soil erosion map of the basin, the territory with ease and accuracy. Within the scope of this study, the authors applied the model USLE (universal soil loss equation) [1], integrated with Open GIS (GRASS and QGIS) to study erosion in Da Nang City. The USLE equation is a multiplicative function of five factor controlling erosion process, has the form:

$$A = R * K * LS * C * P \qquad (1)$$

where A is an annual soil loss rate (ton/ha/yr); R is the rainfall factor (MJ.mm/ha.yr); K is the soil erodibility factor (ton.ha.h/ MJ.ha.mm); LS is slope steepness and slope length factor (dimensionless); C is the cover factor (dimensionless); P is the conservation practices (dimensionless).

The Universal Soil Loss Equation (USLE) predicts the long–term average annual rate of erosion (ton/ha/year) on a certain area based on rainfall pattern, soil type, topography, land cover and conservation practices. Universal Soil Loss Equation (USLE) is considered as the best model and is being used worldwide for the estimation of surface erosion [7–10]. This study aimed to assess the soil erosion susceptibility for Da Nang City, Vietnam using the USLE equation integrating with the open–source GIS applications.

Da Nang is a coastal city in the Central Vietnam, which is considered as a sensitive area to climate change such as typhoon, flood. In this developed city, hilly terrain occupies an area of mostly 75%, the average annual rainfall is considerable (around 2000 mm), therefore the risk of erosion as well as natural disaster is very high. Due to the geographical location, the topographic and geomorphological characteristics of study area along with the impact of global climate change, the situation of natural disasters in Da Nang City is very complicated and increased in quantity and severity. This study tends to identify the erosion risk in Da Nang City using the Geographic Information System (GIS) based and remote sensing approach. Recently, the production and exploitation of territory in western mountains have a negative impact on the slop land. Mapping the erosion situation, potential erosion of Da Nang City is very important in urban planning and natural resources utilities for the objective of sustainable development of the city.

2. Materials and Methods

2.1. Study area

Da Nang is bordered with Thua Thien–Hue Province in the north, Quang Nam Province in the south and the west, and the East Sea in the east (Figure 1). Da Nang covers an area of 1,285 km^2, comprising 980 km^2 of mainland and 305 km^2 of Hoang Sa Islands [9]. The mainland latitude and longitude are from 15°55'N to 16°14' N and 107°18'E to 108°20'E with elevation range from 0 m to 1655 m above mean sea level. In addition, the Hoang Sa islands (also namely as Paracel Islands) is located at 15°45'N to 17°15'N and 111° to 113°E. This study was conducted in the mainland with an area of 980 km^2, not considering the area in the Hoang Sa Island. The climate is characterized by two seasons in a year: a rainy season from August to December and a dry season from January to July, with rainfall mainly concentrated from September to December. On an average, this area is directly or indirectly affected by 1–2 typhoons and 1–2 serious flooding spells each year [10]. Average humidity is 83.4%, average temperature is about 26°C, the highest is 28–30°C in June, July, and August; the lowest temperature is 18–23°C in December, January and February. Average precipitation is 2505 mm per year that concentrates during October and November (*https://danang.gov.vn*). The topography of this area has great variation from flat to mountainous regions with elevation ranging from 0 to 1664 m above mean sea level. The location and topographic overview of Da Nang City is shown in Figure 1.

2.2.Materials

The average rainfall data for many years of some meteorological stations in the region from Thua Thien Hue to Quang Nam, including the stations: A Luoi, Hue, Nam Dong, Da Nang, Tam Ky, Tra My. The data was collected from the rainfall data from 172 weather stations in Vietnam extracting from the Report of natural disasters and hold–house welfare, version 1.0 published by The World Bank in 2010 [11]. Soil map of Da Nang in 2007 provided by

Department of Natural Resources and Environment (DONRE), Da Nang City Government. The Digital Elevation Model (DEM) data that was very important input data for calculation of the LS factor was taken from Shuttle Radar Topographic Mission (SRTM) digital elevation model (DEM) (*https://srtm.csi.cgiar.org*). SRTM version 4 in resolution of 30m is a global free DEM data that was used widely in many applications related to disaster management and environmental studies.

