CHAPTER IV

RESEARCH METHODS

Three soil erosion models namely Universal Soil Loss Equation (USLE), Soil Loss Estimation Model for Southern Africa (SLEMSA) and Morgan and Morgan and Finney model (MMF) were integrated within IDRISI32 environment to estimate the spatial distribution of soil loss. A well-worked model was then selected to estimate its extra production cost, accordingly. Soil loss estimation steps and its extra cost are briefly illustrated in Figure 4-1.

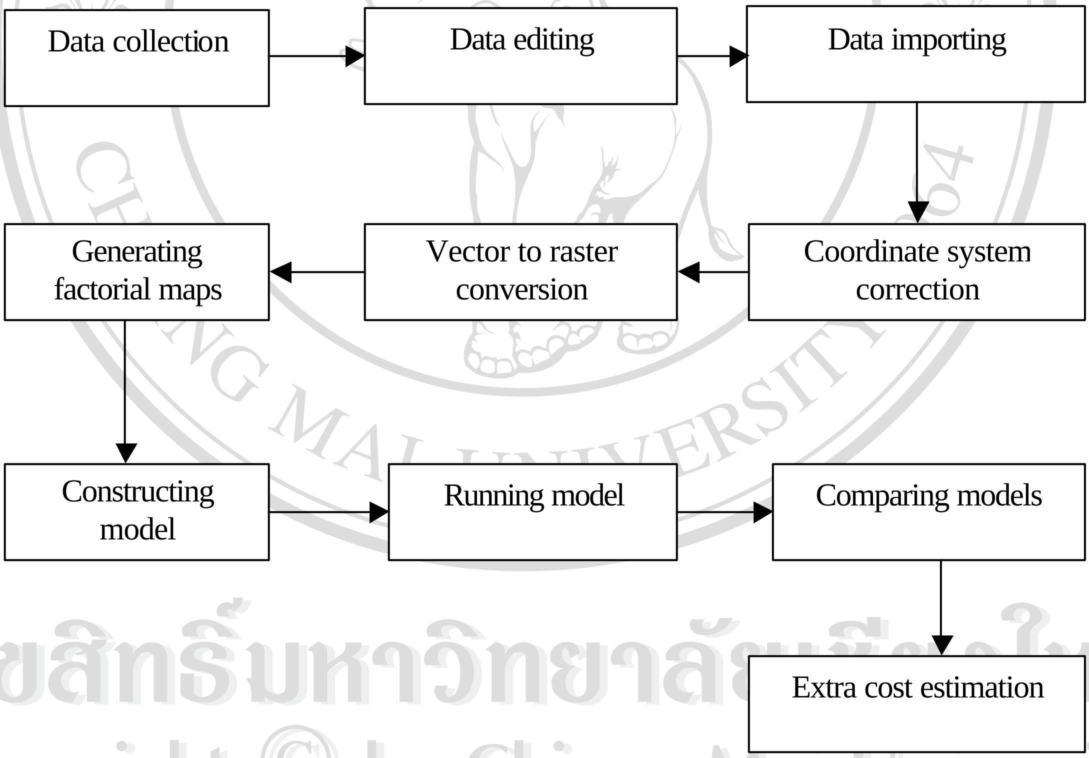

Figure 4-1 The steps of the soil loss estimation and its extra production cost

4.1 Data collection

The required dataset for this study includes maps of elevation, land cover, soil types, and rainfall data. Monthly rainfall records were colleted from Ba Be Weather Observation Station for a 12-year period between 1990 and 2001. A soil type map, scale 1:100,000, was obtained from Bac Kan Department of Agriculture and Rural Development. Names of soil types followed 1973 soil classification that was established by Soil Survey Division of National Institute for Soil Science and Fertilizer (Bac Kan Department of Agricultural and Rural Development, 2000). The soil characteristics have been updated and supplemented between 1995 and 2000. The topographic map was obtained from existing database of PARC project. It was produced in 1972, with the scale of 1: 50,000. The land cover map deriving from remote sensing interpretation was also obtained from the existing database of PARC project. The related social and economic data were colleted from Ba Be Department of Agricultural and Rural Development, PARC Survey Report, Bac Kan Department of Agriculture and Rural Development. Observed soil loss at field plots for models comparison was collected from previous experimental results from the Upland Management Project, Bac Kan Department of Agriculture and Rural Development.

