Sains Malaysiana 46(4)(2017): 529–535
http://dx.doi.org/10.17576/jsm-2017-4604-03

Soil Erosion Assessment in Tasik Chini Catchment using Remote Sensing and GIS Techniques

(Penilaian Hakisan Tanih di LembanganTasik Chini menggunakan Teknik Pengesanan Jarak Jauh dan GIS)

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ABSTRACT

Over many years, forested land transformation into urban, agriculture and mining areas within Tasik Chini Catchment become more intense. These activities have negatively affected the catchment through soil erosion and increased the amount of sediments that deposited into the lake. Hence, the present study aimed to estimate soil erosion risk within Tasik Chini Catchment integrating the Revised Universal Soil Loss Equation (RUSLE) model and remotely sensed geospatial data. The multispectral imagery from LANDSAT 8 was used to provide up to date information on land cover within the catchment. The result shows the majority of Tasik Chini Catchment is classified at very low class (< 10 ton ha^{-1} yr^{-1}) about 4835.34 ha (92.38%), followed by the low class (10-50 ton ha^{-1} yr^{-1}) with total area of 175.47 ha (3.35%), moderate high class (50-100 ton ha^{-1} yr^{-1}) with total area of 65.11 ha (1.24%), high class (100-150 ton ha^{-1} yr^{-1}) with total area of 38.37 ha (0.73%) and very high class (> 150 ton ha^{-1} yr^{-1}) with total area of 120.04 ha (2.30%). Tasik Chini Catchment is very susceptible to soil erosion especially on northwest and southeast regions, where the main sources of soil loss come from the agricultural, new settlements and mining activities. To conclude, the estimation of soil erosion model using remotely sensed data can be used to build sustainable development strategy within Tasik Chini Catchment in the future.

Keywords: LANDSAT 8; NDVI; RUSLE; soil loss; Tasik Chini Catchment

ABSTRAK

Dalam tempoh masa yang lama, transformasi kawasan hutan di Lembangan Tasik Chini kepada kawasan-kawasan bandar, pertanian dan lombong menjadi lebih giat. Aktiviti-aktiviti ini telah memberi kesan kepada kawasan lembangan tersebut melalui hakisan tanih dan meningkatkan jumlah sedimen yang masuk ke dalam tasik. Oleh itu, kajian ini bertujuan untuk meramalkan risiko hakisan tanih di kawasan Lembangan Tasik Chini menggunakan penggabungan model Revised Universal Soil Loss Equation (RUSLE) dan data georeruang penginderaan jauh. Imej multispektral daripada LANDSAT 8 digunakan untuk memperoleh maklumat terkini mengenai litupan tanah dalam lembangan. Hasil menunjukkan bahawa kebanyakan kawasan di Lembangan Tasik Chini dikelaskan kepada sangat rendah (< 10 ton ha^{-1} yr^{-1}) sekitar 4835.34 ha (92.38%), diikuti oleh rendah (10-50 ton ha^{-1} yr^{-1}) sekitar 175.47 ha (3.35%), sederhana tinggi (50-100 ton ha^{-1} yr^{-1}) sekitar 65.11 ha (1.24%), tinggi (100-150 ton ha^{-1} yr^{-1}) sekitar 38.37 ha (0.73%) dan kelas sangat tinggi (> 150 ton ha^{-1} yr^{-1}) sekitar 120.04 ha (2.30%). Lembangan Tasik Chini sangat kritikal kepada hakisan tanih terutama di kawasan-kawasan barat laut dan tenggara, dengan punca utama kehilangan tanih tersebut berasal daripada aktiviti-aktiviti pertanian, perbandaran dan perlombongan. Kesimpulannya, peramalan model hakisan tanih menggunakan data penginderaan jauh dapat digunakan bagi membina strategi pembangunan yang mampan di Lembangan Tasik Chini pada masa hadapan.

