CHAPTER III

SOIL EROSION AND HEAVY METAL DISTRIBUTION IN CATCHMENT AREA

Soils are critical environments where can be interface between rocks, air and water. Consequently, soils may be subjected to a number of pollutants due to various anthropogenic activities (e.g., industry, agriculture and transportation); consequently, soils can also be a source of pollutants to surface and ground waters, living organisms, sediments and oceans.

In the last few decades, heavy metals have been the most environmental concern because of their peculiar pollutant characteristics (Wang et al., 2005):

1. They do not decay with time, unlike many organics and radionuclides;
2. They can be necessary or beneficial to plant at certain levels, but can also be toxic when exceeding specific thresholds;
3. They are always present at a background level of non-anthropogenic origin, their input in soils being related to weathering of parent rocks and pedogenesis; and
4. They often occur as cations, which strongly interact with soil matrix; consequently, heavy metals in soils, even at high concentrations, may be present in inert and nor harmful forms, but they can become mobile as a result of changing environmental conditions (e.g., land use, agricultural input and climate change) or by saturation is referred as a "chemical time bomb" (Facchinelli et al., 2001).

In the last decades, the natural input of several heavy metals to soils due to pedogenesis has been hugely increased by the human input, even on a regional scale. See for examples, the comparison of Cd, Pb and Zn content between soils from remote and from more densely populated areas were reported and discussed in Alloway (1995). However, in areas with heterogeneous lithology, "natural" heavy metal contents in soils can exhibit a high variability controlled by the parent material.

Because of both natural variability and widespread anthropic input, the terms "background concentration" or "natural concentration" have proved to be theoretical rather than practical concepts. It is often more useful to use geochemical baseline concentrations, statistically defined as 95% of the expected range of background concentrations (Gough et al., 1994 and Chen et al., 1999).

To establish reliable and realistic guidelines, it is necessary not only to have a good knowledge of the mean content and the variability in space of heavy metals in soils, but also to apportion anthropogenic and lithogenic inputs. The apportioning, in particular, is an important and difficult task in populated and industrial areas, where totally unpolluted soils are almost impossible to find.

Maas et al. (1985) show that areas of severe soil loss are often critical for agricultural non-point source pollution. Schauble (1999) mentioned that erosion includes not only the transport of sediment particles but also the transport of nutrients and pollutants. Both mechanisms depend on the amount of surface runoff and are therefore linked together. Both processes can only be lessened by reducing the surface runoff in favors of ground water infiltration. Due to this inseparability of both processes, erosion models can be used to find out critical areas of non-point source pollution (Sivertun and Prange, 2003). For erosion modeling, many models have been developed. De Roo (1993) gave an overview of some important models: universal soil loss equation (USLE; Wischmeier and Smith, 1978), revised universal soil loss equation (RUSLE; Renard et al., 1991), modified universal soil loss equation (MUSLE87; Hensel and Bork, 1988), areal non-point source watershed environment response system (ANSWERS; Beasley and Huggins, 1982) and agricultural non-point source pollution model (AGNPS; Young et al., 1987).

In this thesis report, geochemical data from soil sample and stream sediments were used for the analysis of erosion and contamination of the SKL study area. These data were selected from the report of Department of Mineral Resources (2006). Among 12 elements analyzed, the author found that only 6 elements are integrating and having significant relation. They are arsenic (As), chromium (Cr), copper (Cu), nickel (Ni), lead (Pb), and zinc (Zn) which are the same elemental set used for the evaluation of lake-sediment contamination that will report in the next chapter. In this study, concentrations of these elements from integrations of soil sample and stream sediment are compared with Dutch's standard (VROM, 2001). Heavy metals concentrations in both soil and stream sediments were derived from uplands by natural surface processes which are the natural products and may be involved by the anthropogenic process. Therefore, in this chapter, two parts are involved- one is the determination of soil erosion and the other is the evaluation of heavy metal contamination in soils and stream sediments.

3.1 Soil Erosion Calculations

3.1.1 Calculation using Revised Universal Soil Loss Erosion (RUSLE)

The expected soil loss potential (erosion hazard) expressed as t ha^{-1} $year^{-1}$ for the study area was determined using the Revised Universal Soil Loss Equation (RUSLE) model (Renard et al., 1991) in a GIS environment application. Generally, the control factors of soil erosion are climate, soils, vegetation cover, topography and management practice of land. These factors are combined together in the empirical USLE as described in the equation (3.1) below.

$$A=R\times K\times LS\times C\times P \tag{3.1}$$

Where, A = RUSLE calculated soil loss t $ha^{-1}year^{-1}$,
R = rain erosivity (joules m^{-2}),
K = soil erodibility (ts m^{-2}),
LS = slope steepness and length combined in a single index, and
CP = cover and management practices.

For sensitivity analysis, several methods of paramerization of the RUSLE are used for some factors that will be detailed later in the following sections. In order to comprehend the surface erosion configuration of the Songkhla Lake (SKL) study area, all the individual parameters mentioned above need to be evaluated in the forms of maps. These maps are then overlain onto Digital Elevation Model (DEM) base maps.

Rainfall Erosivity Map Layer

The rainfall erosivity was determined using a segment data map (isopleth) derived by clipping the SKL study area from the entire SKL isopleth. The isolines were interpolated using the contour interpolation method to generate a continuous surface (map) of annual precipitation.

In order to get the erosivity map from the rainfall map, regression coefficients derived by regressing long-term rainfall against erosivity values determined by Moore (1979). For this study, EI30 index (Morgan, 1986) is applied to the rainfall distribution map.

$$R=47.5+(0.38\times P) \tag{3.2}$$

where, R=rain erosivity (joules m^{-2}), and
P=annual rainfall (mm $year^{-1}$).

The rain erosivity (or R-value) map of the SKL study area is shown in Figure 3.1. It is quite clear that the high R-value (about 900 mm/yr) is located in the northwest (e.g., Khao Chaison and Tamode) whereas the low R-value (about 460 mm/yr) is located in the southeast (e.g., north of Rattaphum and Pak Payoon)

Soil Erodibility Map Layer

A systematic land resources inventory was conducted following the Land Development Department to produce a soil map (Figure 3.6) at a scale of 1:50,000. Soil erodibility classes (K-value) for the identified soil units were derived from generic soil properties in Thailand (Table 3.1) and adjust the K-value using topsoil surveying and soil analyses based on grain size and organic matter in comparison with Witchmeir's nomograph (Wischmeier and Smith, 1978).

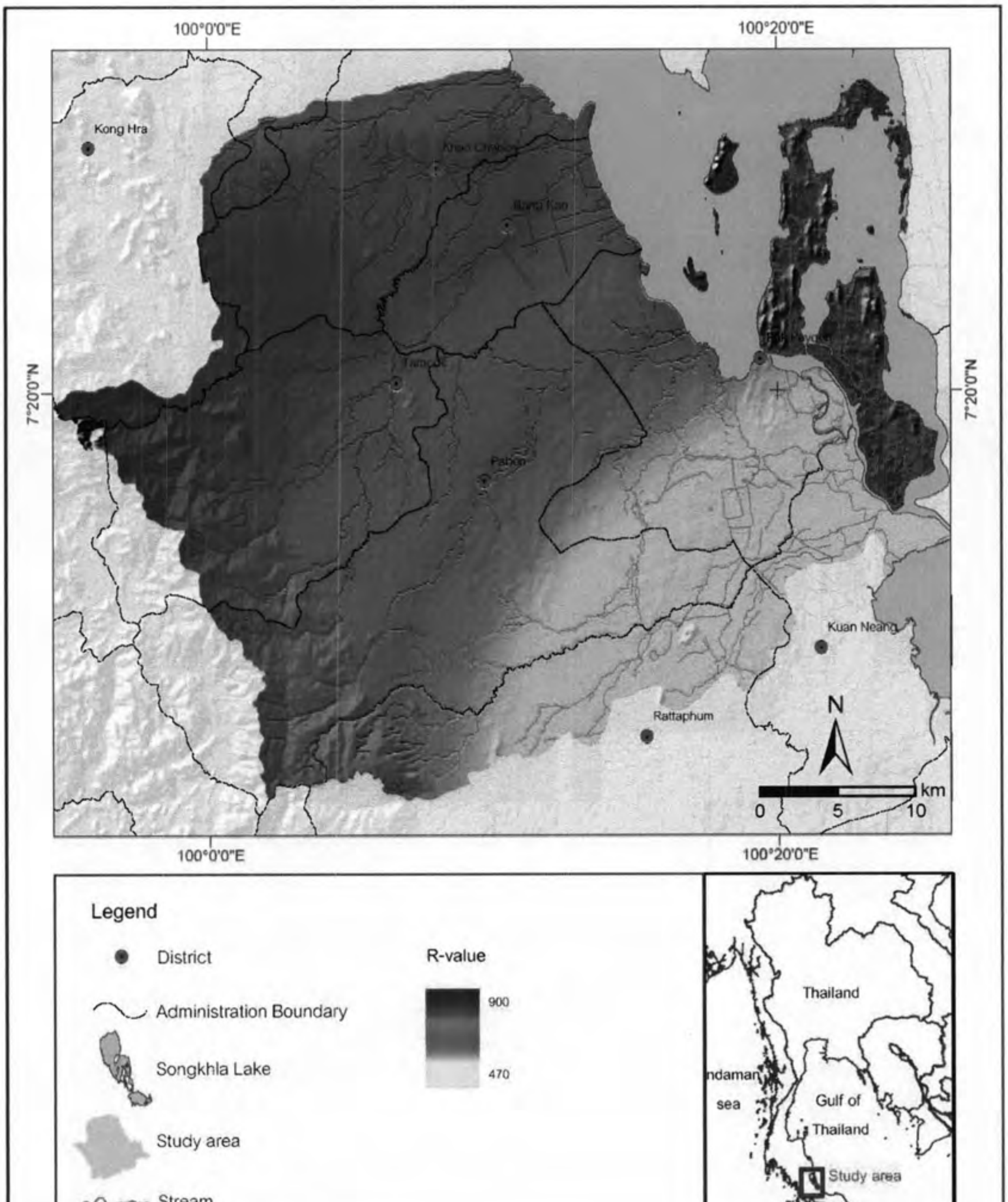


Figure 3.1 R-value map used for RUSLE analysis of the SKL study area.

Figure 3.2 displays the soil erodibility (or K-value) map of the SKL study area. It is abvious that the maximum K-value is close to 0.4 while the minimum is almost 0. The high K-value are mainly located at high mountains along Nakorn Si Thammarat range. On the other hand, low K-values are mainly situated at lower land area, such as southern part of Amphoe Kao Chaison, and along the coastal line of the Songkhla Lake.

Slope Length and Steepness Map Layer

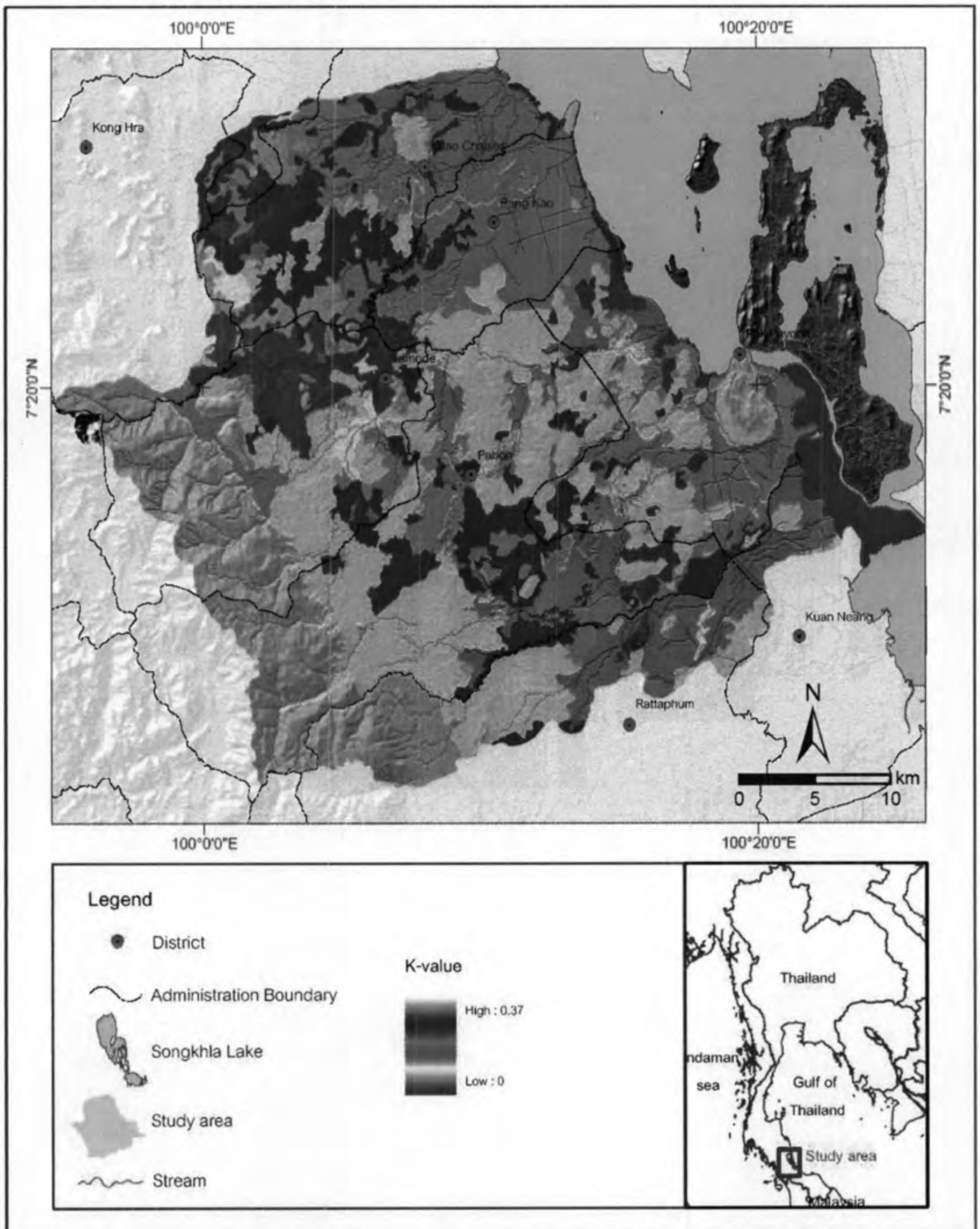
The technique for estimating the slope lengh and steepness (LS) value used herein this project was proposed by Moore and Burch (1986a and b). They derived an equation for estimating LS based on flow accumulation and slope steepness for each grid cell. In this study, one grid cell is about 30x30 m^2. The equation is described below.

$$LS = (\text{Flow Accumulation} * \text{Cell Size}/22.13)^{0.4} * (\sin \text{slope}/0.0896)^{1.3} \qquad (3.3)$$

In order to get the LS map, two important factors need to be solved. The first factor is flow accumulation and other one is slope. The flow accumulation map of the SKL study area is illustrated in Figure 3.3. The high value which is about 100 is located sparsely throughout the area. The low value (about 0) show similar pattern. The other imprtant factor for equation 3.3 is the slope map which is shown in Figure 3.4. There is no doubt that steep areas are located in the western part of the SKL study area whereas the gentle slope areas are mostly situated along the lake coast. Integration of both maps using the equation 3.3, the result is the LS-value map (Figure 3.4).

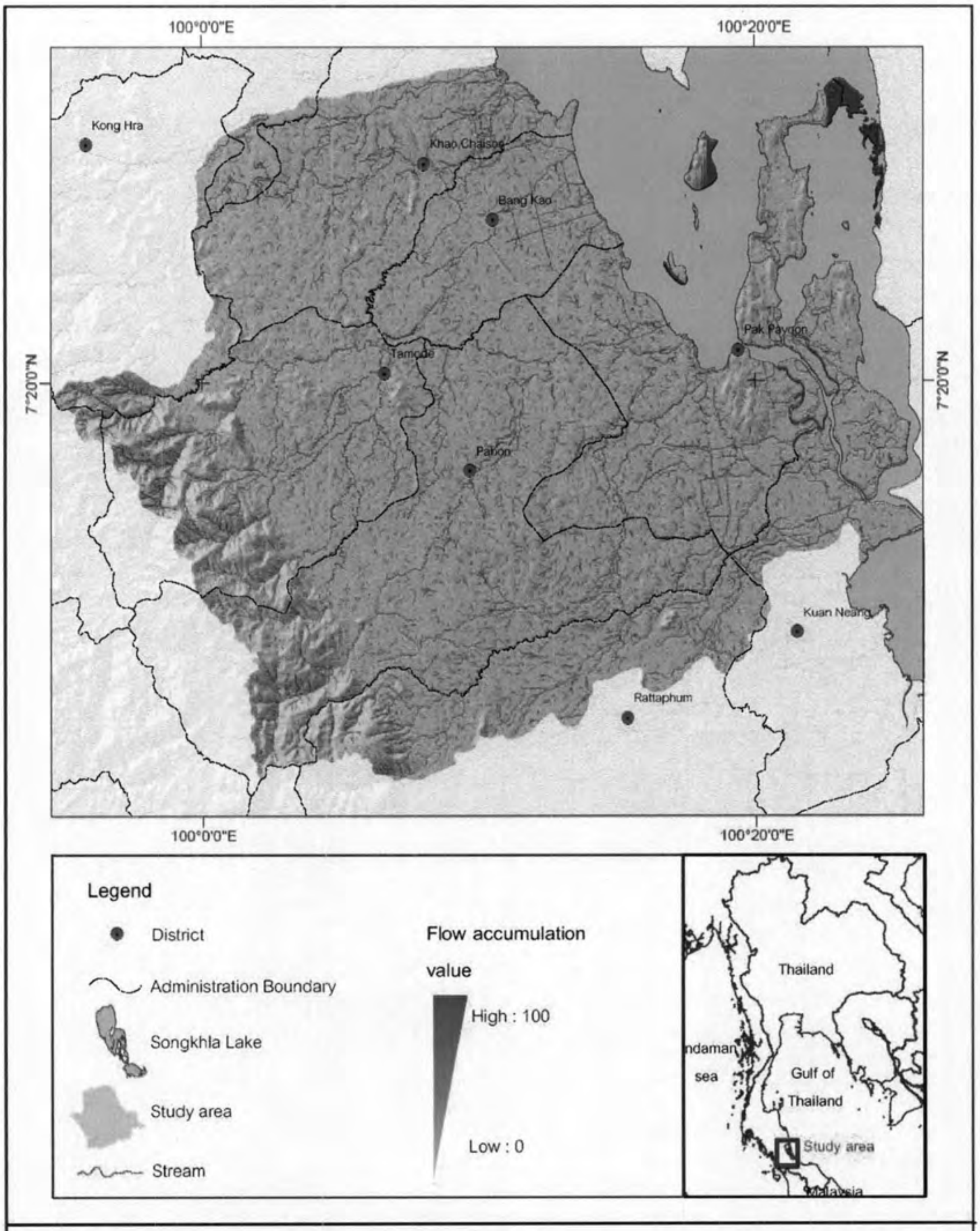
Cover and Management Practices Map Layer

The C-factor evaluation incorporates cropping and management factors that include interrelated effects of cover, crop sequence, cultural practices and length of growing season (Wischmeier and Smith, 1978). Within the catchment study, multiple families own land within a single profile and use different cropping and cultural practices. The problems arising from this complexity were overcome by dividing the slope profile into segments with uniform slopes, making the evaluation of cropping pattern easier. The C-factor used in this study is presented in Table 3.1.