4.2 Soil loss estimation models

In this study, three models, namely, USLE, SLEMSA and MMF model were integrated within IDRISI32 environment (Eastman, 2001) to generate factor maps and then were used to produce final maps of the spatial soil loss distribution across study area.

4.2.1 Universal Soil Loss Equation (USLE)

A cartographic model of the Universal Soil Loss Equation (Figure 4-2) and all detailed equations are presented as follows

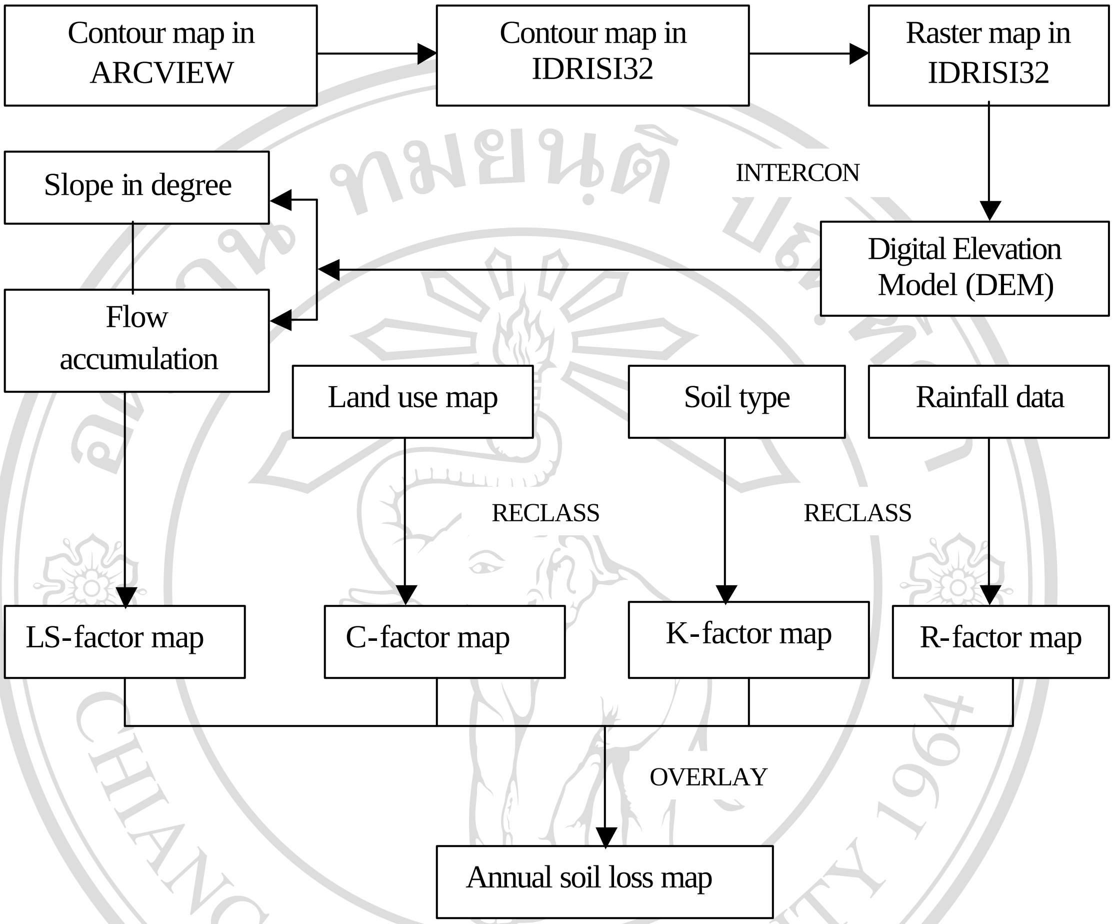

Figure 4-2 A cartographic model of the Universal Soil Loss Equation

The soil loss in tons per ha per year is the product of six causative factors and it is given as (Wischmeier and Smith, 1978).