Kata kunci: Kehilangan tanih; LANDSAT 8; lembangan Tasik Chini; NDVI; RUSLE

INTRODUCTION

Soil erosion has become a major environmental problem in recent years especially in catchment areas where intensive use of land for development, including urbanization and agricultural activities are being carried out. Hence, the catchment erosion has been a worldwide phenomenon and never ending problem. Tasik Chini Catchment has been transformed from forests to agricultural and ecotourism areas, mines and settlements. Due to these changes, the rate of erosion and sedimentation has subsequently increased. These conditions have been normally associated with the runoff phenomenon in the bare slope surfaces to the streams and lake. These activities also contributed significantly to the decline of water quality in the Tasik Chini due to the presence of nutrients and heavy metals (Barzani et al. 2013). Therefore, estimation of soil erosion risk and its spatial distribution are the one of key factors for the successfull of soil erosion assessment. Then, it can be used to develop and implement policies to reduce the effect of soil loss under varied geographical conditions (Colombo et al. 2005). The accuracy of soil erosion model depends on model and its factors (Ahmet 2010). Modeling can provide quantitative and consistent approaches to estimate soil loss under a wide range of condition. For evaluating on soil erosion from catchment area, several empirical models based on geomorphological parameters have been developed to quantify the sediment yield (Jose & Das 1982).

Common empirical methods, such as the Universal Soil Loss Equation (USLE) (Wischmeier & Smith 1965) and the Revised Universal Soil Loss Equation (RUSLE) (William 1975) have been frequently used for the estimation of surface erosion and sediment yield from catchment areas (Kothyari & Jain 1997). The RUSLE model follows the same formula as USLE, but it has a subfactor for evaluating the cover management factor (C), a new equation for slope length, steepness and new conservation practice values. This model is also applicable to non-agricultural conditions like construction sites. The RUSLE model has been widely applied as a predictive model for estimating soil erosion potential and effects of different management practices by many researchers. For example, Bhattarai and Dutta (2007) adopted RUSLE and GIS approaches for soil loss analysis. Lee and Lee (2006) used the remotely sensed geospatial technique to estimate soil loss. One of the most critical factors in RUSLE equation is the cover management factor (C) that represents effects of vegetation and land cover. In conventional way, C factor is computed using empirical equation that contained field measurements of ground cover (Renard et al. 1997). Now, since the satellite imagery such as LANDSAT 8 and other multispectral satellites provide up to date information on land cover, the use of satellite imagery for the preparation of land cover map is widely applied in natural resource surveys (Deng et al. 2008; Serra et al. 2008; Yuan 2008). In general, spatial estimation of C factor assigns value to land cover class using classified remotely sensed image (Efe et al. 2008; Karaburun 2009). Since all pixels in a vegetation class have the same C factor value, those pixels are not able to represent variation of the vegetation class over the area (Wang et al. 2002). Hence, researchers have developed a new method to estimate C factor by using Normalized Difference Vegetation Index (NDVI) (Lin et al. 2002; Wang et al. 2002). This method employs regression model to create the correlation analysis between C factor value measured in the field and NDVI value derived from remotely sensed data. The unknown C factor value of land cover class can be predicted by using equation obtained from linear regression analysis. In present study, NDVI was applied to estimate C factor in study area, then soil erosion risk map was generated using GIS software.

Materials and Methods

Study Area

Tasik Chini Catchment was located in the southeastern region of Pahang, Malaysia. It lies between 3°22’13.84”N to 3°28’05.40”N and 102°52’45.53”E to 102°58’00.04”E, covering a total area of approximately 52.4 sq km (Figure 1). The catchment comprised twelve open water bodies and was linked to Pahang River by the Chini River. Tasik Chini was the second largest natural fresh-water lake in Peninsular Malaysia, encompassing 202 ha of open water, as well as 700 ha of Riparian Peat and Lowland Dipterocarp forest (Wetlands International Asia Pasific 1998). The lake was surrounded by variously vegetated low hills and undulating land which constituted the catchment (Sujaul et al. 2012). The study area had a humid tropical climate with two monsoon periods, such as the southwest and northeast monsoons. The mean annual rainfall was 2,500 mm and the temperature range was from 21 to 32°C.

Methods

Soil samples were collected from ten stations within the catchment, which were taken to the lab for further analysis. *In situ* parameters were observed and noted in the field based on the coordinates of the sampling stations, their canopy cover and the natural conservation practices in 2015 year. The particle size distribution, organic matter content and hydraulic conductivity were determined for soil samples. Particle size was determined using the pipette method (Abdulla 1966). The organic matter content was determined using the gravimetric method (Avery & Bascomb 1982) and the hydraulic conductivity was determined using the falling head method described by Kirkby (1980). Soil loss prediction for the study area was carried out with the widely used RUSLE soil erosion model. With this model, the amount of soil loss (A) can be obtained by measuring five key factors: Rainfall erosivity (R), soil erodibility (K), slope length and steepness (LS), land canopy cover (C) and conservation practice (P). The RUSLE equation model was as followed: $A = R \times K \times LS \times C \times P$. The ArcGIS 10 software was used in spatial data analysis to determine soil erosion potential, spatial distribution and for development of the erosion risk map of study area. The conversion of coordinate projection from WGS 1984 to Kertau RSO Malaya Meter was carried out to obtain the accurate coordinate of study area.