K-value derived from soil map using spatial analysis

Figure 3.2 K-value map used for the RUSLE analysis of the SKL study area.



Flow accumulation map derived from DEM data using Spatial Analysis in ArcMap

Figure 3.3 Flow accumulation map used for RUSLE analysis of SKL study area.

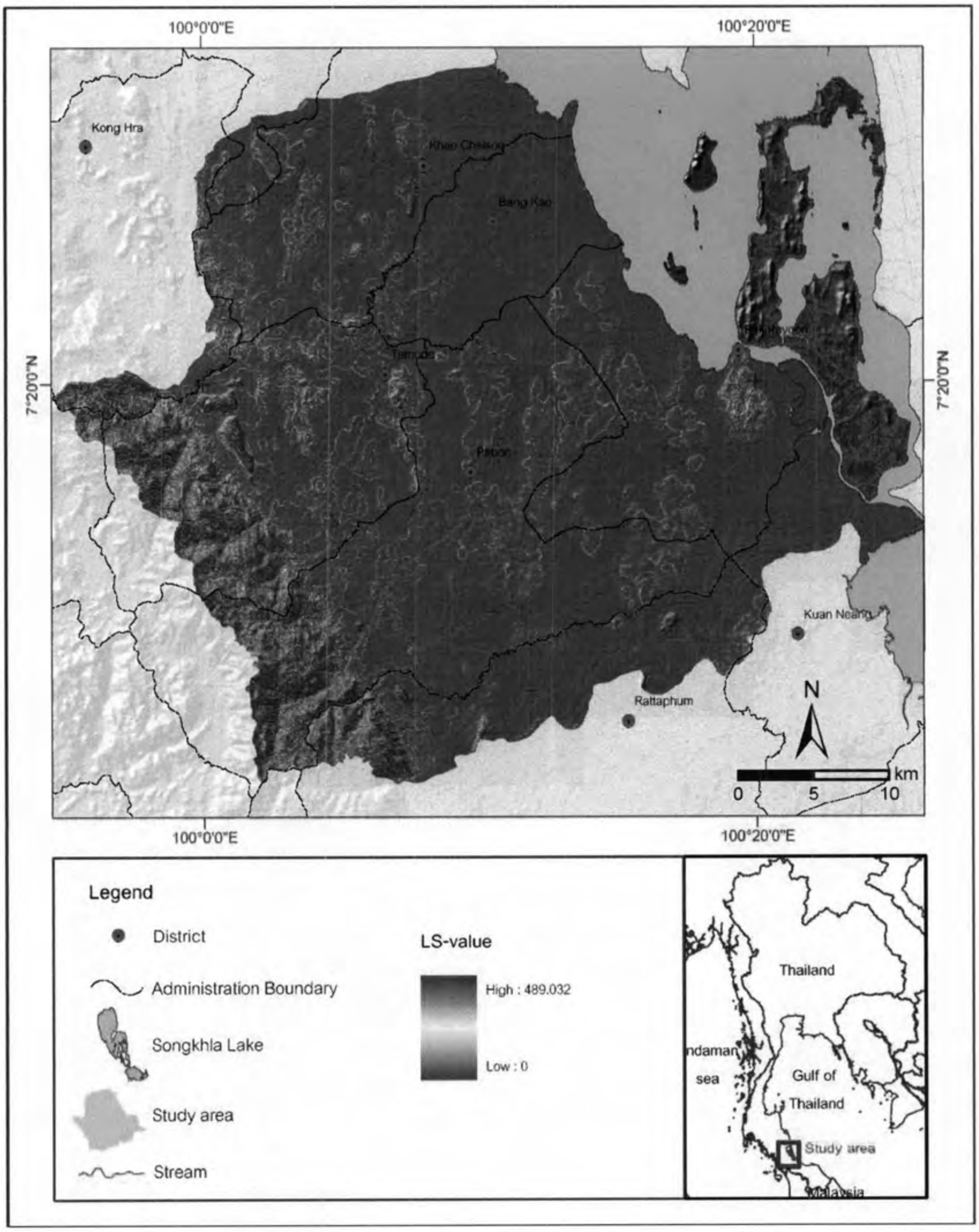


Figure 3.4 LS-value map used for RUSLE analysis of the SKL study area.

Table 3.1. Selected C-value colleted from several literatures used for this study.

Crop	C-value	references
rice	0.27	Rao (1981)
Fruit	0.30	Watanasak (1978)
Perennial plant	0.088	LDD (2526)
Grassland	0.02	Watanasak (1978)
Forest	0.088	Watanasak (1978)
Mixed deciduous forest	0.043	KU (2524)

C-value map of the SKL study area is shown in Figure 3.8. Data of the C-values were deduced from the year 2002, and the highest value is about 0.5 and the low value is about 0.0. It is notified that the high C-value is generally located at mountainous area along Nakron Si Thammarat ranges and hilly area around there whereas the low C-value is located along the lake coast.

RUSLE Results

The RUSLE soil erosion estimated for the SLK study area is shown in Figure 3.7 for the year 1983 and in Figure 3.8 for the year 2002. It should be noted that the units in this study would be tons/hectare/year. Average erosion can be computed from the theme using techniques described previously.

Table 3.2 depicts rates of soil ersion for four subcatchment areas within the SKL study area. Tha Chiat subcatcment has the highest amount of soil erosion (37.5 ton/ha/year equivalent to the rate of erosion about 2.34 mm/year). Pa Bon subcatchment shows the lowest average amount of soil erosion (about 16 ton/ha/year or about 1 mm/year for erosion rate) and Pru Por subcatchment area exhibits the amount of soil erosion about 17 ton/ha/year (about 1.1 mm/year). In general, the SKL study area has been affected by soil erosion at the average amount of 26 tons/ha/year with the rate of about 1.6 mm/year (Table 3.3); this number falls within the ranges of India (0.2-3.7 mm/yr), northern China (1.5-3.7 mm.yr), and Ivory Coast & Ghana (0.7-3.7 mm/yr).

Table 3.2 Rates of soil erosion in subcatchment areas of the SKL study area.

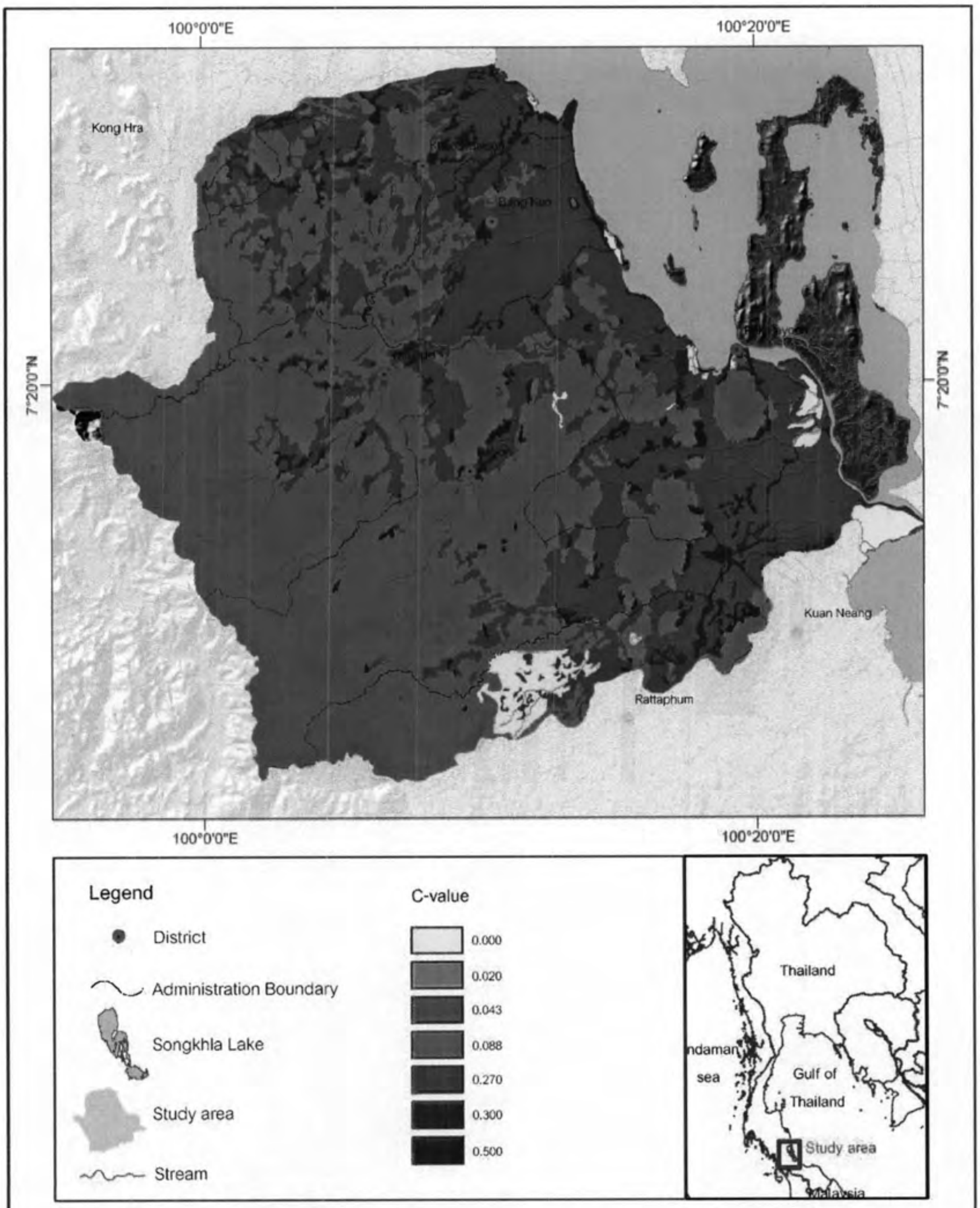
	Mean of soil erosion	
Catchment area	ton/ha/yr	mm/yr
Khlong Tha Chiat	37.53 tons/ha/yr	2.34 mm/yr
Khlong Pa Bon	15.97 tons/ha/yr	1.00 mm/yr
Khlong Pru Por	17.23 tons/ha/yr	1.08 mm/yr
SKL study area	26.15 tons/ha/yr	1.63 mm/yr

3.1.2 Sediment yield calculation by Sediment Delivery Ratio (SDR) model

Several models have been developed to estimate the sediment delivery ratio and sediment yield (**Vanoni 1975; USDA SCS, 1979; Walling, 1983; Richards, 1993; Arnold et al. 1996**). They can generally be grouped into two catalogs. One is called statistical or empirical models such as the USLE (**Jain and Kothyari, 2000; Fernandez et al., 2003**). These kinds of models are statistically established, based on observed data, which are usually easier to use and computationally efficient. The other kinds of models can be called parameteric, deterministic or physically based models (Fu et al., 2004). These models are developed using fundamental hydrological and sedimentological processes. They may provide detailed temporal and spatial simulation but usually require extensive data input.

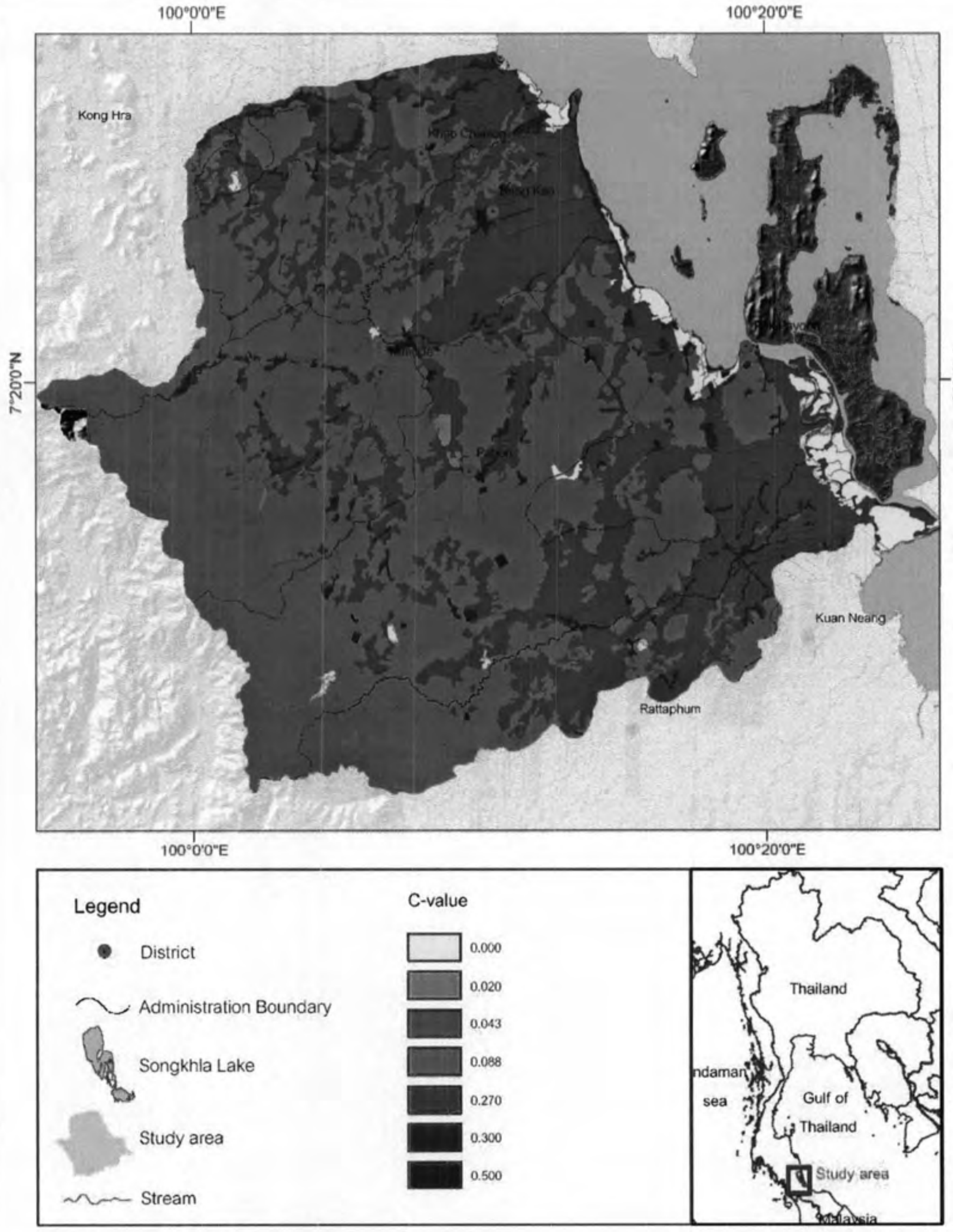
Table 3.3. Comparison of measured soil erosion rates in different areas with predicted soil erosion in SKL study area.

Location		Erosion rate (mm/y) from literature	Sources
Europe	England & Wales	0.004-0.05	Boardman and Favis-Mortlock (1993)
		0.0074-0.037	Evans (1992,1993)
	Mediterranean	0.0006-0.106	Kosmas (1997)
	Poland	0.019-0.039	Ryszkowski (1993)
	East Germany	0.96	Pimentel (1993)
	Belgium	0.74-1.85	Pimentel (1993)
Asia	China		
	Loess plateau	1.48-7.4	Wen (1993)
	Southern region	3.33	Wen (1993)
	Northern region	1.48-3.7	Wen (1993)
India		0.148-7.4	Craswell (1993)
Africa			
	Savanna in West Africa	0.37-3.7	Lal (1993)
	Ivory Coast & Ghana	0.74-3.7	Lal (1993)
	Ethiopia	5.33	Hurni (1985)
		7.4	Mesfin (1972)
Thailand	Songkhla Lake	1.63	This study



C-value derived from landuse map of the year 1981 classified based on data in Table 5.1 using Spatial Analysis in ArcMap

Figure 3.5 C-value map of the year 1981 used for the RUSLE analysis of SKL study area.



C-value derived from landuse map of the year 2002 classified based on data in Table 5.1 using Spatial Analysis in ArcMap

Figure 3.6 C-value map of the year 2002 used for the RUSLE analysis of SKL study area.