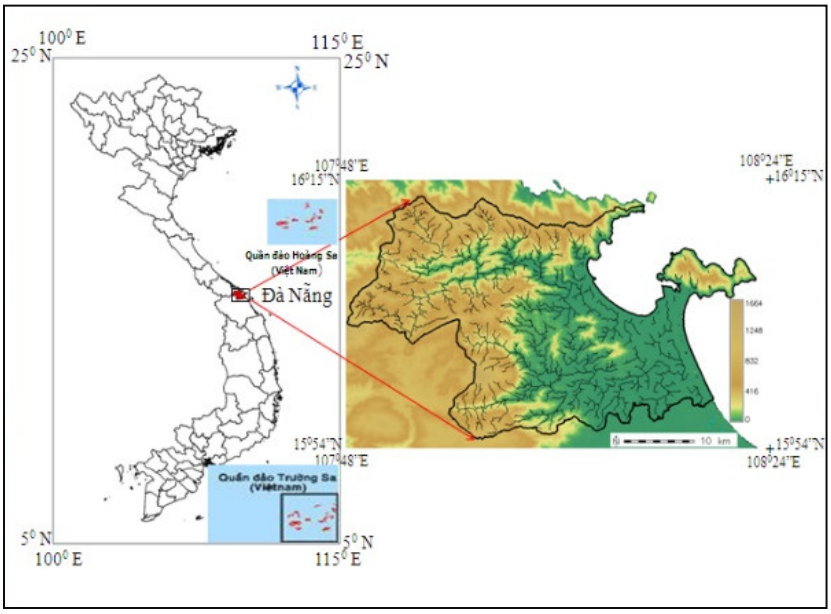

Figure 1. Location of Study Area.

Satellite images: Landsat 8 OLI of Middle Central was freely downloaded from http://earthexplorer.usgs.gov. Landsat 8 is the most recently launched Landsat satellite and carries the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS) instruments. These two sensors provide seasonal coverage of the global landmass at a spatial resolution of 30 meters. The Landsat imagery is high–quality moderate spatial resolution remote sensing data providing information that meets the broad and diverse needs of agribusiness, global change researchers, environment, disaster management and other applications [12]. Rainfall map was interpolated from precipitation data that were collected in some weather stations in Da Nang City. A 30 m digital elevation model (DEM) was used to extract slope length–steepness (LS) parameter. Soil erodibility (K) was calculated from soil map of study area based on analysis of previous studies. Cover parameter was calculate using Normalized Different Vegetation Index (NDVI) extracting from Landsat satellite data.

2.3. Methodology

Modeling soil erosion process based on USLE equation [13] integrated with the Open–Source GIS technique (using GRASS GIS and QGIS software) is the primary method of this research. QGIS software was used to prepare, standardize the input data; GRASS GIS software also performed the main tasks of the study: calculation, establishment, transformation, integration of map coefficients in the model; Statistics of potential erosion.

In addition, in this study the authors have proposed a new approach in the calculation of the coefficient C in the USLE model using the normalized difference vegetation index (NDVI) derived from Landsat 8 satellite images. Through these Landsat 8 images the calculation of the coefficient C in the USLE model becomes easier. The soil erosion modeling workflow can be expressed by Figure 2.

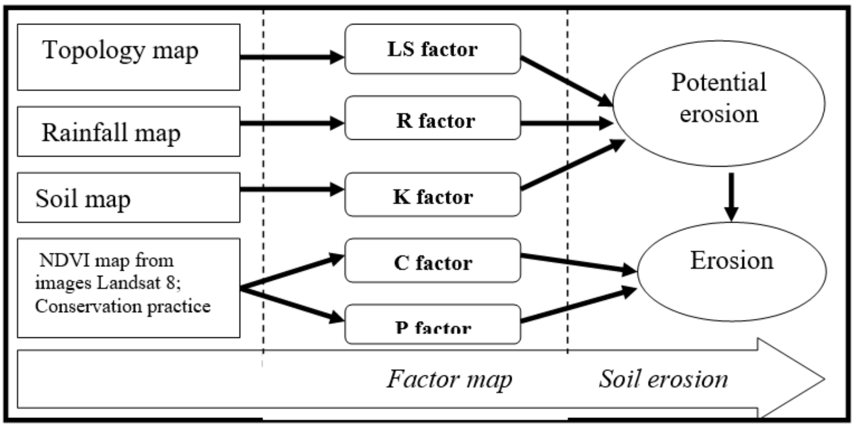

Figure 2. The soil erosion modeling workflow.