Results and Discussion

Erosivity Factor (R)

Rainfall data were collected from the Meterology Department of Malaysia. The mean annual rainfall calculated from 2013 to 2015 was 2058.5 mm per year. The formula of R factor in this study was proposed from Morgan (2005) and Roose (1977). Spatial annual rainfall data were derived from each of station using Simple Kriging estimator technique with Spherical Semivariogram Model. The mean of annual rainfall (P) was calculated using R factor formula in GIS sofware and the best estimated value of rainfall erosivity was obtained, which is ranged from 11884 to 13178 MJ mm ha^{-1} h^{-1} yr^{-1} (Figure 2(a)). The erosivity factor value found a higher in northern parts of area and a lower in southern parts of area.

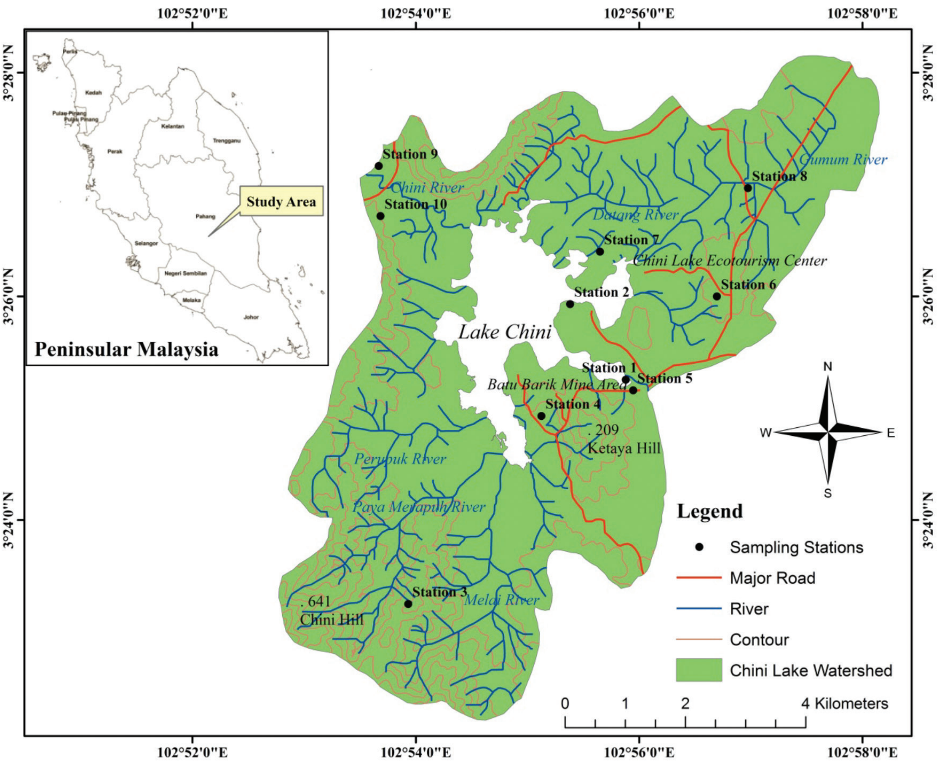

FIGURE 1. The location of study area

The rainfall erosivity became increasingly as a dominant factor in RUSLE model if the area was situated at the higher topography and less land cover.

R = [(9.28P - 8838.15) × (75)] / 100 (Morgan 2005)

R = 0.5P × 17.3 (Roose 1977)

Best estimation = (Morgan + Roose) / 2.

ERODIBILITY FACTOR (K)

The erodibility factor was calculated using the nomograph formula by Tew (1999). The soil erodibility factor ranged from 0.00 to 0.04 Ton h MJ^{-1} mm^{-1} (Figure 2(b)). The highest erodibility factor was found at Station 4, followed by Stations 5 and 3. A high soil erodibility factor at Station 4 can be attributed to the combined effect of the soil texture with a low percentage of organic matter. The lowest value is found at Stations 6 and 8. The sandy texture contributed to high infiltration rates and reduced surface runoff, resulting in the sediments getting eroded from these soils not easily transported.

$$K = (2.1 \times 10^{-4} (12 - OM\,\%)\,(N1 \times N2)^{1.14} + 3.25\,(S - 2) + 2.5\,(P - 3)) / (100 \times 7.59)$$
(Tew 1999),

where K is the soil erodibility factor (Ton h MJ^{-1} mm^{-1}); OM is the organic matter (%); N1 is the clay + very fine sand (0.002 - 0.125 mm); S is the soil structure; N2 is the clay + very fine sand + sand (0.125 - 2 mm) and P is the hydraulic conductivity (cm h^{-1}).