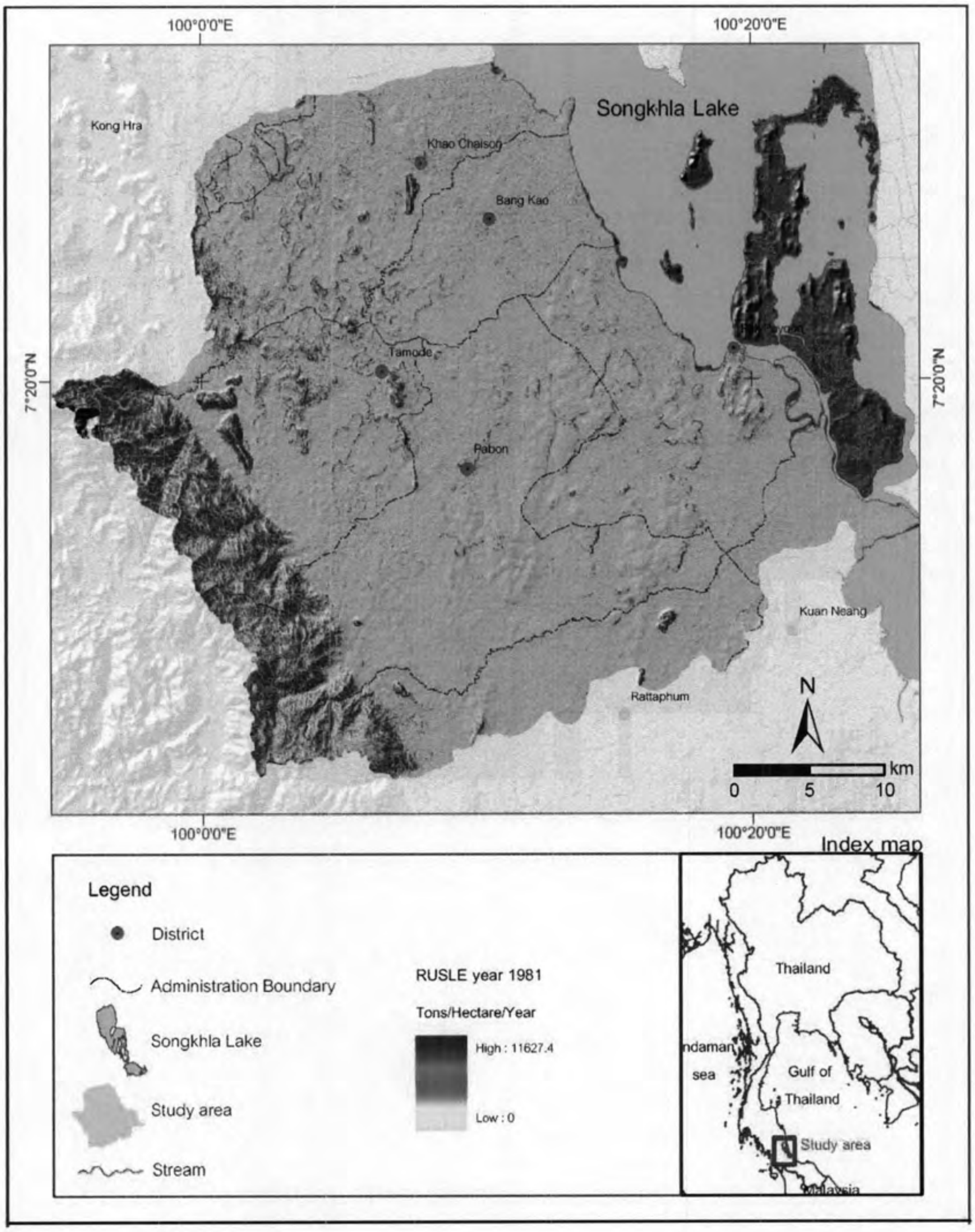


Figure 3.7 Soil erosion map year 1981 derived from the RUSLE of SKL study area.

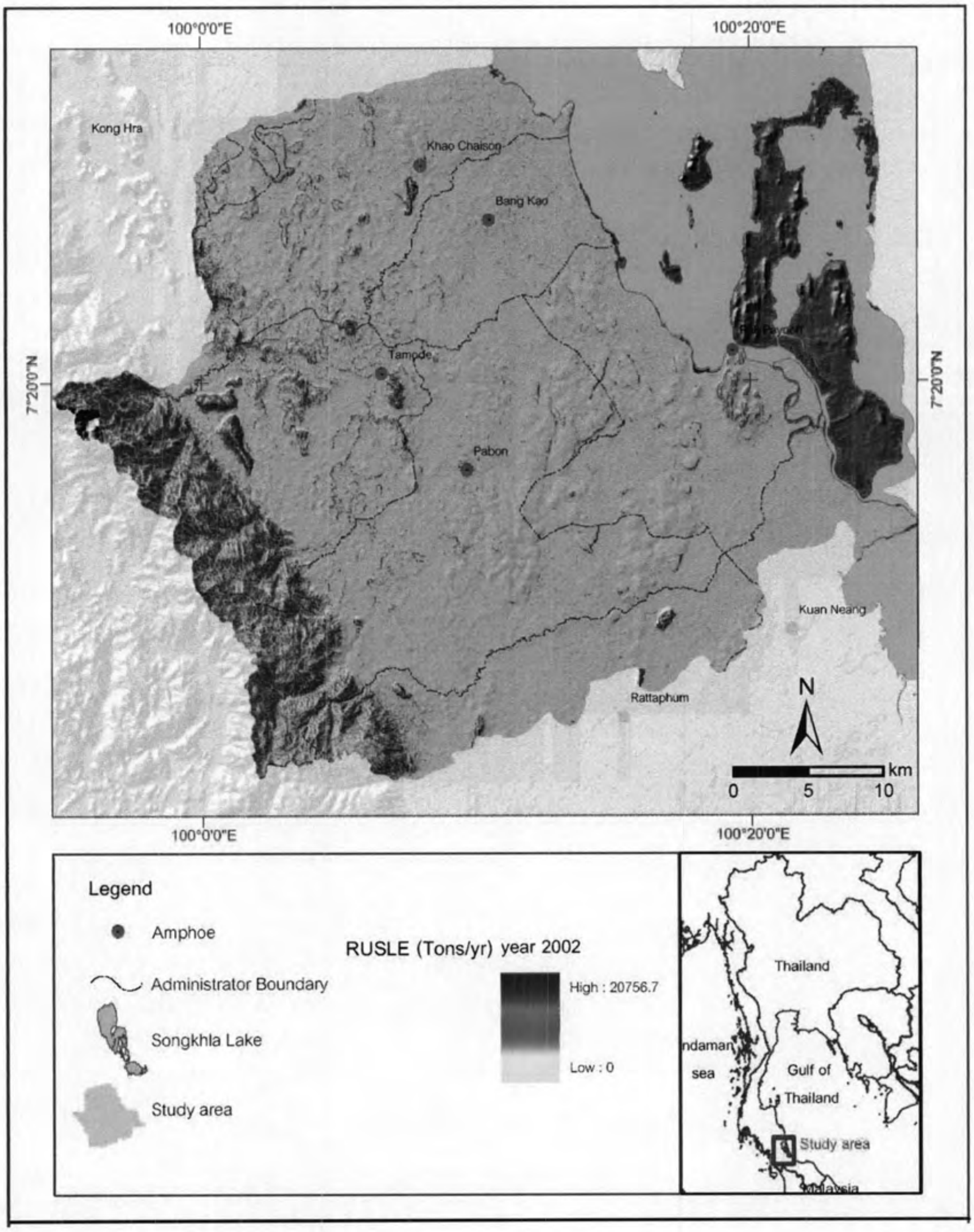


Figure 3.8 Soil erosion map year 2002 derived from the RUSLE of SKL study area.

The methods which are used for estimating sediment delivery ratios in the previous research are reviewed and described. Some of these models are used in this study after considering the model applicability and data availability.

In terms of the definition of sediment delivery ratio, the expression for calculating sediment delivery ratio can be written follows:

$$SDR = SY / E \tag{3.4}$$

where SDR = the sediment delivery ratio,

SY = the sediment yield,

E = the gross erosion per unit area above a measuring point (RUSLE result)

Detailed analysis of the SY values are described below and the E-value is derived from A-value. In several cases, both values are identical (Erskine et al., 2002; Lim et al., 2005)

From the equation (3.4), the sediment yield (SY) of year 1983 is about 133 x 10^3 tons per year whereas that of year 2002 is about 150 x 10^3 tons per year. For this compilation, its can infer that 20 year different between year 1983 and 2002, the load of sediment is 17 x 10^3 tons per year or 12.8 % higher.

Model Validation

The objective of this step is to validate the accurate of the model that is a useful model for the study or not. Because there is no sediment monitoring station over the study area, the measuring station at the U Tapao catchment area is used for this test. The results from DSR model are used to compare. As the result, the SDR value of the U Tapao Catchment area is about 410 x 10^3 tons/year whereas the direct measurement of Irrigation Department (2003) is about 366 x 10^3 tons/year. It is likely that the estimated and measured values are close to each other. Therefore, it is anticipated that the estimated values for the SLK study are is applicable for further study.

3.2 Heavy Metal Distribution

3.2.1 Soil

The data of heavy metal analyses of soil samples are provided by DMR (2006). A hundred soil samples distributed throughout the study area were analyzed for 16 elements as summarized in Table 3.4. All of the data are examined; then, arsenic (As), chromium (Cr), copper (Cu), nickel (Ni), lead (Pb), and zinc (Zn) are selected for this study due to their close relation.

From the summarized data in Table 3.4, arsenic ranges from 0.10 to 19.80 ppm with average of 4.05 ppm; chromium rages from 0.39 to 62.76 ppm with average of 14.41 ppm; arsenic ranges from 0,10 to 19.80 ppm with average of 4.05 ppm; copper ranges from 0,71 to 110.99 ppm with average of 2.62 ppm; Nickel ranges from 0.59 to 89.68 ppm with average of 1.94 ppm; lead is ranges from 0.17 to 111.85 ppm with average of 17.39 ppm; zinc ranges from 0.21 to 141.60 ppm with average of 13.63 ppm.

Histograms and cumulative curves are constructed from DMR dataset and shown in Figure 3.9. It can be concluded that there are 2 refraction points which can be used to divide As, Cr, and Ni concentrations in soil into 3 ranges. On the other hand, 3 refraction points which can be used to divide Cu, Pb, and Zn concentrations into 4 ranges are observed in these elements. All of the ranges of heavy metal concentrations are mapped by kriging technique in the geochemical mapping and will be analyzed in the next step. The heavy metal distribution maps for individual element are displayed in Figure 3.11 to 3.16.

They can be described that Arsenic is concentrated near the Nakron Si Thammarat range and the western part of Tamode District. Arsenic is also distributed in the eastern part of the study area near the lake shore. Chromium shows very high concentration in the area of Lam Jong Tanon, area near the Tamod city, and nortern part of Rattaphum district. High concentration of Copper is shown in the nortern part of the study area located in the Ta Chiat subcatchment area. High concentration spot of Nickel is located in the western part of Tamode district. Lead is distributed in large area, mostly in the eastern part of the area such as Lam Jong Tanon and covered in the southern part of the area in Pru Por subcatchment area. Zinc concentration is presented within 2 parts such as Laem Jong Tanon, and western part of Pabon district near the Nakorn Si Thammarat range.

3.2.2 Stream sediment

The data of heavy metals in stream sediments are provided by DMR (2006). There are 200 samples collected within the study area; analyses comprise 16 elements as summarized in Table 3.5. All of the data are selected to study; however, arsenic (As), chromium (Cr), copper (Cu), nickel (Ni), lead (Pb), and zinc (Zn) show close relation and then are selected for this research project.

From the summarized data in Table 3.5, Arsenic ranges from 0,10 to 680.00 ppm with average of 7.43 ppm; Chromium rages from 0.39 to 59.64 ppm with average of 6.40 ppm; Copper ranges from 0,71 to 119.08 ppm with average of 3.09 ppm; Nickel ranges from 0.59 to 133.00 ppm with average of 2.24 ppm; Lead ranges from 0.49 to 1,062.80 ppm with average of 33.59 ppm; Zinc ranges from 0.49 to 2,663.03 ppm with average of 18.19 ppm.

Histograms and cumulative curves are constructed from the DMR dataset as shown in Figure 3.10. They mostly reveal 2 or 3 refraction points which can be used to divide ranges of As, Cr, Cu, Ni, and Zn concentrations in stream sediment into 3 or 4 ranges of concentration, respectively. These concentration ranges of each heavy metal are mapped and will be analyzed in the next step. The heavy metal distribution maps of these elements are displayed in Figures 3.17 to 3.22.

They can be described that Arsenic is concentrated near the Nakron Si Thammarat range at the southwestern part of Rattaphum District. Chromium shows high concentration distributed in the Khao Chaison District and some are located along foothill of Nakorn Si Thammarat range. High concentration of Copper is shown in the southwestern part of the study area located in the Rattaphum and Pabon Districts. High concentration spots of Nickel are distributed in the western part of Rataphum District. Lead and zinc are distributed in a large area mostly in the western part along foothill of Nakorn Si Thammarat range.

Table 3.4 Summary of heavy metal data in soils (DMR, 2006).

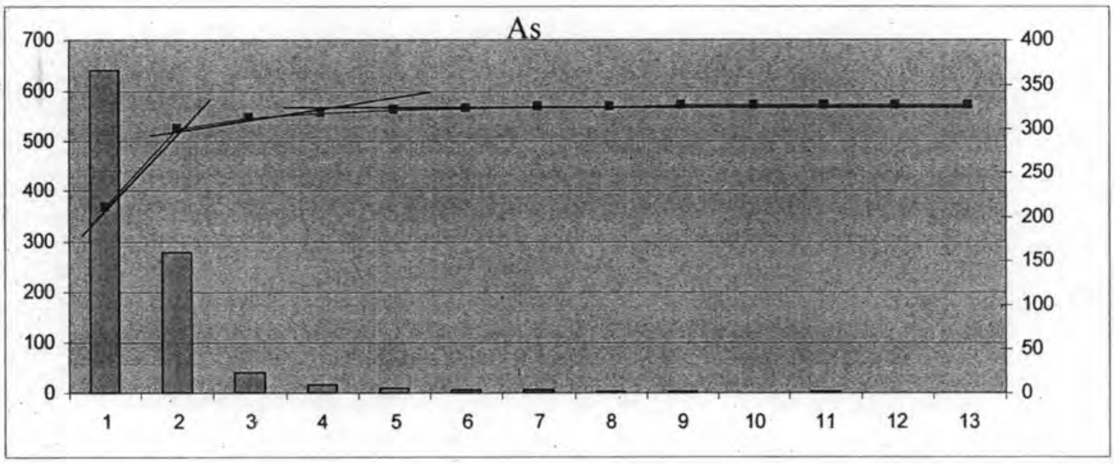
	Ag	Al	As	Bi	Cd	Co	Cr	Cu
Min	0.45	758.77	0.10	19.99	0.49	0.49	0.39	0.71
Max	0.45	46,622.16	19.80	19.99	0.49	0.49	62.76	110.99
Range	N/A	758.77-46,622.16	0.10-19.80	N/A	N/A	N/A	0.39-62.76	0.71-110.99
Mean	0.45	13,408.18	4.05	19.99	0.49	0.49	14.41	2.62
Median	0.45	11,170.78	4.25	19.99	0.49	0.49	9.89	0.71
Mode	0.45	N/A	0.10	19.99	0.49	0.49	0.39	0.71
Std. Deviation	0.00	9,497.51	3.20	0.00	0.00	0.00	13.55	8.82
Variance	0.00	90,202,659.26	10.23	0.00	0.00	0.00	183.66	77.86
Skewness	-1.01	1.08	1.15	1.01	1.01	1.01	1.22	10.17
Kurtosis	-2.02	1.00	3.79	-2.02	-2.02	-2.02	0.98	118.28

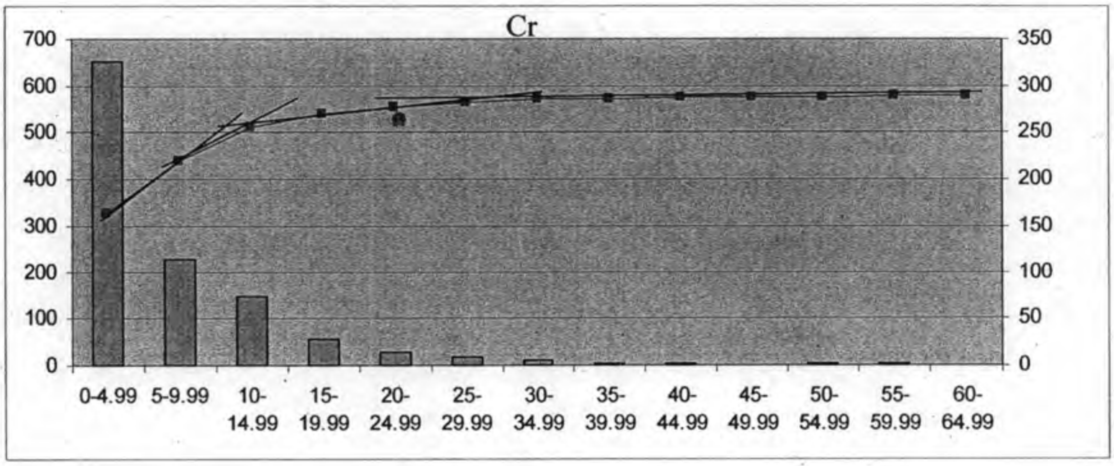
	Fe	Hg	Mn	Ni	Pb	Zn	Mo	Sb
Min	349.40	0.10	0.49	0.59	0.17	0.21	3.99	3.99
Max	30,731.83	0.20	854.20	89.68	111.85	141.60	16.38	17.73
Range	349.40-30,731.83	0.10-0.20	0.49-854.20	0.59-89.68	0.17-111.85	0.21-141.60	3.99-16.38	3.99-17.73
Mean	6,513.21	0.10	84.89	1.94	17.39	13.63	4.07	4.16
Median	5,061.34	0.10	34.86	0.59	14.54	9.71	3.99	3.99
Mode	N/A	0.10	0.49	0.59	0.49	0.49	3.99	3.99
Std. Deviation	5,025.33	0.01	132.01	6.57	17.26	17.19	0.90	1.24
Variance	25,253,984.47	0.00	17,427.85	43.19	298.02	295.50	0.81	1.55
Skewness	1.48	7.58	3.24	12.15	1.59	3.82	13.15	9.15
Kurtosis	3.49	61.61	13.49	161.55	4.48	21.46	178.91	89.21

Table 3.5 Summary of heavy metal data in stream sediment (DMR, 2006).