2.3.1. Determination of soil erosion factors

a) Slope length–steepness (LS)

The Slope length–steepness (LS) factor represents a ratio of soil loss under given conditions to that at a site with the "standard" slope steepness of 9% and slope length of 22.13 m [13]. In order to establish the LS factor, the author used the input DEM model of Da Nang. DEM model was extracted from 30m SRTM that was freely accessible (Figure 3). From this DEM data, we have calculated the slope and flow accumulation which are two main parameters in generation of LS factor. Both slope and flow accumulation parameters were generated using the terrain analysis tool in GRASS GIS software.

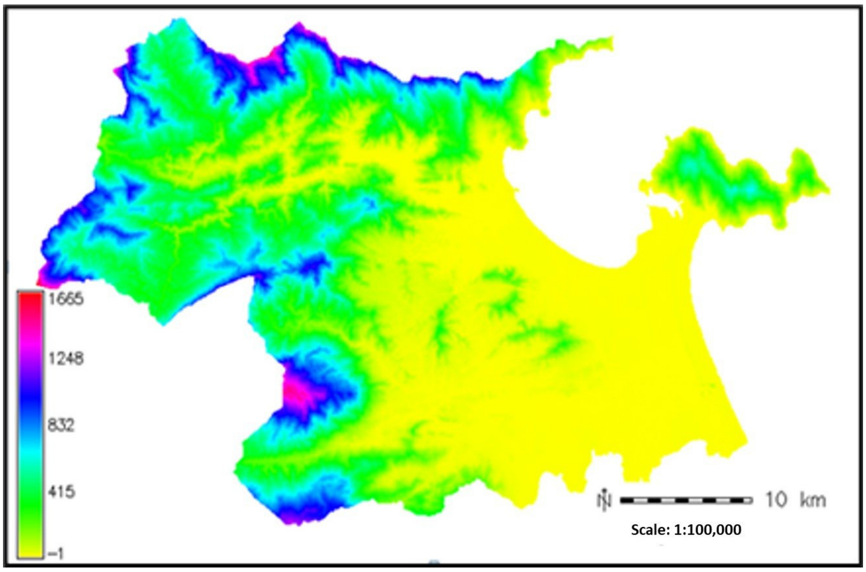

Figure 3. SRTM DEM data of Da Nang City.

DEM model is the basic input to calculate the erosion caused by LS factor. The terrain factor LS is determined by the formula as follows [13]:

$$LS = (t+1)\left(\frac{A}{L_0}\right)^t \left(\frac{\sin\beta * 0.01745}{b_0}\right)^n \quad (2)$$

where LS is the slope length–steepness factor; A represents for the flow accumulation of given study area and $\sin\beta$ is the slope of a given terrain in degree. LS coefficients calculated by formula (2) using the Map Calculator module in GRASS GIS is expressed below:

r.mapcalc "Lsfactor" = 1.5*exp(flowacc*30/22.1,0.5)*exp(sin(slope)*0.01745/0.09,1.3)

Results LS factor map of study area is shown in Figure 4.

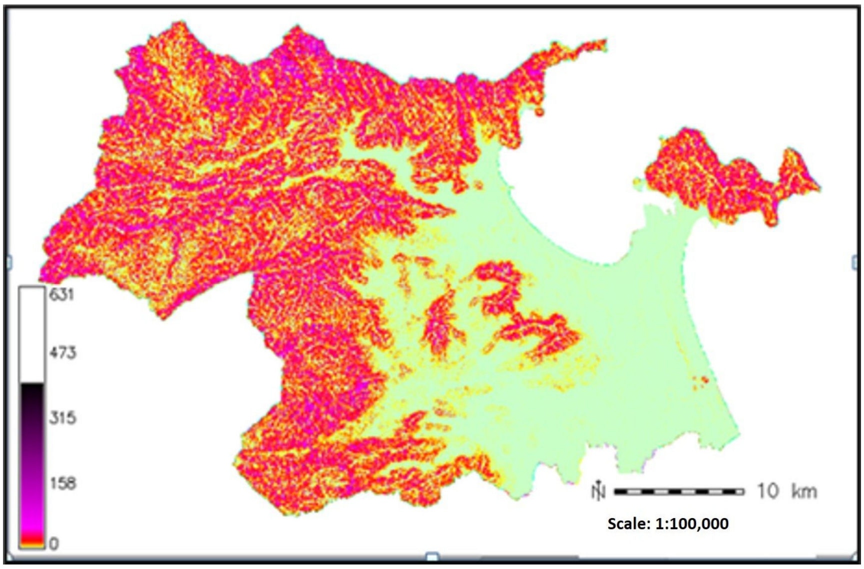

Figure 4. LS factor of Da Nang City.