$$A = R \,.\, K \,.\, LS \,.\, C \,.\, P \qquad [4-1]$$

Where

A = mean annual soil loss (ton ha^{-1} $year^{-1}$)

R = rainfall erosivity index

K = soil erodibility index

LS = factors of slope length and slope steepness

C = crop management factor

P = soil conservation factor

Equation [4-2] developed by Siem (1999) was adopted for calculating the rainfall erosivity index.

$$R = 0.548527\ P - 59.9 \qquad [4-2]$$

Where

R = rainfall erosivity index (MJ ha^{-1} $year^{-1}$)

P = average annual precipitation (mm)

Soil erodibility index was estimated using the Nomograph method (Wischmerier et al.. 1971), which required % very fine sand, % silt, % sand, % organic matter, soil permeability and structure.

LS calculation equation of Wishchmeier and Smith (1978), suitable for estimating erosion interrill and rill processes, was adopted as follows.

$$LS = (\chi /22.13)^{m} (0.065 + 0.045\ S + 0.0065\ S^{2}) \qquad [4-3]$$

Where

χ = flow accumulation*cell size (Moore and Burch, 1986)

S = slope in percent

m = 0.3 for slope is less than 3 percent; m = 0.4 for slope is >3 to < 5 and m = 0.5 for slope is more than 5.

Assuming that there is an upper bound of 150 meters for case of rill and interill erosion (More and Burch, 1986). The USLE was designed to estimate only rill and interill erosion, so modification was made to create a continuous surface of flow accumulation (Figure 4-3) according to such assumption.