	Ag	Al	As	Bi	Cd	Co	Cr	Cu
Min	0.49	935.81	0.01	0.19	0.49	0.49	0.39	0.71
Max	1.17	31,273.47	680.00	0.19	33.08	8.71	59.64	119.08
Range	0.49 - 1.17	35.81-31,273.47	0.01 - 680.00		0.49-33.08	0.49-8.71	0.39-59.64	0.71-119.08
Mean	0.49	7,431.15	7.43	0.19	0.99	0.54	6.40	3.09
Median	0.49	6,626.52	4.00	0.19	0.49	0.49	3.66	0.72
Mode	0.49	7,422.15	0.01	0.19	0.49	0.49	0.39	0.72
Std. Deviation	0.03	3,849.88	31.43	0.00	2.85	0.52	8.48	6.41
Variance	0.00	14,821,587.93	987.78	0.00	8.10	0.27	71.87	41.07
Skewness	24.04	1.74	18.02	1.00	8.57	14.27	2.52	11.07
Kurtosis	578.00	5.29	370.28	-2.01	77.68	216.65	9.16	187.37

	Fe	Hg	Mn	Mo	Ni	Pb	Sb	Zn
Min	362.88	0.00	0.49	3.99	0.59	0.49	3.99	0.49
Max	51,061.90	0.31	38,384.00	277.91	133.00	1,062.80	61.08	2,663.03
Range	52.88-51,062.90	0.00-0.31	0.49-38,384.00	3.99-277.91	0.59-133.00	0.49-1,062.80	3.99-61.08	0.49-2,663.03
Mean	9,509.80	0.03	330.37	18.48	2.24	33.59	8.95	18.19
Median	8,357.18	0.00	164.94	13.60	0.59	15.89	6.16	11.09
Mode	5,982.30	0.00	0.49	3.99	0.59	0.49	3.99	0.49
Std. Deviation	6,128.09	0.06	1,700.61	20.52	9.42	96.64	7.44	111.26
Variance	37,553,443.29	0.00	2,892,078.00	420.93	88.83	9,339.03	55.32	12,379.42
Skewness	2.39	1.99	19.91	5.73	10.71	7.77	2.73	23.36
Kurtosis	10.19	2.87	437.71	56.17	124.09	65.88	10.46	556.15





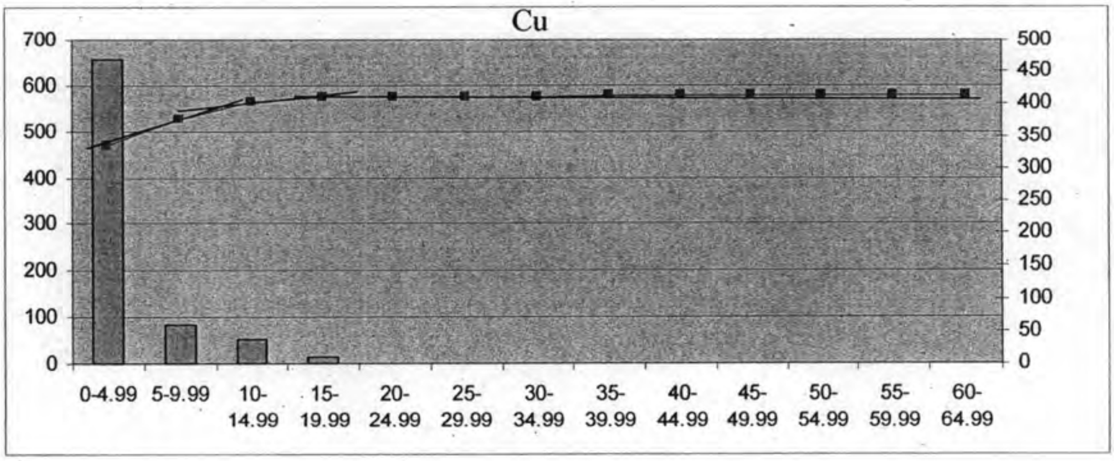
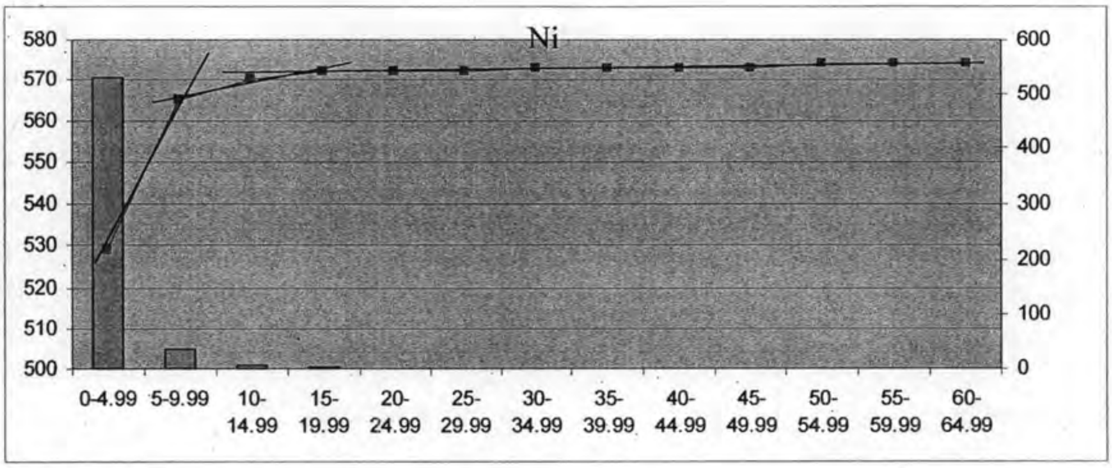
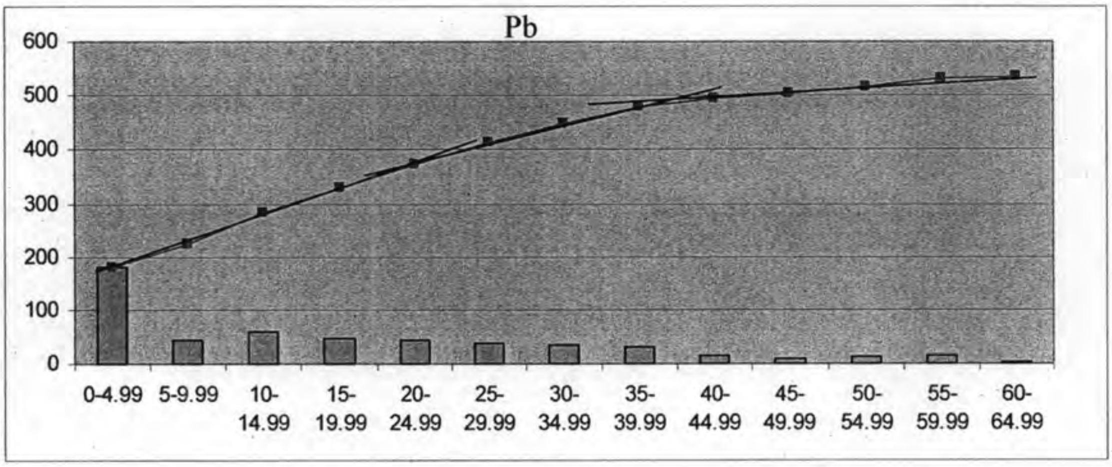


Figure 3.9 Histogram and cumulative curve of heavy metals in soil samples of the study area.





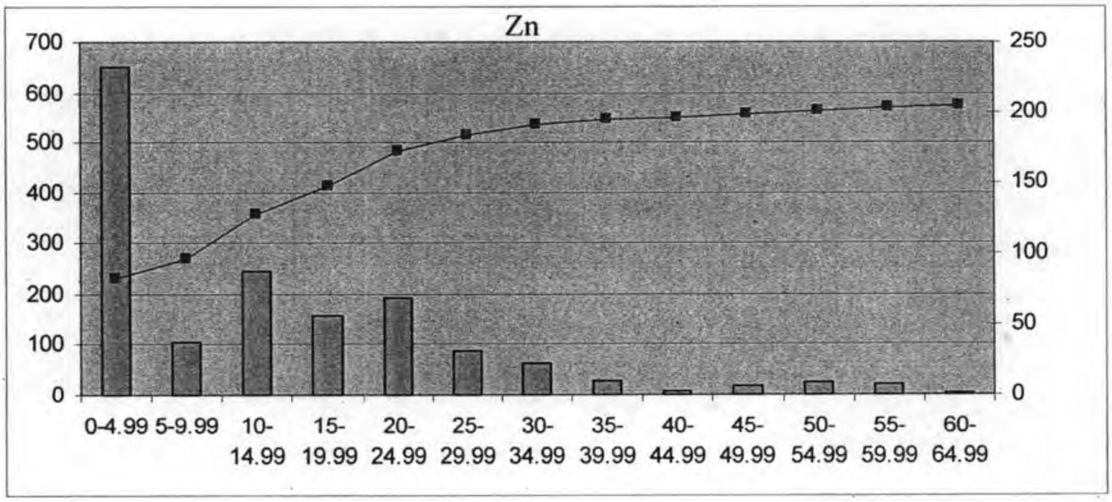


Figure 3.9 Histogram and cumulative curve of heavy metals in soil samples of the study area. (cont.)

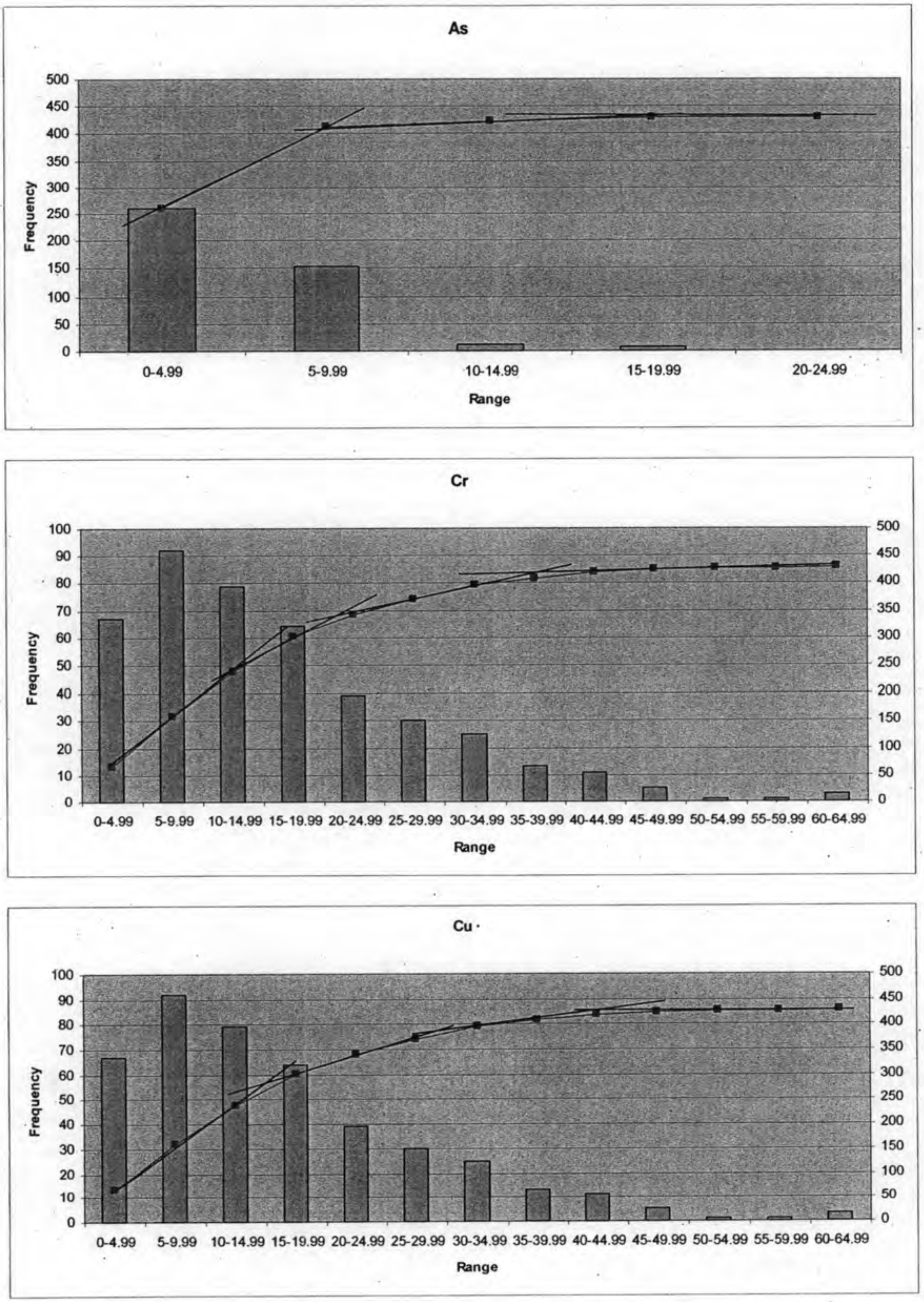
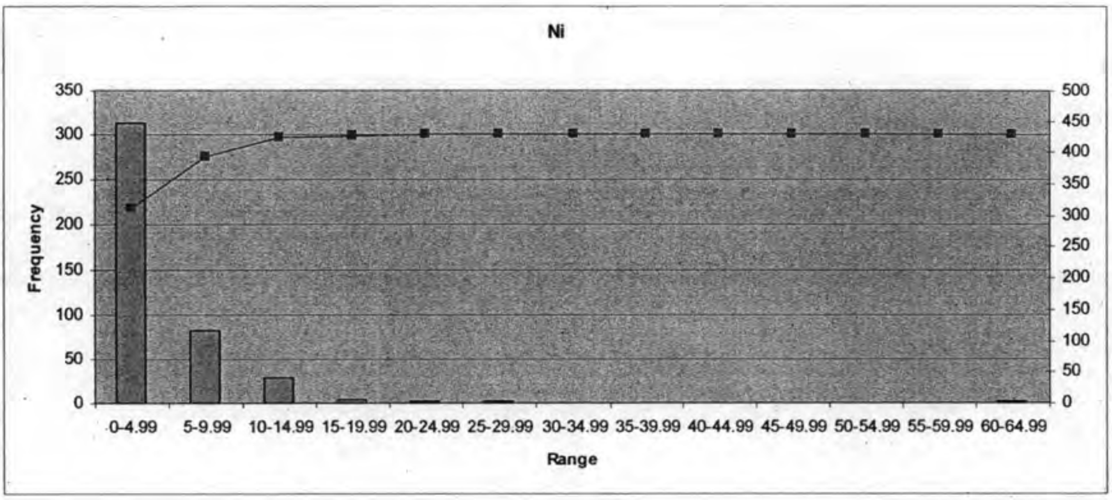
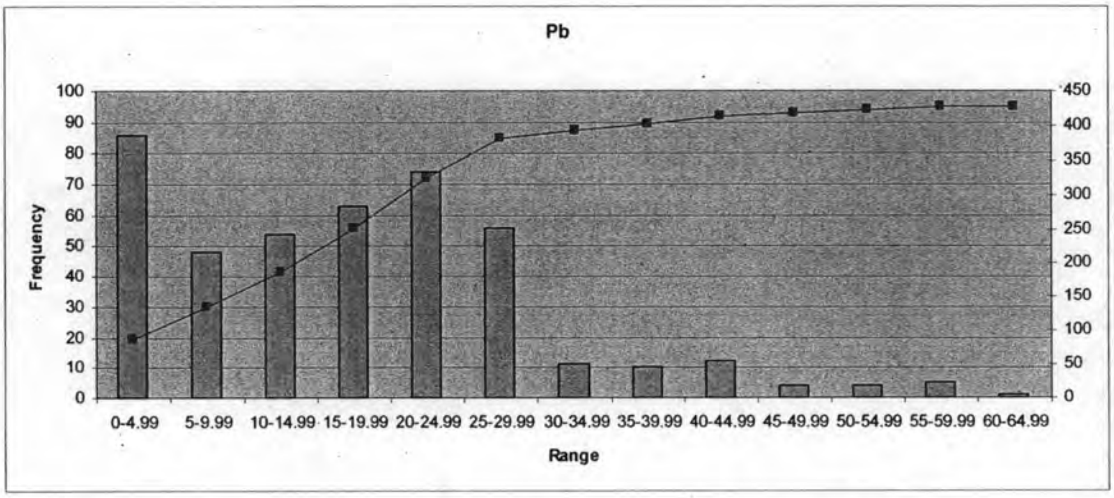


Figure 3.10 Histogram and cumulative curve of heavy metals in stream sediment samples of the study area.