b) Rainfall erodibility (R)

Rainfall data along with geographical coordinates of five meteorological stations nearby Da Nang City, including: A Luoi, Hue, Nam Dong, Da Nang, Tam Ky and Tra My [11] were used as the input data to interpolate rainfall distribution map for the entire area. The Inverse Distance Weighting (IDW) interpolation algorithm in GRASS GIS has been applied to generate the rainfall map for Da Nang area. This rainfall distribution map was used to calculate the erosion caused by R factor. In this case study, we applied the formula developed by Nguyen Trong Ha for the work system of erosion caused by rainfall for Da Nang [14]:

$$R = 0{,}548257 * P - 59.9 \quad (3)$$

where R is the coefficient of erosion by average annual rainfall (J/m^2); P is an average annual rainfall (mm/year).

The process of calculating the coefficient R is also done through Map Calculator module in GRASS GIS, as follows:

r.mapcalc “Rfactor” = 0.548257 * Rainfall – 59.9

c) Soil erodibility (K)

Based on soil properties from soil maps of Da Nang City, the K factor has identified for soil classes in Da Nang as shown in Table 1. The class of “others” here are mainly ground water, rivers, and lakes, so K coefficient is considered as the smallest one (0.01) [15]. The result of K factor updated to soil map of Da Nang Using Edit Attribute Table tool in Quantum GIS software. This K map was imported to GRASS software and converted to raster format with the same resolution as 30m as other data layers. The K factor map for Da Nang is shown in Figure 5.

Table 1. Coefficient of soil erodibility (K) applied for Da Nang City.

Symbol	Name	K factor	Resources
Fa	Gold Soil	0.23	Nguyen Trong Ha (1996) [14]
Fs	Ferralsols	0.32	Nguyen Trong Ha (1996) [14]
Smi	soils alkaline	0.04	Nguyen Tu Siem and Thai Phien (1999) [16]
Cc	Sandy soil	0.19	Nguyen Tu Siem and Thai Phien (1999) [16]
Py	Fluvisol	0.44	Nguyen Trong Ha (1996) [14]

Symbol	Name	K factor	Resources
Dt	Humic–Feralic Fluvisols	0.61	Nguyen Trong Ha (1996) [14]
Pg	clay silt	0.52	Nguyen Trong Ha (1996) [14]
Nv	golden brown soil	0.21	Nguyen Tu Siem and Thai Phien (1999) [16]
Pb	Fluvisol	0.46	Nguyen Tu Siem and Thai Phien (1999) [16]
Others	Other's soil	0.01	Le Van Bien (2014) [15]