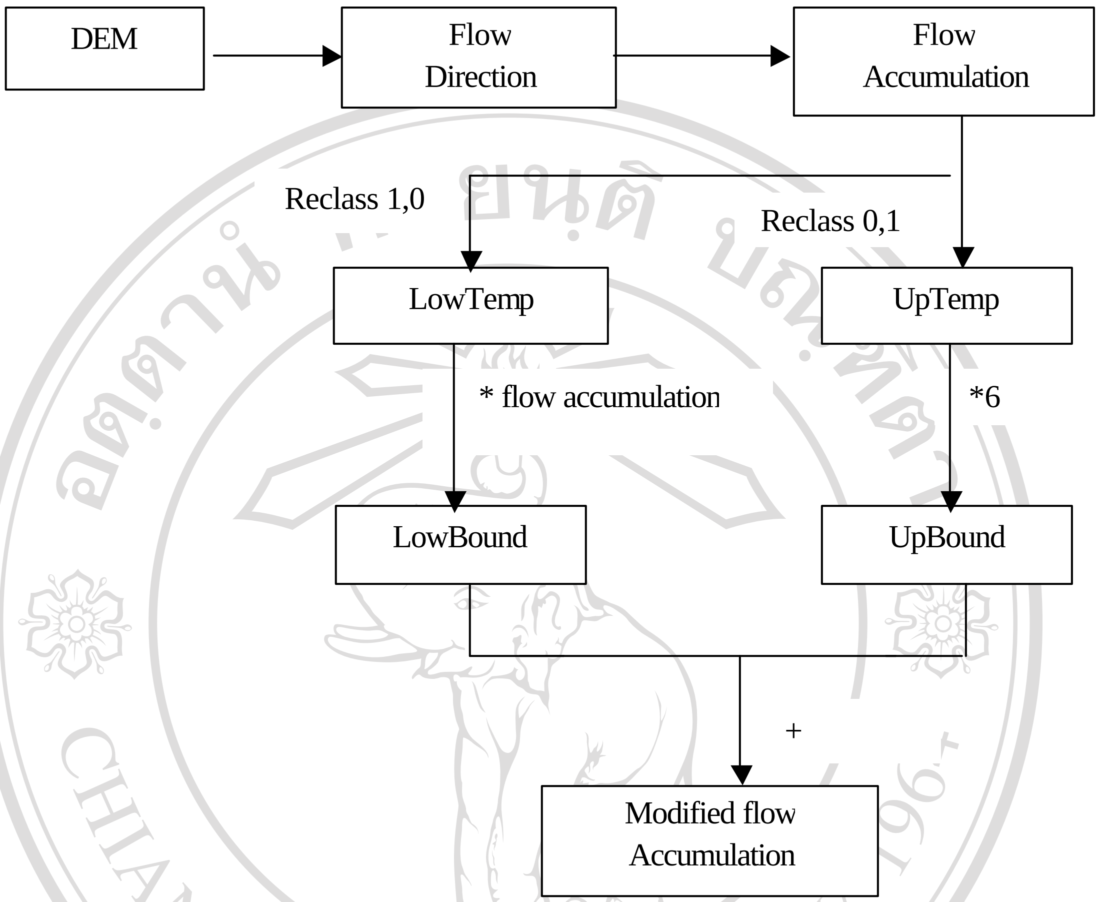

Figure 4-3 A cartographic model for estimating LS factor

According to assumption of the upper bound of 150 meter and adopted cell size of 25 meter in this study, so maximum flow accumulation was 6. This value was used to create a continuous surface of flow accumulation from 0 to 6. A continuous surface of flow accumulation was created within ARCVIEW environment. Upperbound map (UpBound) was created by reclassing flow accumulation map into 0 (flow accumulation less than or equal to 6) and 1 (flow accumulation greater than 6). And then multiplied this reclassed map (UpTemp) by 6. Lowerbound map (LowBound) was created by reclassing flow accumulation map into 1 (flow accumulation less than or equal to 6) and 0 (flow accumulation greater than 6). And then multiplied the reclassed map (LowTemp) by flow accumulation map. Finally, the modified accumulation map was created by adding UpBound with LowBound.

Cover management factor was estimated by using average annual C values of types of crop and tree (Wischmerier, 1978), and information from land use map of the study area.

The C-values for lowland and upland were calculated according to the seasonal rainfall erosivity index and its corresponding percentage of land cover crops. Average annual cover degree for crops were cited from the table of the average annual C-value (Wischmeier and Smith, 1978). The percentage of rainfall erosivity index was calculated from the 12-years annual mean rainfall in the study area with an assumption of linear relationship between annual rainfall and erosivity index. Modules of RECLASS in IDRISI32 were then used to produce the crop management factor map.

The remaining land cover classes, which were constantly assumed around year, were allocated C-values with references from previous works reviewed by Morgan (1995).

P = conservation practice factor is 1.0 because there is no conservation practices applied in this area.

4.2.2 Soil Loss Estimation for Southern Africa (SLEMSA)

The SLEMSA (Elwell, 1978) was adopted for soil erosion estimation. A cartographic model (Figure 4-4) illustrate the respective steps for estimating model variables and running model.