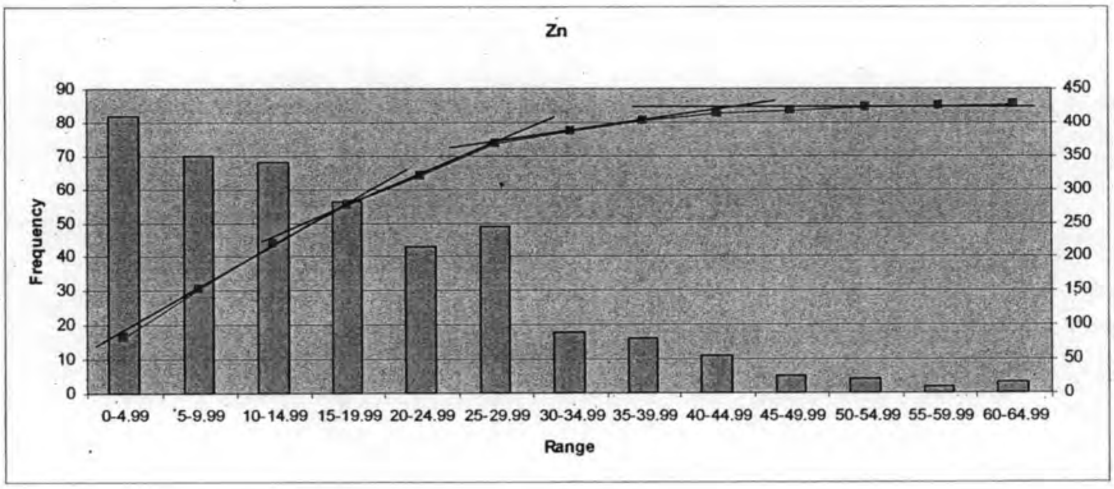


Figure 3.10 Histogram and cumulative curve of heavy metals in stream sediment samples of the study area. (cont.)

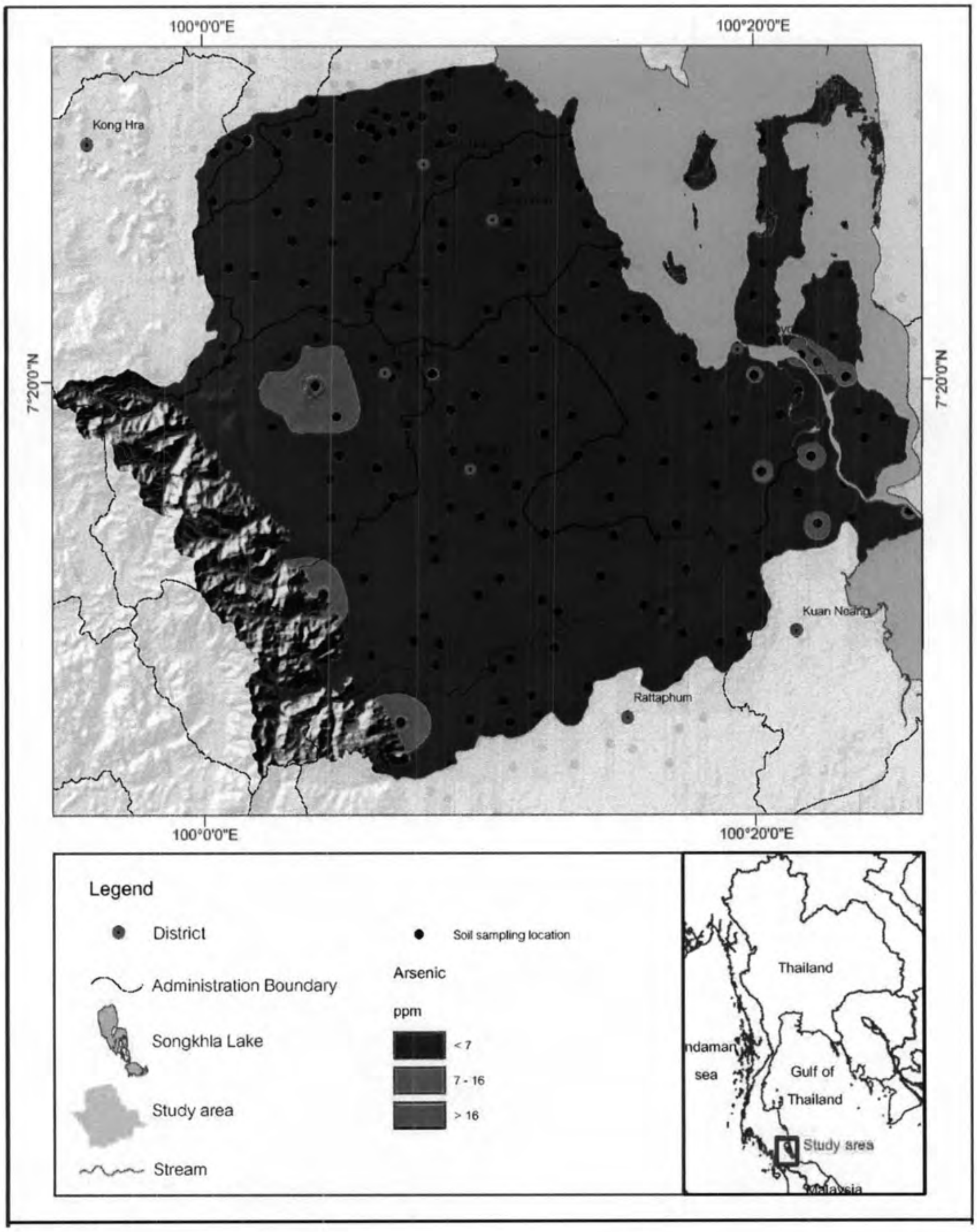


Figure 3.11 Hillshaded map showing location and value of arsenic (As) in soil of the SKL study area

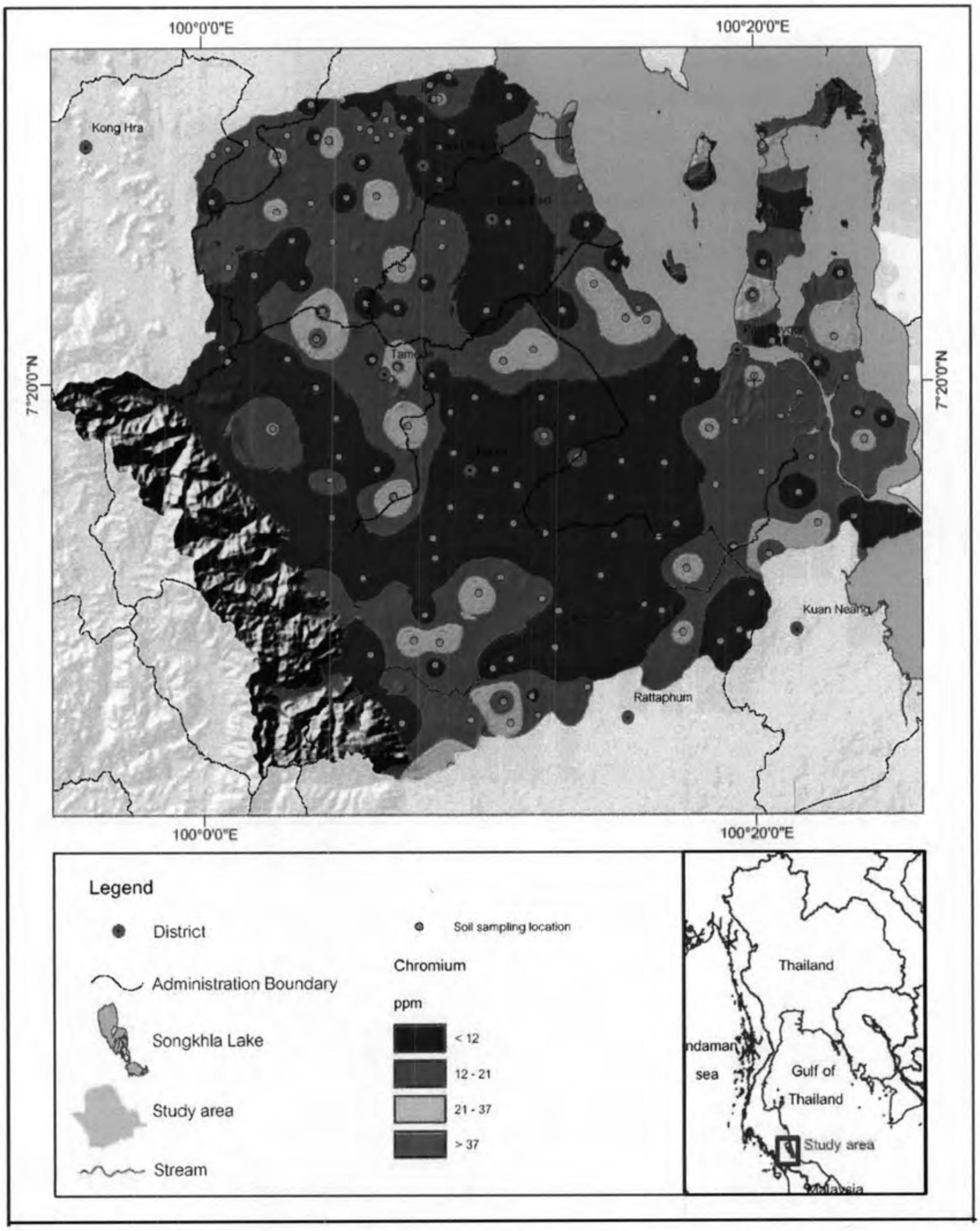


Figure 3.12 Hillshaded map showing location and value of chromium (Cr) in soil of the SKL study area

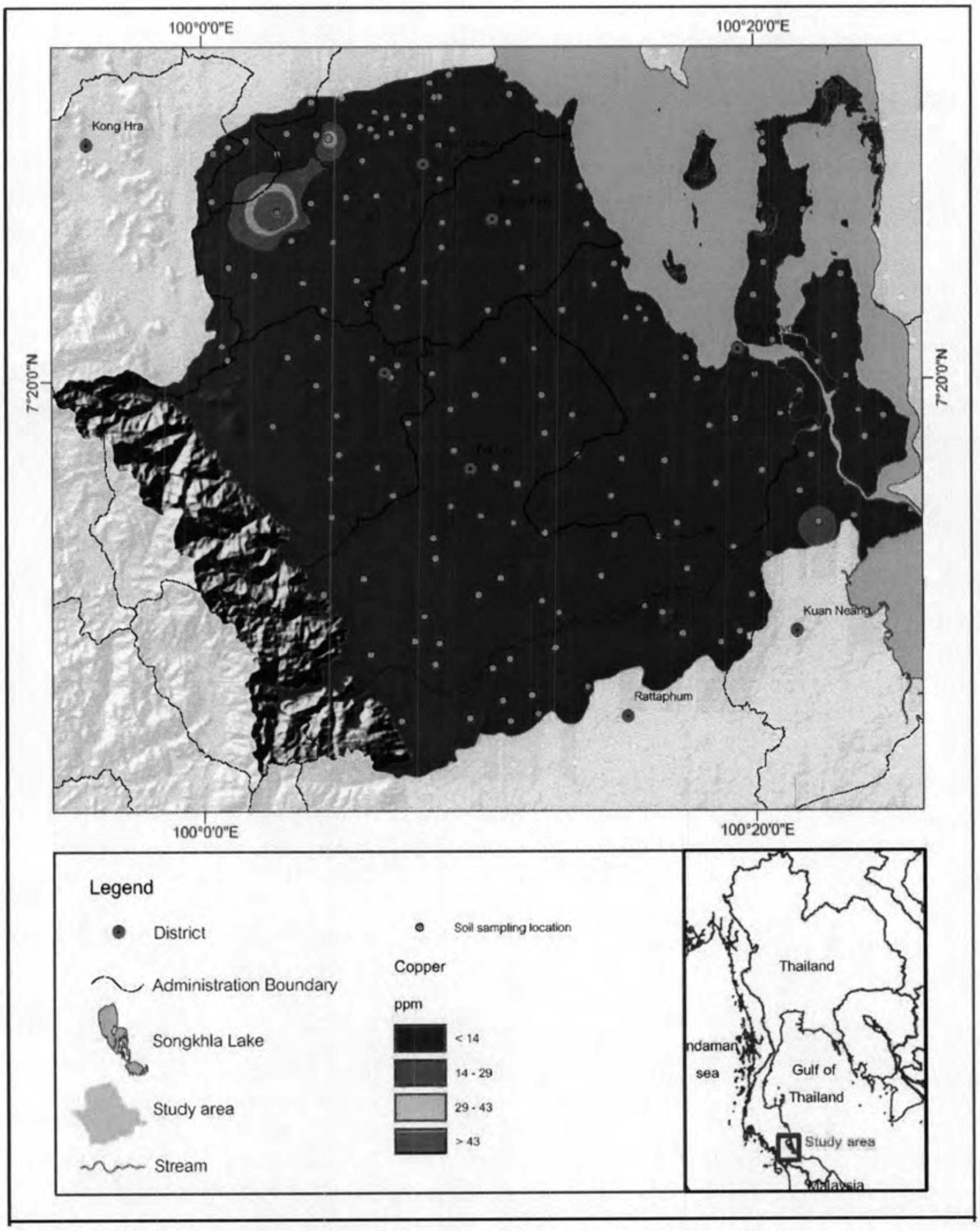


Figure 3.13 Hillshaded map showing location and value of copper (Cu) in soil of the SKL study area

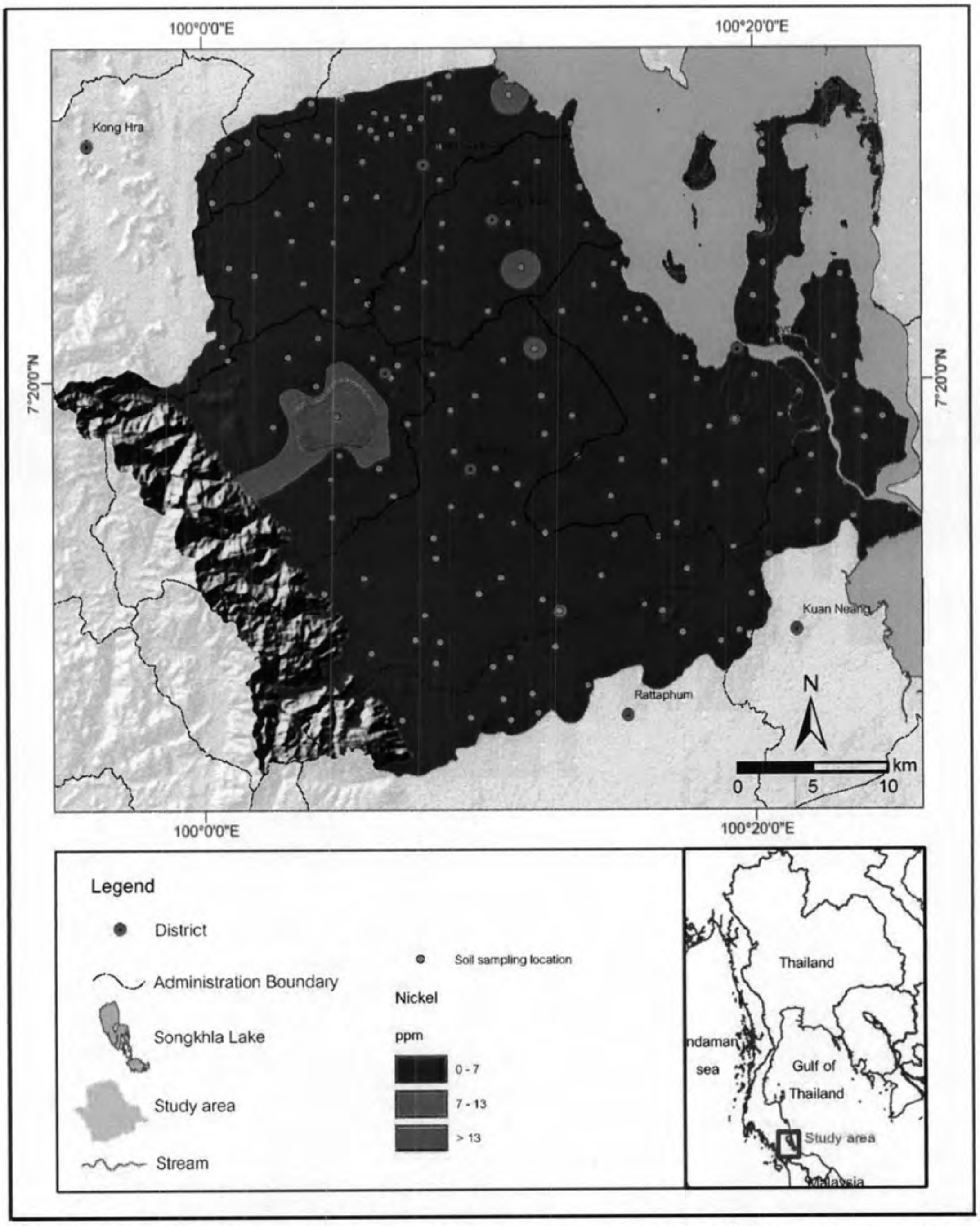


Figure 3.14 Hillshaded map showing location and value of Nickel (Ni) in soil of the SKL study area.