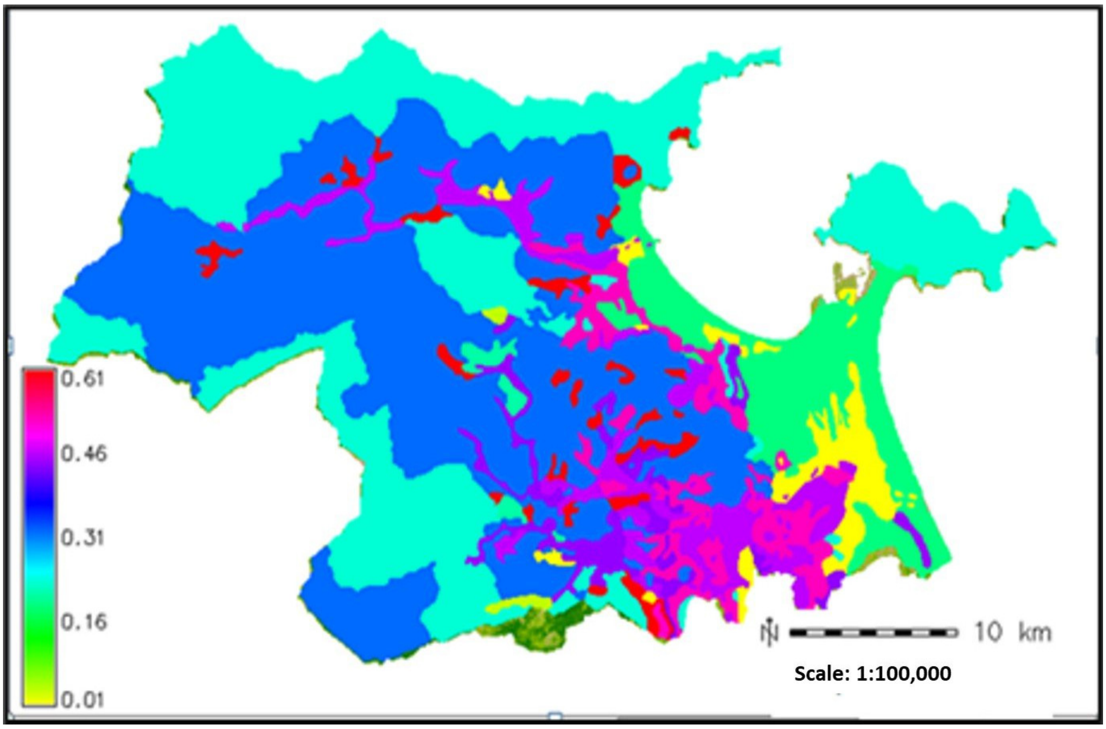

Figure 5. Soil erodibility (K factor) of Da Nang City.

d) Land cover (C)

The vegetation index called NDVI (Normalized Difference Vegetation Index) was calculated to determine the coefficient C that can refer land cover. NDVI is a common and widely used remote sensing index representing the resistance of an area to the hazards [17]. In this study, NDVI data derived from Landsat 8 OLI images of Da Nang area. Normally, NDVI index is calculated using the formular [18]:

$$NDVI = (NIR – Red)/ (NIR + Red) \quad (4)$$

For Landsat 8, the near–infrared (NIR) band corresponds to band 5, and the red band (Red) corresponds to band 4. Tool to calculate the NDVI is Map Calculator on GRASS software, the input data is the digital number values from band 4 and band 5 of Landsat 8 images. In this study, the generation of NDVI is based on Landsat 8 data from 2016 to 2021 on the Google Earth Engine environment (*https://earthengine.google.com*). GEE is a powerful application that can support for online generation of any index from time–series of satellite imageries.

There are many works have studied the dependence of the coefficient C in NDVI and estimated coefficient C based on vegetation indices. In this study, the authors used the formula (5) developed by De Jong [19] to calculate the coefficient of erosion by C factor. This calculation is also based on the Map Calculator tool in the GRASS GIS, the input data is NDVI maps. Results coefficient map of vegetation erosion shown in Figure 6.

$$C\ factor = 0{,}431 – 0{,}805 \times NDVI \quad (5)$$

e) Calculation of P factor

There is no conservation practice against to the soil erosion in Da Nang City, P in this study is considered as a constant with a value of 1, meaning that the process of calculating erosion will not be affected by the elements of P.