SLOPE LENGTH AND STEEPNESS (LS)

Slope length and steepness factors (LS) were calculated using DEM (*Digital Elevation Model*) from ASTER Satellite with 30×30 m resolution. The LS factor was calculated using methods suggested by Wischmeier (1975). The LS factor in study area varied from 0 to 221 m (Figure 2(c)). In RUSLE model, slope length should not exceed 1000 feet (304.8 m) to obtain the accurate calculation of LS factor by using GIS software. This study applied 10×10 pixel size which was one pixel covering a slope length of about 100 m. Hence, flow accumulation values with ≥ 30 will be classified at 30, whilst the values with ≤ 30 did not change. The steepest slopes were in the western and northern parts of the catchment. Relatively, low steep areas were located in the eastern and southern parts of the study area. The classification of LS factor showed that 69.97% of the catchment found under nearly flat area 0-1, 11.02% area in range of 1-5, 6.57% area in range of 5-10, 3.63% area in range of 10-15, 7.07% area in range of 15-50, 1.43% in range of 50-100 and 0.31% in range of 100-221.

$$LS = (L/22.13)^m\,(0.065 + 0.046S + 0.0065S^2)$$
(Wischmeier 1975),

where L is the slope length in meter; m is 0.6 for slope more than 12%; and S is slope in percent.