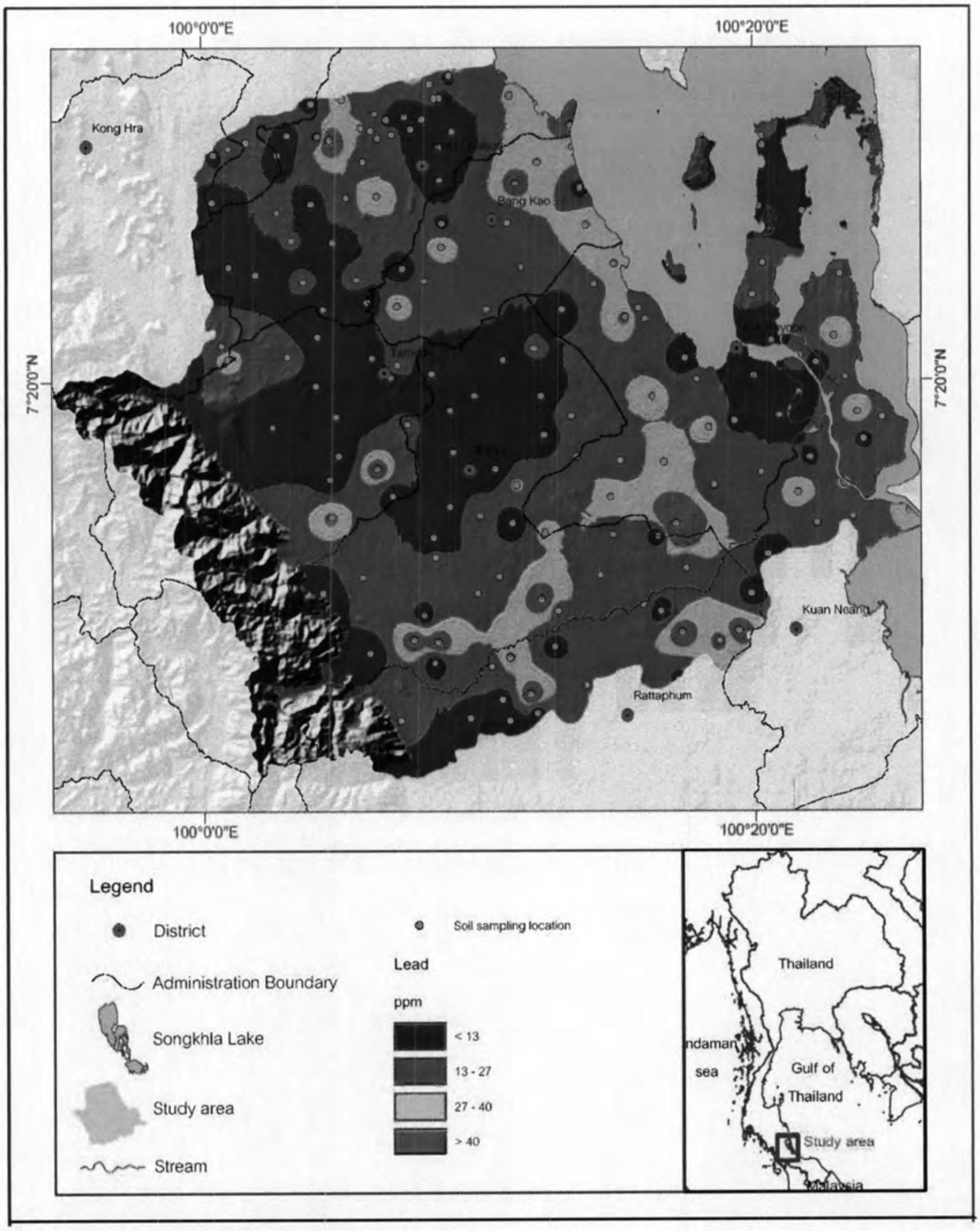


Figure 3.15 Hillshaded map showing location and value of lead (Pb) in soil of the SKL study area.

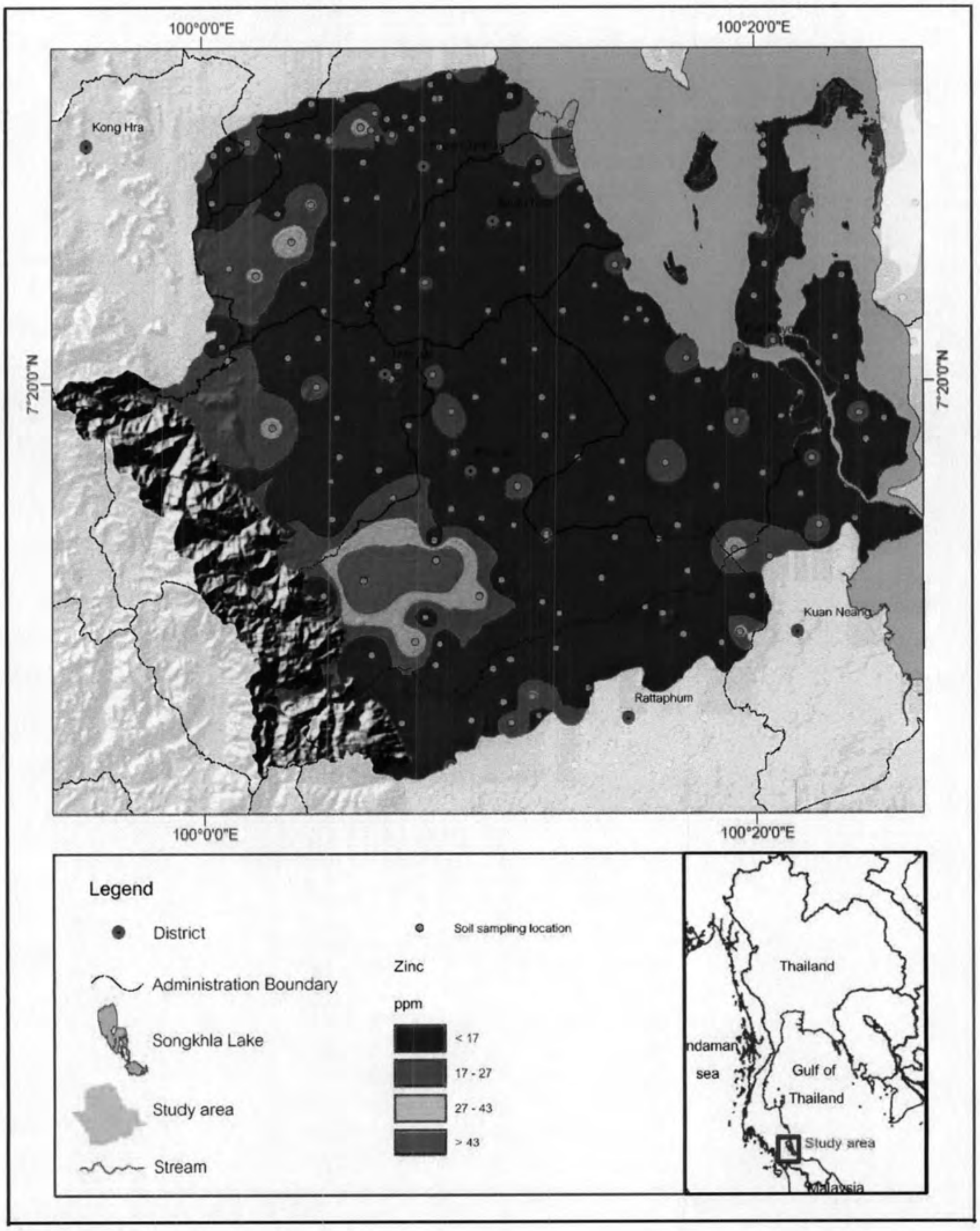


Figure 3.16 Hillshaded map showing location and value of zinc (Zn) in soil of the SKL study area.

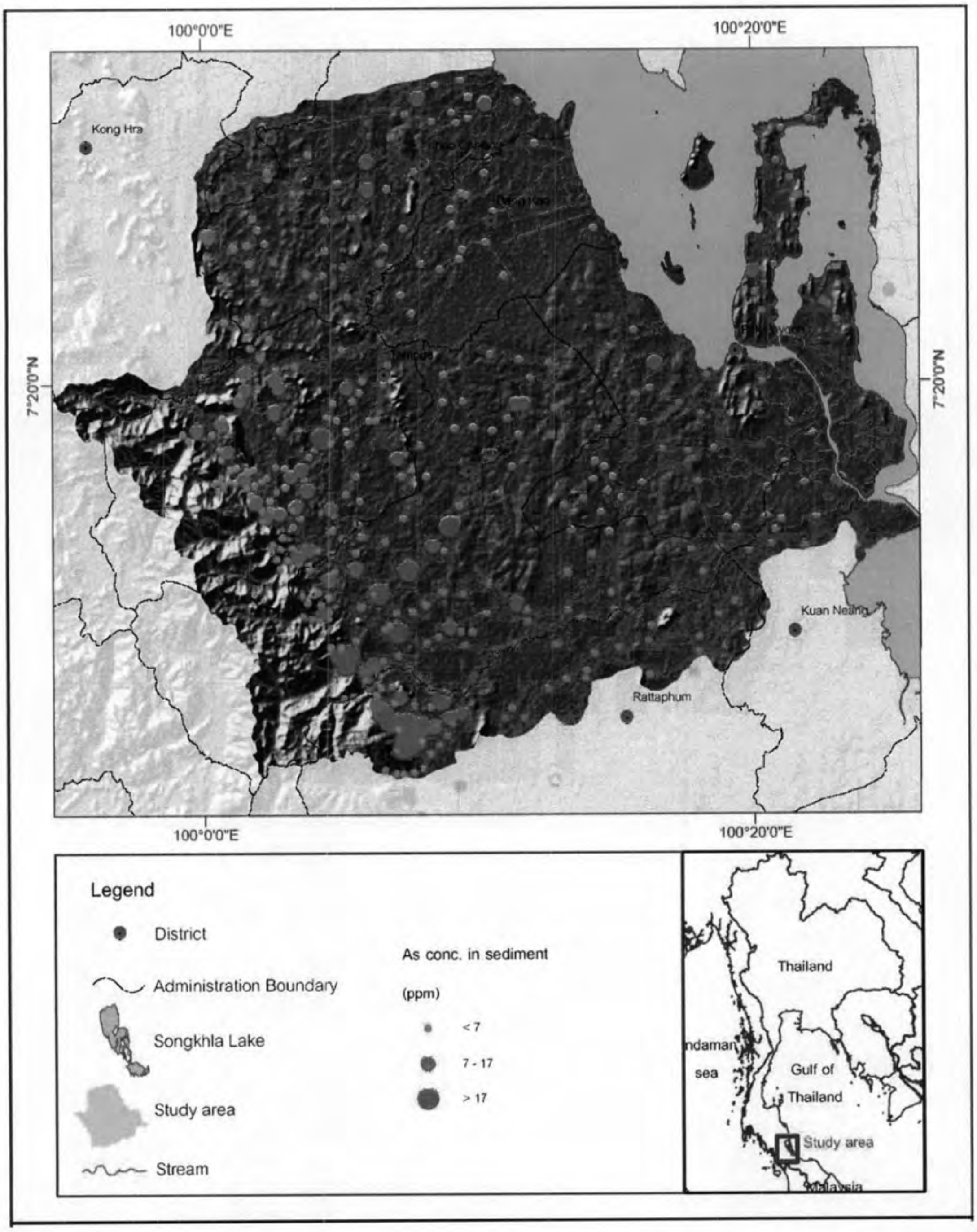


Figure 3.17 Hillshaded map showing location and value of arsenic (As) in stream sediments of the SKL study area.

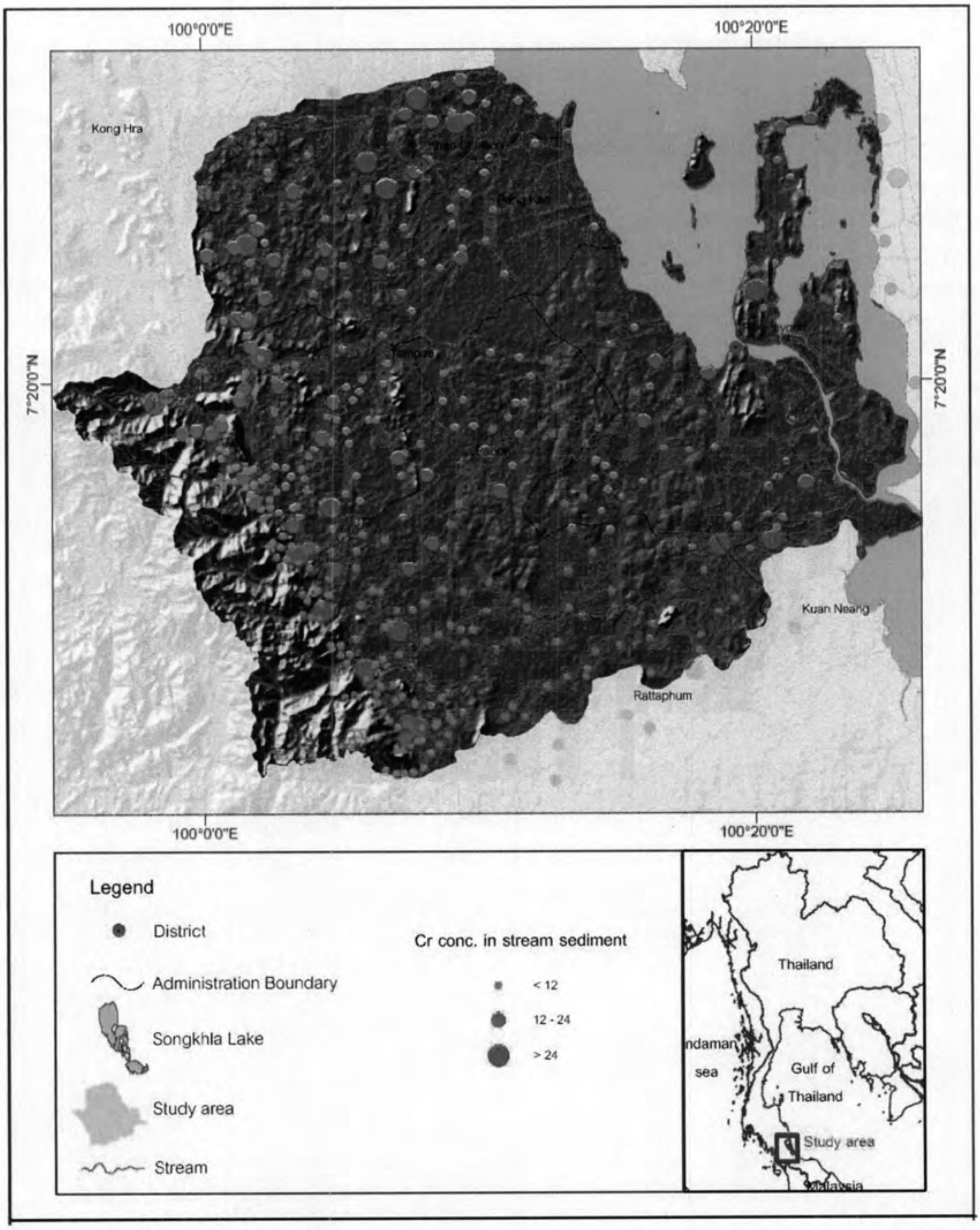


Figure 3.18 Hillshaded map showing location and value of chromium (Cr) in stream sediments of the SKL study area.

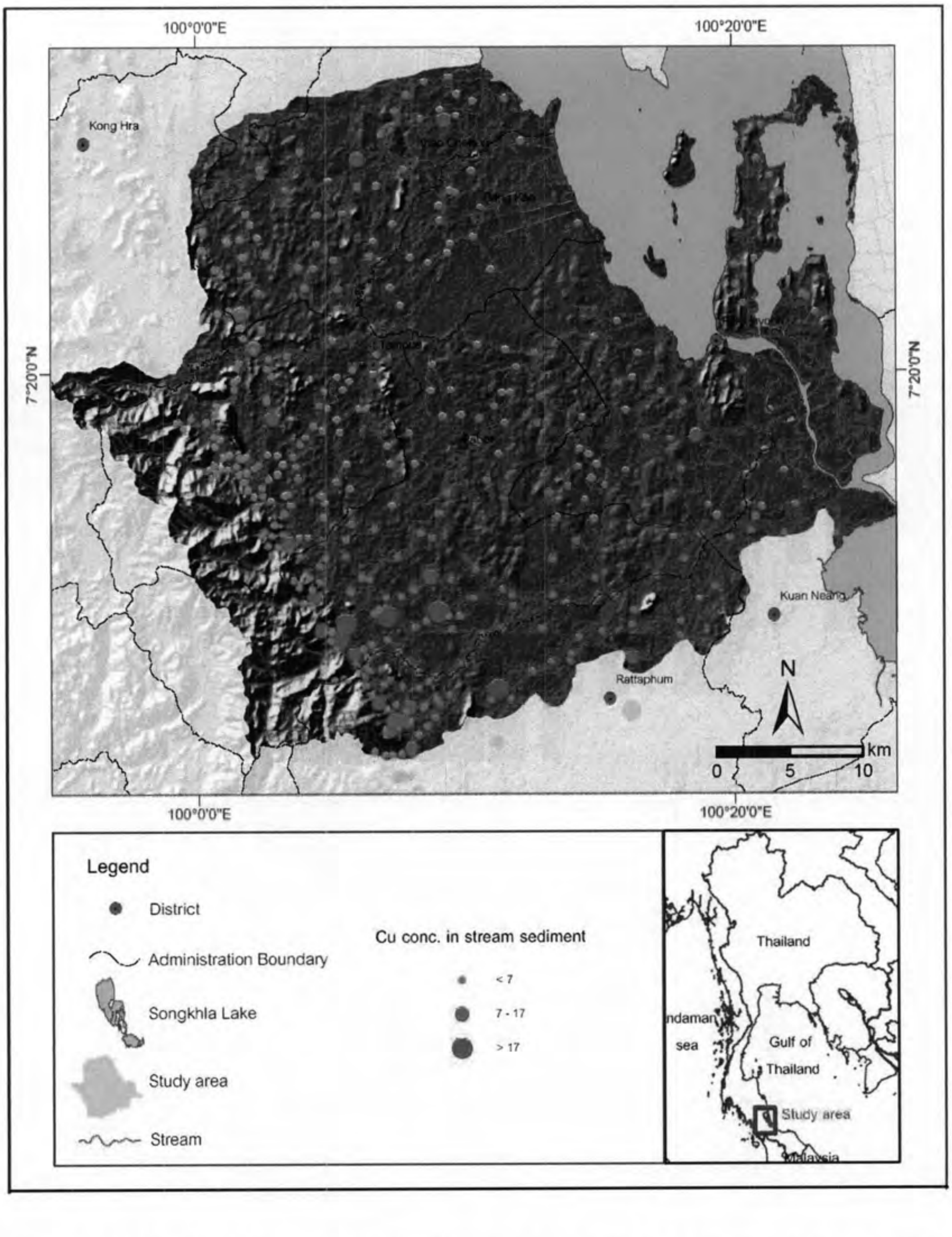


Figure 3.19 Hillshaded map showing location and value of copper (Cu) in stream sediments of the SKL study area.