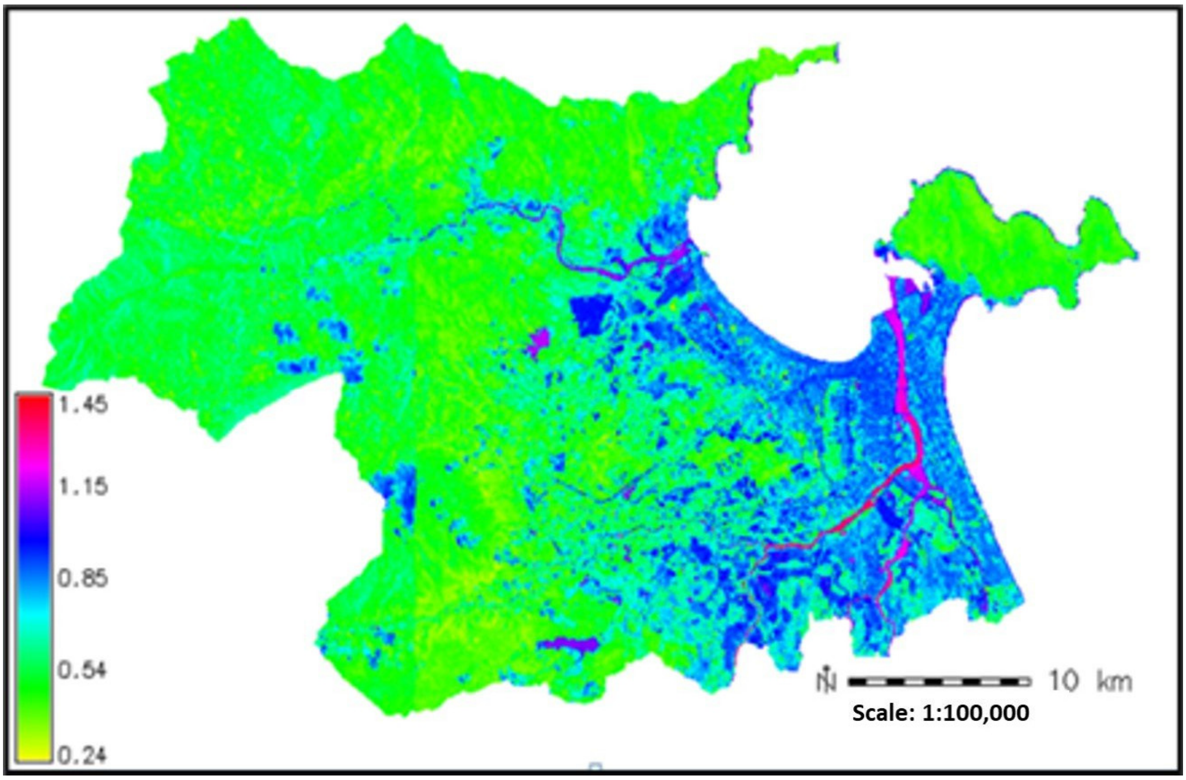

Figure 6. C factor calculated from NDVI of Da Nang City.

3. Results and Discussions

3.1. The potential erosion (without landcover) of Da Nang City

Potential erosion is the process of erosion has not considered the impact of the human's implementation factors and cultural practices. Therefore, the potential erosion map was established by integrating the map coefficient R, K, LS. Calculation process using the Map Calculator tool as follows:

*r.mapcalc"Potential_Erosion"=Rfactor*Kfactor*LSfactor*

Based on the Vietnam standards TCVN 5299–1995 for classify the levels of potential erosion, the authors conducted classification for potential erosion map of Da Nang as shown in Table 2 and Figure 7. Basically, the whole city has two main levels of erosion including the lowest Level I (30.49% of the area) and the highest level VIII (45.2%). The erosion levels from grade II to grade VII occupy only 24.31% of study area. Erosion levels I focuses mainly on the east, southeast (except the Son Tra Peninsula) Hai Chau, Thanh Khe and Ngu Hanh Son, Cam Le, which are urban districts and the coastal plains with high density urbanization, low slope, and rainfall (Figure 7). Erosion levels VIII concentrates mainly in the west and north as Hoa Vang, Son Tra, Lien Chieu, where are the suburban districts and hilly areas with steep slopes, high precipitation, and low level of urbanization.