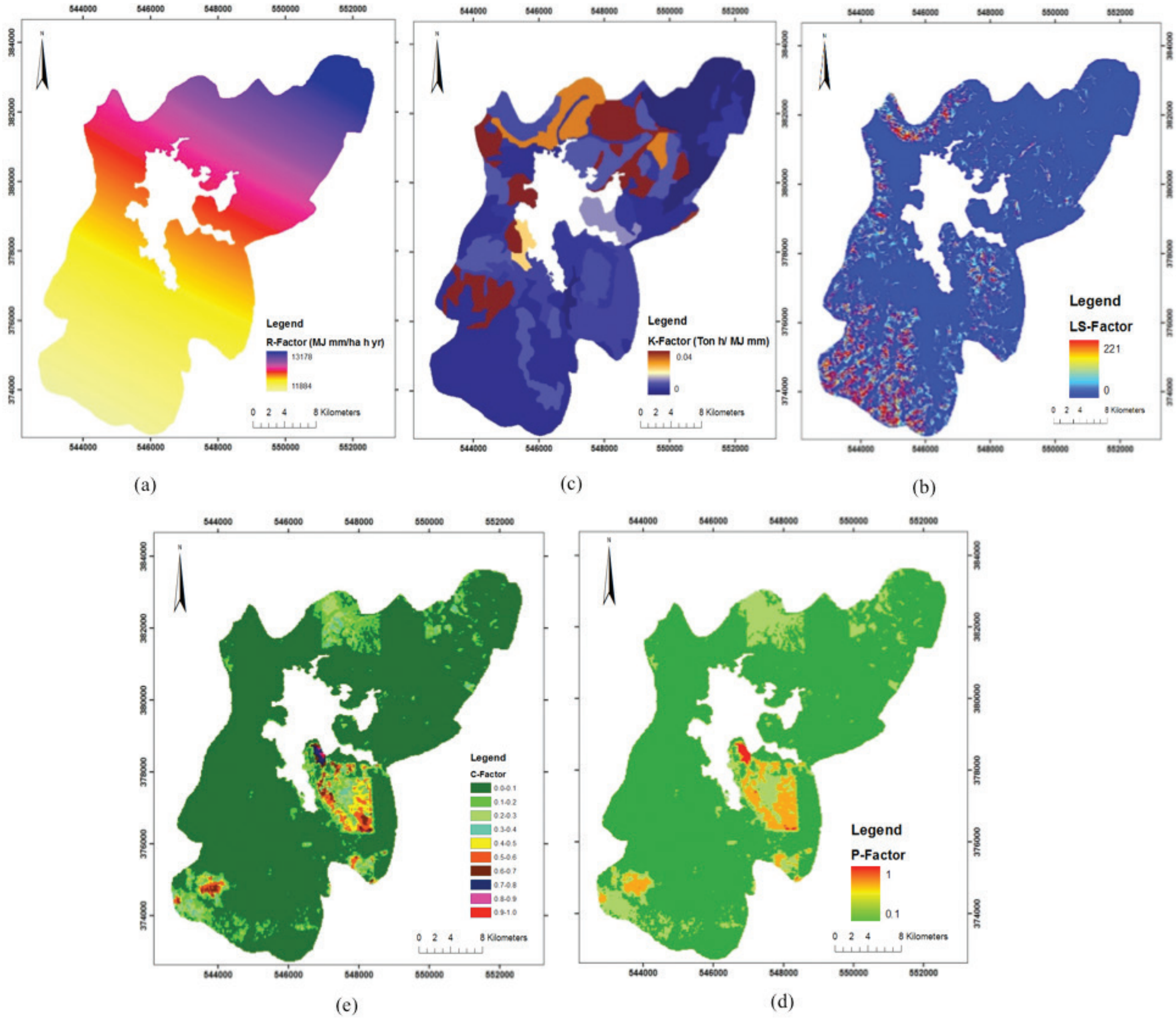

FIGURE 2. (a) rainfall erosivitiy factor, (b) erodibility factor, (c) slope length and steepness factor, (d) land canopy cover factor and (e) conservation practice factor

LAND CANOPY COVER (C)

The 2015 remotely sensed data from LANDSAT 8 has been used to evaluate land canopy cover values. The vegetation index of NDVI was applied to assess C factor in study area using the formula from (1). In general, the NDVI value was in the range from -1 to 1, where -1 indicated bare land and 1 for forest. Based on previous studies, NDVI value had the correlation with C factor, thus it was inferred that C value can be determined by inverting NDVI value. The formula from (2) (van Der Knijff et al. 2000; van Leeuwen & Sammons 2004) had been tested by other researchers and proved to give a better result than using a linear relationship (van Der Knijff et al. 2000). The values of 2 and 1 were selected for the parameters α and β and assumed to give the best result as mentioned in related literatures (Parveen & Kumar 2012). The C factor values in study area were ranged from 0 to 1. The high C factor values (0.70-1.00) were showed in the eastern parts of the area that located in the mining area. A moderate C values (0.20-0.69) were located under oil palm plantation and rubber. The forested area had the lowest C value, ranging from 0.00-0.19 (Figure 2(d)). On the basis of the land use map, the percentage of C factor in study area indicated the forest dominated the study area approximately of 84.93%, followed by agricultural area with total area of 10.90%, urban and associated areas with total area of 4.12%, bare land and mining area with total area of 0.05%.

$$NDVI = (NIR\ RED - RED) / (NIR\ RED + RED). \tag{1}$$

$$C = e^{(-\alpha\, ((NDVI)/(\beta - NDVI)))}. \tag{2}$$

CONSERVATION PRACTICE (P)

Conservation practice factor was determined by the land use classification from satellite imagery using supervised technique. The P factor values adopted from classification of Morgan (2005) and varied from 0.1 to 1. The P value of 0.1 indicated forest area, 0.4 for mixed agricultural area, rubber and oil palm. Urban and newly cleared land areas were 0.7 and 1 for bare land and mining area (Figure 2(e)). In this study, it was assumed that contour terracing practice on slopes was carried out for both rubber and oil palm plantation.

PREDICTED SOIL EROSION RISK MAP

The annual soil erosion risk map was generated by multiplying RUSLE factors using GIS software (Figure 3). Soil erosion risk classification was grouped into five classes by the following guideline from Ministry of Natural Resources and Environment Malaysia (2010). The majority of study area was classified at very low class (< 10 ton ha^{-1} yr^{-1}) about 4835.34 ha (92.38%), followed by the low class (10-50 ton ha^{-1} yr^{-1}) with total area of 175.47 ha (3.35%), moderate high class (50-100 ton ha^{-1} yr^{-1}) with total area of 65.11 ha (1.24%), high class (100-150 ton ha^{-1} yr^{-1}) with total area of 38.37 ha (0.73%) and very high class (> 150 ton ha^{-1} yr^{-1}) with total area of 120.04 ha (2.30%). The result showed the most of catchment area was indicated at very low class of soil erosion risk, but in the reality this area had experiences period of high flushing of sediment, especially during rainy season. The lowest classes were mostly distributed far away from the Tasik Chini fringe. The highest soil erosion class was situated at bare land and mining area. Similar result was also reported from the previous study by Sujaul et al. (2012) that mining area had the highest rate of soil loss. The agricultural and newly cleared areas were classified at moderate to high classes of soil erosion risk.