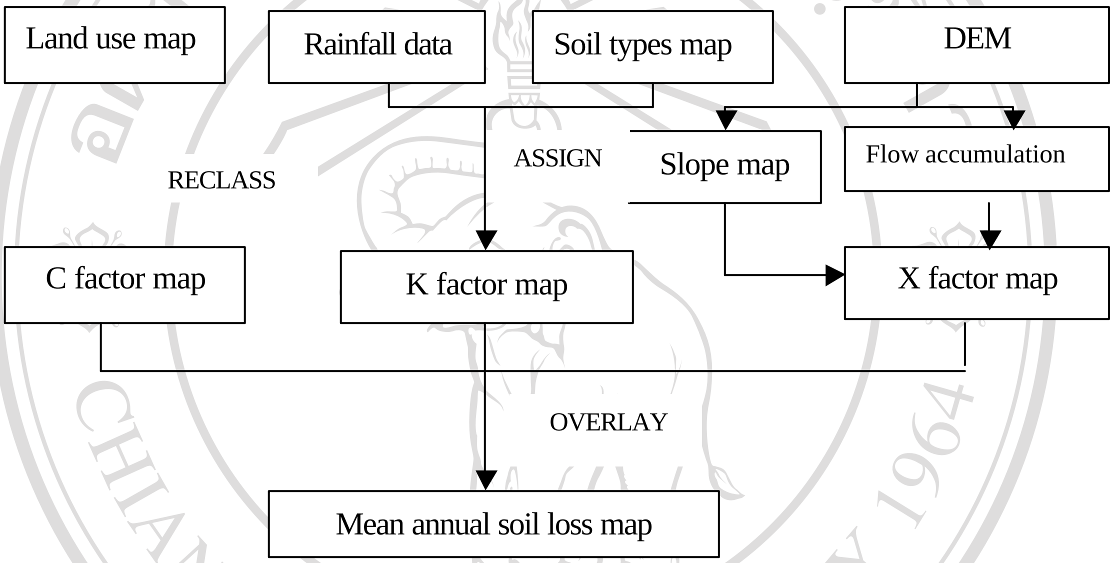

Figure 4-4 A cartographic model of SLEMSA

All equations from [4-4] to [4-11] describe the detail of calculation method for each factor including K, topographic and crop management factors. These are given as follows

$$Z = K \cdot X \cdot C \qquad [4\text{–}4]$$

Where

Z = mean annual soil loss (ton ha^{-1} $year^{-1}$)

K = mean annual soil loss (ton ha^{-1} $year^{-1}$) from a standard field plot, value is determined by relating mean annual soil loss to mean annual rainfall energy using exponential relationship

X = topographic factor (dimensionless)

C = crop management factor (dimensionless)

K factor was estimated by relating mean annual soil loss to mean annual rainfall energy using the exponential relationship (Equation 4-5) as follows

$$\ln K = b \ln E + a \qquad [4\text{–}5]$$

Where

$$a = 2.884 - 8.2109\,F \qquad [4\text{–}6]$$

$$b = 0.4681 + 0.7663\,F \qquad [4\text{–}7]$$

F = 4 for light soil texture (sand, loamy sand loam)

F = 5 for medium soil (sandy clay loam, clay loam and sandy clay)

F = 6 for heavy soil texture (clay and heavy clay)

$$E = 9.28\,P - 8{,}838 \text{ (Morgan, 1974)} \qquad [4\text{–}8]$$

E = mean annual rainfall energy (J m^{-2})

P = mean annual precipitation (mm)

Topographic factor adjusts the value of soil loss calculated for the standard condition to that for the actual condition of slope steepness and slope length. This factor was calculated using the following equation.

$$X = L^{0.5}\,(0.76 + 0.53\,S + 0.076\,S^{2})/25.65 \qquad [4\text{-}9]$$

Where

L = slope length (m)

S = slope (percent)

Crop management factor adjusts soil loss from the standard bare soil condition to that from a cropped field. This value is dependent on percentage of rainfall energy intercepted by crop i. This factor was estimated using equation [4-10] and [4-11].

$$C = e^{-0.06i} \qquad [4\text{–}10]$$

If i is greater than 50% cover (dense pasture and mulches) and

$$C = (2.3 - 0.01\ i) / 30 \qquad [4\ \text{–}11]$$

If i is less than 50% cover (crops and natural grasslands).

The value i for a year was seasonally calculated using data of percentage crop cover according to seasons and percentage rainfall for that period. In this study, measurement of cover degree for crops have not been yet done, so average percentage cover of crops obtained from references (Elwell, 1978) was used for estimation. Seasonal values of i were ultimately weighted to get i value for a year.

4.2.3 Morgan, Morgan and Finney Model (MMF)

Morgan and Finney (1984) developed this method to predict annual soil loss from field-sized area on the hill slopes. A cartographic model (Figure 4-5) is presented as follows