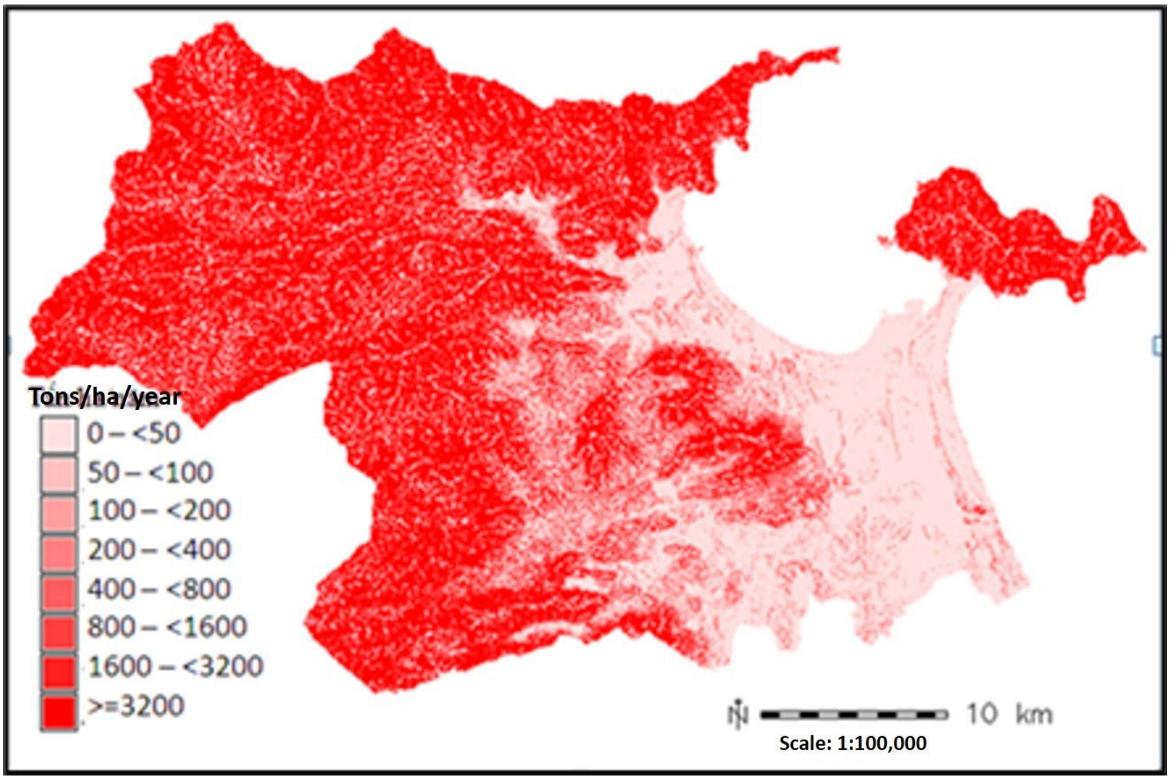

Figure 7. The potential erosion map of Da Nang City.

Table 2. Statistics of potential erosion map of Da Nang City.

Level	potential erosion (tons/ha/ year)	Area (ha)	Percentage (%)
I	0 <50	29064.7	30.49
II	50–100	2818.1	2.96
II	100–200	2784.5	2.92
IV	200–400	2834.2	2.97
V	400–800	3259	3.42
VI	800–1600	4281.4	4.49
VII	1600–3200	7229.4	7.58
VIII	> 3200	43051.5	45.2
Total		95322.930	100

3.2. Erosion actual risk (with landcover) of Da Nang City

In this study, the erosion risk map is considered as the current state of erosion considering the effects of vegetation and cultivation methods. Therefore, the coefficient C and P are included in the equation of erosion model. The formula for calculation is as follows:

*r.mapcalc "Erosion" = Rfactor * LSfactor * Kfactor* Cfactor*

Based on the Vietnam standard TCVN 5291–1995 for erosion risk, the classifications for the current erosion models of Da Nang City are shown in Table 3 and Figure 8.

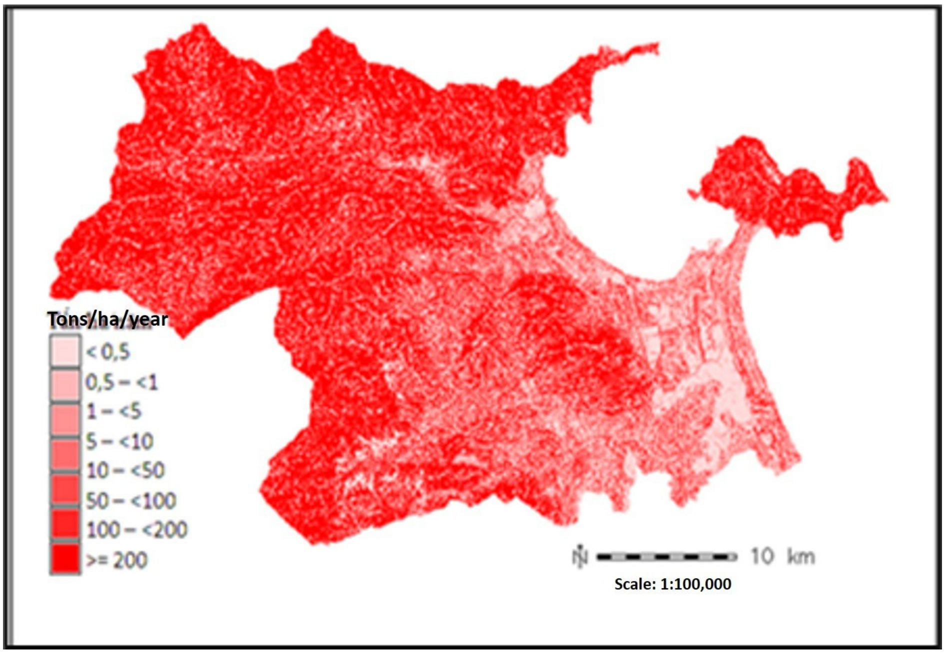

Figure 8. Erosion risk map of Da Nang City.