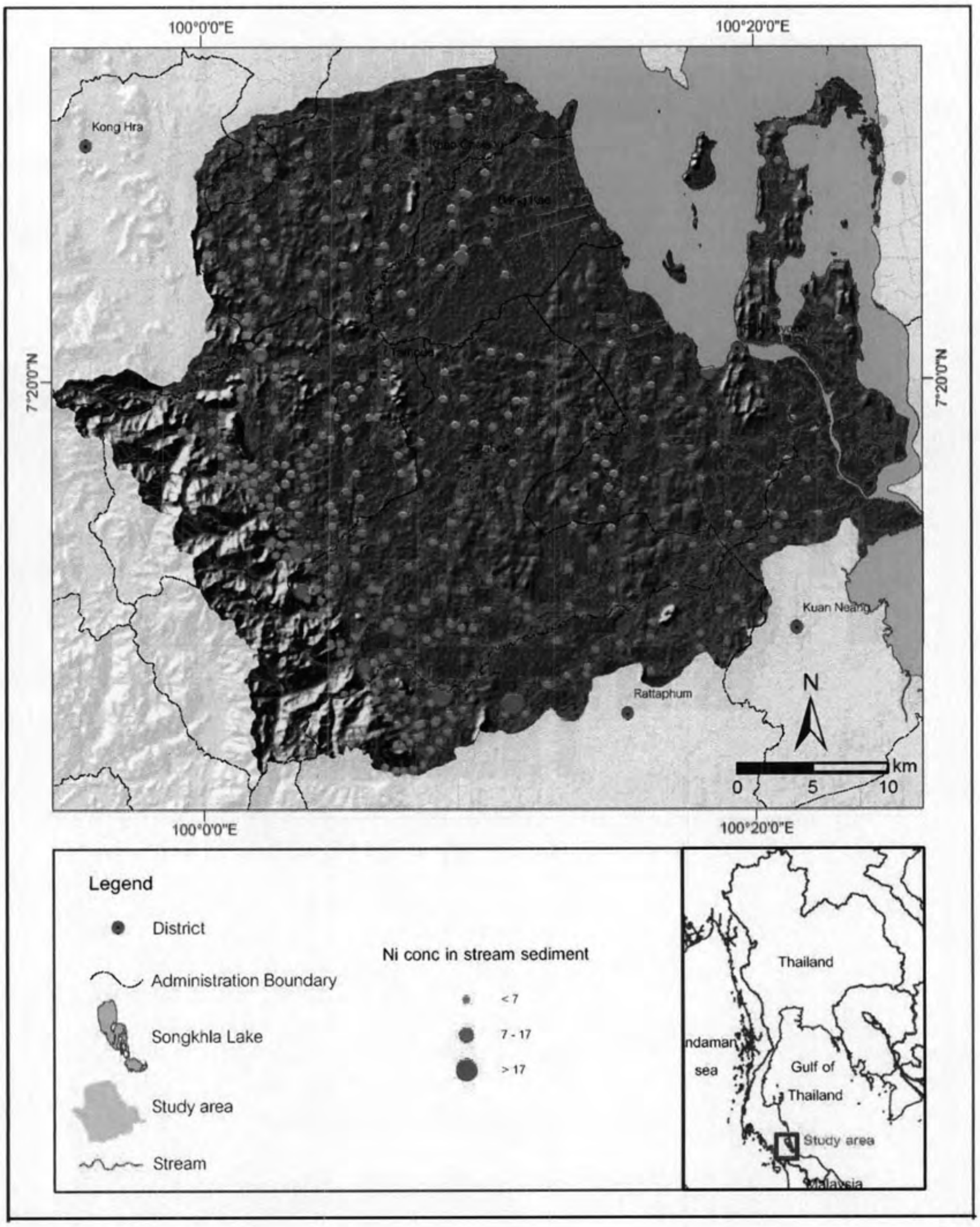


Figure 3.20 Hillshaded map showing location and value of nickel (Ni) in stream sediments of the SKL study area.

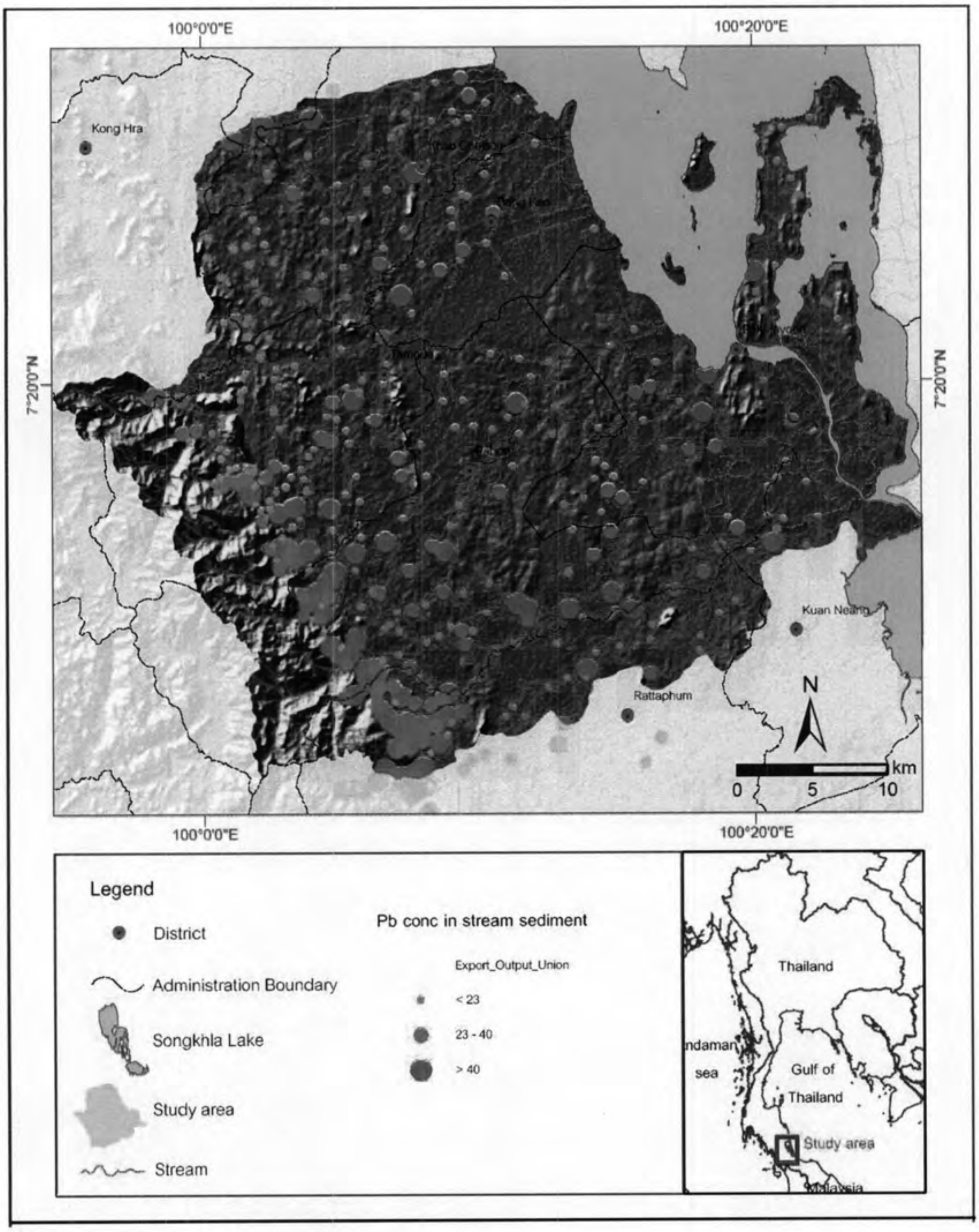


Figure 3.21 Hillshaded map showing location and value of lead (Pb) in stream sediments of the SKL study area.

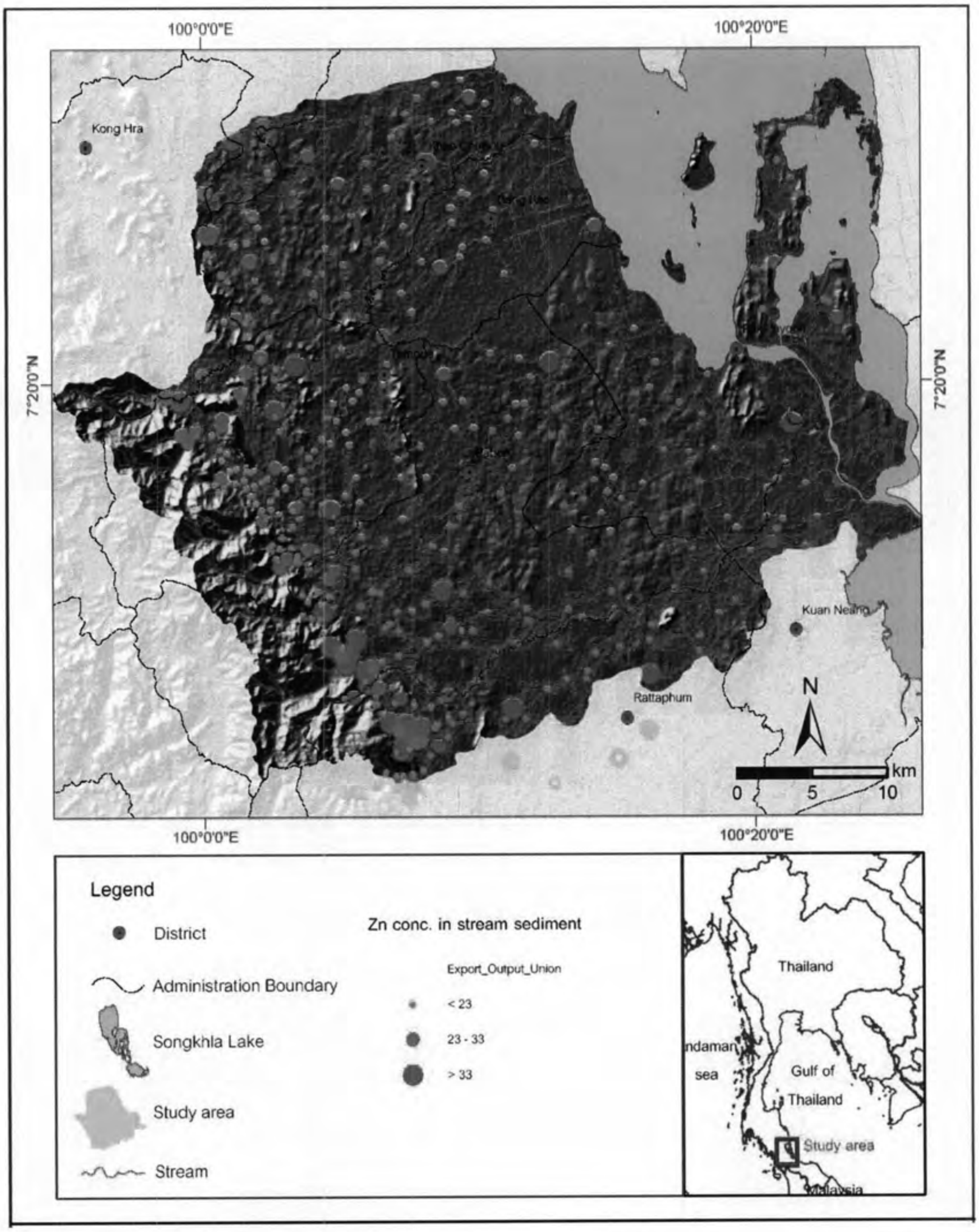


Figure 3.22 Hillshaded map showing location and value of zinc (Zn) in stream sediments of the SKL study area.

3.3 Heavy Metal Variation

In this step, the heavy metal distributions in the study area as shown in the previous section are compared with general background of the study area, i.e., land use, landform, and geology, to find out the relationship between heavy metal and location in the area. The relationships between heavy metals and subcathcments, land use, landform, and rock types are concluded in Tables 3.6 to 3.13. Details of these heavy metals are described below.

3.3.1 Arsenic (As)

Arsenic in soils is concentrated in the Tha Chiat subcatchment that the average concentration is about 4.67 ppm with the maximum concentration is 19.80 ppm. The Arsenic is located mainly in forest area with the average about 5.59 ppm. Regarding to land use type, it is to concentrate in former tidal flat and undurating terrain that is located in granitic rock (average of about 6.39 ppm).

For Arsenic in stream sediments, it is different from As in soil; the highest concentration (680 ppm) and the highest average (14.63 ppm) are located in Pa Bon subcatchment. Regarding to land use, the highest concentration (680 ppm) is located in para rubber area but the highest average (16.25 ppm) is situated in swampy area. For landform, undurating terrain contains the highest concentration (680 ppm) and highest average (10.87 ppm). The relationship between rock type and As concentration is found that the highest value of As (680 ppm) and highest average (6.39 ppm) are located in granite area whereas the second and third averages are in shale and chert area (4.83 ppm) and limestone (4.72), respectively.

3.3.2 Chromium (Cr)

For chromium in soil the highest concentration (62.75 ppm) and average (14.04 ppm) are located in Pru Por catchment area, the second and the third are Tha Chiat (13.32) and Pa Bon (11.36) catchment area, respectively . When compare with land use the highest concentration (62.75 ppm) is located in rice field area but the highest average (15.09 ppm) is situated in swampy area. The floodplain contains the highest concentration (62.75 ppm) whereas colluvium contains highest average (16.76 ppm) when compare with landform type. The relationship between rock type and Cr concentration found that highest value (61.39 ppm) is in loose sediment whereas the highest average (14.93 ppm) is in shale and chert area and the second average is in loose sediment area (14.31 ppm).

For chromium in stream sediments, unlike the concentration in soil, the highest concentration (58.55 ppm) and average (7.15 ppm) are located in Pa Bon and Tha Chiat catchment areas, respectively, the second and the third are Pru Por (5.91 ppm) and Pa Bon (4.88 ppm) catchment area, respectively . When compare with land use, like the Cr concentration in soils, the highest concentration (59.64 ppm) is located in rice field area but the highest average (22.87 ppm) is situated in swampy area. The undurating terrain contains the highest concentration (58.55 ppm) whereas colluvium contains highest average (7.72 ppm) when compare with landform type. The relationship between rock type and Cr concentration found that highest value (59.64 ppm) is in loose sediment whereas the highest average (10.82 ppm) is in sandstone area and the second average is in shale and chert area (6.78 ppm).

3.3.3 Copper (Cu)

For copper in soil the highest concentration (110.99 ppm) and average (3.96 ppm) are located in Tha Chiat catchment area, the second and the third are Pru Por

(2.57 ppm) and Pa Bon (1.3 ppm) catchment area, respectively. When compare with land use the highest concentration (110.99 ppm) is located in rice field area but the highest average (3.79 ppm) is situated in household area. The floodplain contains the highest concentration (110.99 ppm) and highest average (3.27 ppm) when compare with landform type. The relationship between rock type and Cu concentration found that highest value (110.99 ppm) and highest average (2.86 ppm) is in shale and chert area and the second average is in shale and chert area (2.48 ppm).

For copper in stream sediments, the highest concentration (119.08 ppm) and average (3.99 ppm) are located in Pru Por, the second and the third are Pa Bon (2.60 ppm) and Tha Chiat (1.47 ppm) catchment area, respectively. When compare with land use, the highest concentration (119.08 ppm) is located in para rubber area but the highest average (5.97 ppm) is situated in swampy area. The undurating terrain contains the highest average (3.99 ppm) when compare with landform type. The relationship between rock type and Cu concentration found that highest value (119.08 ppm) is in loose sediment whereas the highest average (8.10 ppm) is in limestone area and the second average is in sandstone area (8.06 ppm).

3.3.4 Nickel (Ni)

For nickel in soil the highest concentration (89.67 ppm) and average (3.57 ppm) are located in Tha Chiat catchment area, the second and the third are Pru Por (2.57 ppm) and Pa Bon (1.30 ppm) catchment area, respectively. When compare with land use the highest concentration (89.65 ppm) and the highest average (3.79 ppm) is situated in household area. The undurating terrain contains the highest concentration (88.81 ppm) and highest average (3.31 ppm) when compare with landform type. The relationship between rock type and Ni concentration found that highest value (29.58 ppm) is in shale and chert whereas the highest average (2.62 ppm) is in limestone area and the second average is in loose sediment area (2.4 ppm).

For nickel in stream sediments, the highest concentration (89.00 ppm) and average (2.54 ppm) are located in Pru Por catchment area, the second and the third are Tha Chiat (1.49 ppm) and Pa Bon (1.47 ppm) catchment area, respectively. When compare with land use, the highest concentration (133.00 ppm) is located in forest area but the highest average (5.97 ppm) is situated in swampy area. The colluvium contains the highest concentration (133.00 ppm) and highest average (5.19 ppm) when compare with landform type. The relationship between rock type and Ni concentration found that highest value (133.00 ppm) and highest average (3.08 ppm) is in sandstone area and the second average is in loose sediment area (3.08 ppm).