ACCURACY OF SOIL EROSION MODEL

The accuracy of soil erosion model was conducted by the correlation test between soil erosion analysis using remotely sensed data and field investigation. Based on fieldwork data, very low class was found at Stations 2, 3, 6, 7, 8 and 10 (Figure 3). Stations 5 and 9 were classified at low class. Stations 1 and 4 were moderate high and very high. The correlation test showed a high positive correlation between soil erosion using remote sensing data and field investigation with r value of 0.97.

CONCLUSION

In general, soil erosion in study area increases with annual rainfall, slope and land use with open canopies. The use of NDVI technique for C factor estimation was highly recommended for providing up to date information on land cover. With the use of the RUSLE/GIS methods, spatial distribution of different erosion prone areas were identified in the catchment to successfully take erosion control measures in the severely affected areas. The rate

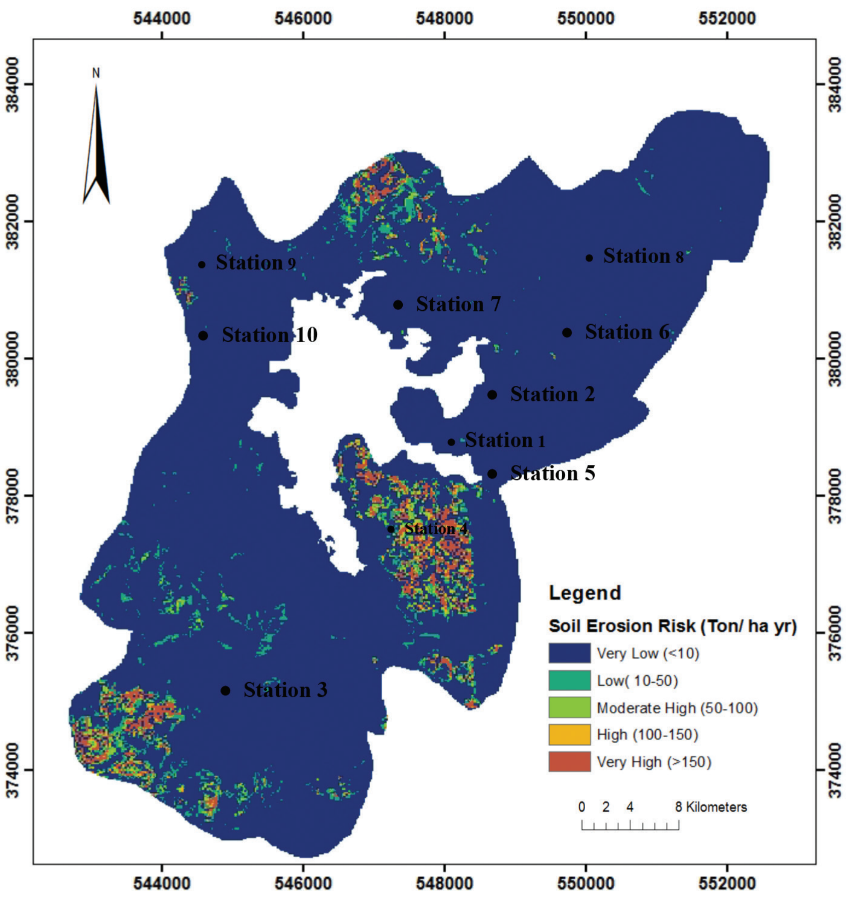

FIGURE 3. Predicted soil erosion risk map in study area

of potential soil loss in the area studied was very severe, especially on northwest and southeast regions, where the main sources of soil loss were come from agricultural, new settlements and mining areas. Close proximity of these activities may contribute to further deterioration of Tasik Chini water body through accelerated soil loss if no precaution measure was employed. To conclude, estimation of soil erosion model using remotely sensed data can be used to build sustainable development strategy within Tasik Chini Catchment in the future.

ACKNOWLEDGMENTS

The authors would like to thank the School of Environmental and Natural Resource Sciences, Faculty of Science and Technology, UKM for the facilities and logistics provided. This research was partly funded by research grants AP-2013-004 and ETP- 2015-003.

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Received: 27 February 2016
Accepted: 8 September 2016