Table 3. Statistics of erosion risk map of Da Nang City.

Level	Erosion (tons/ha /year)	Area (ha)	Percentage (%)
I			
Ia	0–0.5	22021.6	23.1
Ib	0.5–1	894.4	0.9
Ic	1–5	3991.1	4.2
Id	5–10	2979.6	3.2
II	10–50	9371.9	9.8
III	50–200	13751.6	14.4
IV	> 200	42312.6	44.4
Total		95322.930	100

From the map and statistical table of erosion risk, it is observed that the erosion in the City has been changed compared to the potential erosion map. The high erosion levels (above 50 tons/ha /year) and the low erosion level (less than 5 tons/ha/year) have decreased; erosion at medium levels increased significantly. Thus, after adding the vegetation cover, the amount of soil loss changes to the direction of decreasing. In the whole City, the areas of potential erosion at highest level (grade VIII) were reduced compared to the highest level of the erosion risk map (level IV), from 43051.5 hectares, covered 45.2% of City area to 42312.6 hectares, corresponding to 44.4% of the area. In some places, statistic from ratio and area of potential erosion was significantly high, but in the erosion risk map, they were observed as not so high levels (under the effect of vegetation cover).

The evaluation results and classification in this study are classified into 8 levels of erosion (base on Vietnam standard TCVN 5291–1995 for erosion risk) which is suitable for the territory of Da Nang City and has good application for administrative units at district and commune level. However, according to the recently updated Vietnam Standard (TCVN 5299:2009), actual erosion is classified into 5 levels, including level I (less than 1 ton/ha/year), level II (1–5 tons/ha)/year), level III (5–0), level IV (10–50) and level V (> 50). This new classification is calculated for the study area, shown in Table 4.

Table 4. Statistics of erosion risk map of Da Nang City (based on TCVN 5299: 2009).

Level	Erosion (tons/ha /year)	Area (ha)	Percentage (%)	Erosion Assessment
I	0 – 1	22916	24	No erosion
II	1 – 5	3991.1	4.2	Weak erosion
III	5 – 10	2979.6	3.2	Medium Erosion
IV	10 – 50	9371.9	9.8	Strong Erosion
V	> 50	56064.2	58.8	Very strong erosion
Total		95322.93	100	

Accordingly, in the study area, Hoa Vang district, the area of potential erosion and actual erosion is widest, about 37335.8 hectares, occupying the proportion 51.7% Da Nang City. This indicates the need to establish vegetation cover on reducing soil erosion.

4. Conclusions

Integrating remote sensing and open–source GIS applications (GRASS GIS and QGIS) is a new approach in soil erosion research in Vietnam. This study has investigated new method in modeling soil erosion using USLE equation integrating the meteorological data (rainfall), geomorphological condition (steep–length slope), soil properties and the use of Landsat 8 satellite image to interpolate C factor. Using model USLE and GIS technology, this research has built potential erosion and erosion risk maps for Da Nang area, which was analyzed clearly in term of spatial distribution.

This study is limited in validation of the results with field data since field measurement for soil erosion requires well–equipped technology and labor–intensive support that are still restriction in developing countries. In further study, we will develop a robust soil erosion model for Da Nang City by combining USLE equation with the spectral indices extracted from remote sensing data integrating with field measurement. This approach is expected to support more precise estimation of soil erosion and comprehensive evaluation of the effects of soil erosion on agriculture as well as other economic activities in Da Nang area. In addition, the assessment of the impact of precipitation changes under the climate change scenario on soil erosion will be considered and further developed in the study territory.

Author contribution statement: Conceived and designed the experiments: T.T.A., T.T. T.; Analyzed and interpreted the data: L.N.H., T.P.M.; Manuscript editing: T.T.T.; Performed the experiments: H.T.D.H.; contributed reagents, materials, analyzed and interpreted the data: N.T.D., L.N.H.; wrote the draft manuscript: T.T.A.

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