3.3.5 Lead (Pb)

For lead in soil the highest concentration (111.83 ppm) and average (20.75 ppm) are located in Pru Por catchment area, the second and the third are Pa Bon (18.25 ppm) and Tha Chiat (16.50 ppm) catchment areas, respectively. When compare with land use the highest concentration (111.83 ppm) is located in para rubber area but the highest average (26.86 ppm) is situated in swampy area. The undurating terrain contains the highest concentration (62.75 ppm) whereas floodplain contains highest average (19.65 ppm) when compare with landform type. The relationship between rock type and Pb concentration found that highest value (111.83 ppm) and the highest average (18.96 ppm) are in loose sediment whereas and the second average is in limestone area (14.56 ppm) and shale and chert (13.85 ppm), respectively.

For lead in stream sediments, like the concentration in soil, the highest concentration (147.26 ppm) and average (31.79 ppm) are located in Pru Por, the second and the third are Pa Bon (20.25 ppm) and Tha Chiat (18.40 ppm) catchment area, respectively. When compare with land use, the highest concentration (1,062.80 ppm) is located in para rubber area but the highest average (47.94 ppm) is situated in forest area. The undurating terrain contains the highest concentration (1,062.80 ppm) and highest average (47.54 ppm) when compare with landform type. The relationship between rock type and Pb concentration found that highest value (1,062.80 ppm) and the highest average (146.32 ppm) is in sandstone area and the second average is in limestone (95.88 ppm) and granite (43.97 ppm), respectively.

3.3.6 Zinc (Zn)

For zinc in soil the highest concentration (141.58 ppm) and average (15.62 ppm) are located in Pa Bon catchment area, the second and the third are Tha Chiat (14.57 ppm) and Pru Por (11.71 ppm) catchment areas, respectively. When compare with land use the highest concentration (141.58 ppm) is located in para rubber area but the highest average (20.03 ppm) is situated in swampy area. The undurating terrain contains the highest concentration (137.34 ppm) and highest average (15.13 ppm) when compare with landform type. The relationship between rock type and Zn concentration found that highest value (111.83 ppm) and the highest average (18.96 ppm) are in loose sediment whereas and the second average is in limestone area (14.56 ppm) and shale and chert (13.85 ppm), respectively.

For zinc in stream sediments, like the concentration in soil, the highest concentration (2,663.03 ppm) and average (43.29 ppm) are located in Pru Por, the second and the third are Tha Chiat (12.10 ppm) and Pa Bon (8.55 ppm) catchment area, respectively. When compare with land use, the highest concentration (2,663.03 ppm) and highest average (22.06 ppm) is located in para rubber area. The undurating terrain contains the highest concentration (135.56 ppm) and highest average (18.09 ppm) is in colluvium area when compare with landform type. The relationship between rock type and Zn concentration found that highest value (2,663.03 ppm) is in loose sediment area and the highest average (27.78 ppm) is in limestone area and the second average is in sandstone (24.02 ppm) and granite (19.20 ppm), respectively.

Table 3.6 Heavy metals in stream sediment in each catchment area is the Songkhla Lake catchment area.

Tha Chiat Sub-catchment area

	As	Cr	Cu	Ni	Pb	Zn
Mean	4.689	7.146	1.466	1.488	18.395	12.097
Minimum	0.01	0.39	0.705	0.59	0.49	0.49
Maximum	18.6	35.873	16	17	140.691	135.562
SD	2.97	8.1	2.203	2.31	19.955	14.511

Pa Bon Sub-catchment area

	As	Cr	Cu	Ni	Pb	Zn
Mean	14.637	4.878	2.599	1.467	20.249	8.554
Minimum	0.01	0.39	0.72	0.59	0.49	0.49
Maximum	680	58.553	36.13	11.878	107.813	57.269
SD	72.336	8.387	5.547	2.043	23.218	13.566

Pru Por Sub-catchment area

	As	Cr	Cu	Ni	Pb	Zn
Mean	10.791	5.914	3.988	2.536	31.793	43.286
Minimum	0.01	0.39	0.705	0.59	0.49	0.49
Maximum	237	51.5	119.08	89	147.262	2663.031
SD	29.719	8.313	12.58	10.573	32.835	278.124

Table 3.7 Heavy metals in soil in each catchment area is the Songkhla Lake catchment area.

Tha Chiat Sub-catchment area

	As	Cr	Cu	Ni	Pb	Zn
Mean	4.67	13.32	3.96	3.57	16.5	14.57
Minimum	0	0.39	0	0	0	0.01
Maximum	19.8	60.84	110.99	89.67	83.26	106
SD	2.15	6.49	8.08	6.6	9.33	9.49

Pa Bon Sub-catchment area

	As	Cr	Cu	Ni	Pb	Zn
Mean	3.19	11.36	1.3	1.74	18.25	15.62
Minimum	0.1	0.39	0.71	0.59	0.49	0.49
Maximum	10.92	39.03	5.92	9.17	92.43	141.58
SD	1.44	6.52	0.73	1.21	9.75	14

Pru Por Sub-catchment area

	As	Cr	Cu	Ni	Pb	Zn
Mean	4.26	14.04	2.57	1.57	20.75	11.71
Minimum	0.1	0.39	0.71	0.51	0.49	0.49
Maximum	17	62.75	28.46	7.21	111.83	32.47
SD	2.12	7.17	2.9	0.93	11,49	4.62

Table 3.8 Relationship between heavy metals in stream sediment and landform.

	As	Cr	Cu	Ni	Pb	Zn
Hill						
Mean	9.02	4.27	1.80	1.66	24.95	13.25
Minimum	0.01	0.39	0.72	0.59	0.49	0.49
Maximum	136.00	14.74	11.09	13.00	107.81	36.98
Standard Deviation	27.14	4.83	2.33	2.74	25.15	11.43
Undulating Terrain						
Mean	10.87	5.98	3.99	2.33	47.54	16.36
Minimum	0.01	0.39	0.71	0.59	0.49	0.49
Maximum	680.00	58.55	36.13	109.00	1062.80	135.56
Standard Deviation	47.15	8.32	5.10	9.61	127.94	17.08
Colluvium						
Mean	5.88	7.72	3.45	5.19	42.33	18.09
Minimum	1.19	0.39	0.72	0.59	0.49	0.49
Maximum	23.10	30.85	15.35	133.00	713.09	59.67
Standard Deviation	5.37	8.00	4.59	21.83	114.81	15.54
Floodplain						
Mean	3.66	6.72	1.25	0.86	18.65	9.98
Minimum	0.01	0.39	0.71	0.59	0.49	0.49
Maximum	10.80	25.73	5.53	3.00	71.72	32.37
Standard Deviation	2.28	7.26	1.27	0.67	18.36	9.01
Formor tidalflat						
Mean	3.06	6.31	1.75	1.43	13.84	8.76
Minimum	0.01	0.39	0.72	0.59	0.49	0.49
Maximum	8.86	43.02	16.00	17.00	75.15	66.67
Standard Deviation	1.97	8.91	2.70	2.60	16.59	12.29

Table 3.9 Relationship between heavy metals in soil and landform.

	As	Cr	Cu	Ni	Pb	Zn
Hill						
Mean	3.53	15.30	1.96	1.74	12.46	11.16
Minimum	0.00	0.66	0.00	0.00	0.00	0.00
Maximum	18.96	49.45	11.24	17.27	56.81	45.68
Standard Deviation	2.59	8.16	1.45	1.93	8.75	6.57
Undulating Terrain						
Mean	4.46	11.01	1.78	3.13	15.60	15.13
Minimum	0.00	0.39	0.00	0.00	0.00	0.49
Maximum	19.80	44.41	23.40	88.81	111.83	137.34
Standard Deviation	2.65	5.86	1.67	6.41	11.34	11.32
Colluvium						
Mean	4.02	16.76	1.99	0.59	11.68	13.09
Minimum	0.28	5.18	0.71	13.24	0.49	0.50
Maximum	7.16	44.16	9.23	33.5	24.56	23.89
Standard Deviation	1.54	7.49	1.03	2.07	3.50	5.18
Floodplain						
Mean	3.71	13.50	3.27	2.18	19.65	13.92
Minimum	0.00	0.39	0.05	0.00	0.17	0.01
Maximum	13.10	62.75	110.99	83.26	83.26	141.58
Standard Deviation	1.53	7.01	7.10	9.29	9.29	10.63
Former tidal flat						
Mean	5.32	15.78	2.53	1.57	17.99	12.50
Minimum	0.10	0.39	0.71	0.59	0.49	0.21
Maximum	8.17	60.84	17.95	10.26	53.26	98.97
Standard Deviation	1.52	6.82	1.86	1.31	7.71	8.51

Table 3.10 Relationship between heavy metals in stream sediment and rock type.

	As	Cr	Cu	Ni	Pb	Zn
Loose sediment						
Mean	5.55	6.26	2.57	2.19	24.26	17.56
Minimum	0.01	0.39	0.71	0.59	0.49	0.49
Maximum	237.00	59.64	119.08	109.00	784.39	2,663.03
Standard Deviation	13.01	8.67	6.86	8.71	60.41	128.41
Sandstone						
Mean	6.15	10.82	8.06	1.87	146.32	24.02
Minimum	0.01	0.39	0.72	0.59	0.49	0.49
Maximum	29.20	33.34	20.02	8.87	1,062.80	59.67
Standard Deviation	6.80	8.74	5.66	2.44	311.52	17.58
Shale and chert						
Mean	3.98	6.78	1.46	1.47	6.31	8.15
Minimum	0.01	0.39	0.72	0.59	0.49	0.49
Maximum	8.75	39.70	6.00	7.00	33.07	29.32
Standard Deviation	2.41	10.85	1.77	2.08	9.56	9.21
Limestone						
Mean	10.83	3.99	8.10	0.83	95.88	27.78
Minimum	0.01	0.39	0.72	0.59	0.49	10.17
Maximum	87.60	15.34	19.23	2.99	860.76	57.27
Standard Deviation	17.82	4.65	4.62	0.58	178.47	15.14
Granite						
Mean	17.08	6.45	3.45	3.08	43.97	19.20
Minimum	0.01	0.39	0.71	0.59	0.49	0.49
Maximum	680.00	33.24	15.35	133.00	896.96	71.00
Standard Deviation	75.93	7.42	3.61	14.82	98.03	15.07

Table 3.11 Relationship between heavy metals in soil and rock type.

	As	Cr	Cu	Ni	Pb	Zn
Loose sediment						
Mean	3.44	14.31	2.86	1.94	18.96	13.4
Minimum	0	0.59	0	0	0	0.01
Maximum	14	61.39	110.99	11.86	96.33	98.97
Standard Deviation	1.6	6.98	6.15	1.58	8.78	7.69
Sandstone						
Mean	1.44	7.77	0.86	0.64	10.3	8.25
Minimum	0	0.97	0	0	0	0
Maximum	5.59	24.71	3.7	2.25	42.61	19.51
Standard Deviation	1.2	4.1	0.54	0.52	10	4.42
Shale and chert						
Mean	4.83	14.93	2.48	2.4	13.85	13.48
Minimum	0.1	0.39	0.71	0.59	0.49	0.49
Maximum	19.8	49.57	15.73	29.58	52.61	49.58
Standard Deviation	2.64	8.63	1.95	3.42	8.46	6.49
Limestone						
Mean	4.72	12.17	1.81	2.62	14.56	15.95
Minimum	0.72	2.31	0.81	0.63	3.95	3.28
Maximum	15.44	22.38	4.72	7.03	42.84	80.85
Standard Deviation	1.93	3.39	0.79	1.73	5.29	8.36
Granite						
Mean	6.39	11.79	1.39	1.92	12.77	15.57
Minimum	2.59	0.44	0.71	0.54	0.63	0.85
Maximum	16.97	25.61	2.97	7.22	22.02	25.94
Standard Deviation	3.06	3.69	0.41	1.5	3.67	4.99

Table 3.12 Relationship between heavy metals in stream sediment and land use.

	As	Cr	Cu	Ni	Pb	Zn
Rice field						
Mean	4.03	7.22	1.50	1.25	16.23	9.55
Minimum	0.01	0.39	0.71	0.59	0.49	0.49
Maximum	18.60	59.64	18.91	8.00	94.74	111.45
Standard Deviation	2.59	3.17	9.75	2.27	1.58	19.19
Para rubber						
Mean	9.11	5.64	3.55	2.25	39.70	22.06
Minimum	0.01	0.39	0.71	0.59	0.49	0.49
Maximum	680.00	51.50	119.08	109.00	1062.80	2663.03
Standard Deviation	2.65	40.29	7.29	7.62	9.73	110.67
Mixed orchard						
Mean	5.08	7.35	4.78	2.56	44.92	19.21
Minimum	0.01	0.39	0.72	0.59	0.49	0.49
Maximum	14.10	33.05	19.19	17.00	502.59	135.56
Standard Deviation	1.54	2.80	8.94	5.87	3.77	106.12
Forest and mangrove						
Mean	7.73	7.05	3.67	5.33	47.94	19.05
Minimum	1.19	0.39	0.72	0.59	0.49	0.49
Maximum	122.00	33.34	12.89	133.00	896.96	53.46
Standard Deviation	1.53	19.10	8.36	3.63	21.55	141.47
Swamp area						
Mean	16.25	22.87	8.24	5.97	23.71	6.89
Minimum	1.06	6.05	0.72	0.59	0.49	0.49
Maximum	58.80	58.55	36.13	11.88	76.75	13.35
Standard Deviation	1.52	24.31	20.74	15.61	4.62	32.63
Quarry and abandoned area						
Mean	3.26	2.27	2.33	0.59	23.61	11.66
Minimum	0.01	0.39	0.72	0.59	5.82	3.93
Maximum	6.39	7.11	8.48	0.59	46.06	23.25
Standard Deviation	2.30	2.94	3.44	0.00	18.05	7.32
Household						
Mean	5.32	15.78	2.53	1.57	17.99	12.50
Minimum	0.10	0.39	0.71	0.59	0.49	0.21
Maximum	8.17	60.84	17.95	10.26	53.26	98.97
Standard Deviation	1.52	6.82	1.86	1.31	7.71	8.51

Table 3.13 Relationship between heavy metals in stream sediment and land use.

	As	Cr	Cu	Ni	Pb	Zn
Rice field						
Mean	3.81	13.05	3.06	2.54	10.01	13.64
Minimum	0.10	0.39	0.71	0.18	0.49	0.49
Maximum	13.60	62.75	110.99	89.58	83.26	141.55
Standard Deviation	1.67	6.82	6.85	4.75	9.32	10.66
Para rubber						
Mean	4.20	12.54	2.47	2.51	16.40	14.67
Minimum	6.00	0.39	0.00	0.00	0.00	0.01
Maximum	19.80	53.47	106.99	89.67	111.83	141.58
Standard Deviation	2.31	6.69	4.73	4.43	10.55	10.84
Mixed orchard						
Mean	4.13	13.19	3.18	2.27	19.79	16.14
Minimum	0.09	0.82	0.05	0.03	0.17	0.49
Maximum	15.39	60.84	39.78	13.06	69.00	98.97
Standard Deviation	1.81	6.99	4.26	1.88	9.95	9.91
Forest and mangrove						
Mean	5.59	12.47	2.92	2.02	16.14	12.99
Minimum	0.34	1.36	0.71	0.59	2.47	3.23
Maximum	15.49	26.33	9.90	6.98	31.21	34.29
Standard Deviation	1.45	3.74	1.77	1.47	6.29	4.97
Swampy area						
Mean	3.04	15.09	1.47	2.07	26.86	20.03
Minimum	0.22	2.49	0.71	0.59	5.91	2.03
Maximum	6.30	42.55	5.53	9.74	51.96	55.98
Standard Deviation	1.45	11.05	0.80	2.10	10.53	12.91
Quarry and abandoned area						
Mean	3.80	11.09	1.11	1.61	6.77	17.39
Minimum	2.63	7.00	0.72	0.60	0.63	10.42
Maximum	5.69	16.96	2.17	7.29	25.31	27.38
Standard Deviation	0.92	2.57	0.36	1.96	6.80	3.49
Household area						
Mean	4.31	13.47	3.79	3.31	17.27	12.98
Minimum	0.55	0.94	0.71	0.59	0.49	0.49
Maximum	11.40	41.59	84.29	89.65	56.81	47.39
Standard Deviation	1.62	7.41	8.26	10.51	9.52	7.76

3.4 Conclusions

The rate of soil erosion in this area is about 26.15 tons/ha/yr or about 1.63 mm/yr. The highest erosion area is located along the Nakorn Si Thammarat range in the western part. The Tha Chiat subcatchment area is the highest erosion area among three subcatchment areas in the study area. Results from calculation of sediment yield are about 150 x 10^3 tons/yr in year 2002 and 133 x 10^3 tons/yr in year 1981. It can be estimated that, in 21 years, sediment yield changes about 12%.

Arsenic, chromium, copper, nickel, lead, and zinc are selected for evaluation and examination of heavy metal distribution in this study. The datasets of heavy metals in soils and stream sediments from DMR (2006) show high concentration in some specific areas. Tha Chiat subcatchment area contains significantly abundant As, Cu, and Ni while Pru Por subcatchment area has high concentrations of Cr and Pb. In addition, only Zn has high concentration in Pa Bon subcatchment area. For heavy metal in stream sediments, Pru Por subcatchment has high concentrations of Cu, Ni, Pb, and Zn, whereas high As and Cr concentrations are found in Pa Bon and Tha Chiat subcatchments. From the results of this study, it can be recognized that there are some elements that cannot make a relationship between soil and stream sediment. This problem will be discussed later in Chapter V.