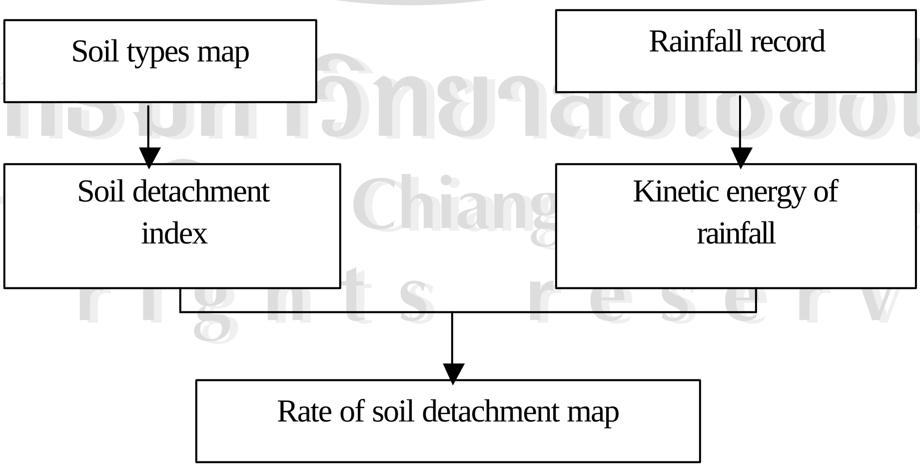

Figure 4-5 A cartographic model of Morgan, Morgan and Finney model

This model was widely practiced to estimate both splash detachment rate and transport capacity of overland follow. In this study, only rate of soil detachment is estimated, which is given as the following equation.

$$F = K \,.\, (E \,.\, e^{-aA})^{b} \,.\, 10^{-3} \qquad [4-12]$$

Where

F = rate of soil detachment by rainfall impact (kg m^{-2})

K = soil detachment index, K = 0.02 for clay soil; K = 0.4 for clay loam; K = 0.3 for sandy loam soil; K = 0.2 for fine sand soil and K = 0.7 for sand soil.

E = kinetic energy of rainfall (J m^{-2})

E = R (11.9 + 8.7 $\log_{10}$ I), R = annual rainfall (mm), I= typical value for rain intensity of erosive (mm h^{-1}).

a = 0.05

A = percentage of rainfall distributing to permanent interception and stem flow (Morgan and Finney, 1982

b = 1.0

4.3 Model comparison

The comparisons were carried out at three sites where soil loss observations were done. The size of experimental plots at site 1, 2, and 3 were 180 square meters under maize and peanut and slopes were 18, 12 and 22 percent, respectively. Soil texture at all three sites is mostly sandy loam. Soil depth are 0.47, 0.58 and 0.35 meter and the bulk density are 1.25, 1.31 and 1.23 ton m^{-3} respectively (Upland Management Project, Department of Agriculture and Rural Development, 2000).

The comparison was done using experimental soil loss data converted into annual soil loss (ton ha^{-1} $year^{-1}$). Each final map of spatial distribution of annual soil loss estimated by USLE, SLEMSA and MMF models were used to locate and pick up data for each site comparison. The slope, soil texture and land use maps were used to define the target area. Fifteen sample sites with similar physical characteristics to site 1, site 2 and site 3 were selected from each soil loss map for comparison.

Then, the Root Mean Square Error (RMSE) (Jamieson *et al*, 1998) was used to calculate the error between measured and estimated soil loss values. The equation is given as

$$RMSE = \frac{1}{n}\sum_{i=1}^{n}(X_i - Y_i)^2 \qquad [4\text{-}13]$$

Where

RMSE = Root Mean Square Error

X_i = measured soil loss values

Y_i = estimated soil loss values

n = number of soil loss values including in the calculation

4.4 Estimation of extra production cost

The soil erosion largely reduces the soil nutrient and subsequent crop productivity.

The extra production cost of soil erosion was estimated on the basis of replacement cost of NPK losses. Quantity of Nitrogen (N), Phosphorus (P) and Potassium (K) required for maintaining the same soil fertility prior to erosion was calculated according to Soil Mapping Unit (SMU) using NPK content in that SMU with an assumption of uniform amount in the entire area of each SMU.

The content of NPK in each SMU was resulted from soil analysis that surveyed between 1995 and 2000 in the study area. A grid pattern was used to represent the entire field in the soil sampling. The soil samples were taken from every grid pattern. The soil samples were collected from locations in each grid patterns with a topsoil depth of 15-20 cm. The sampling patterns represented the sources of variability according to slope, major soil type and cropping patterns. Moreover, the crop yield map and topographic map were used to provide auxiliary information in determining the best sampling pattern (Upland Management Project, Bac Kan Department of Agriculture and rural Development, 2000)

The calculated losses of NPK were then converted to their equivalent amount of most common fertilizers applied for those crops. They were finally converted to corresponding costs in Vnd or US \$ ha $^{-1}$ year $^{-1}$ for each SMU with reference to recent market price of these fertilizers (Figure 4-6).

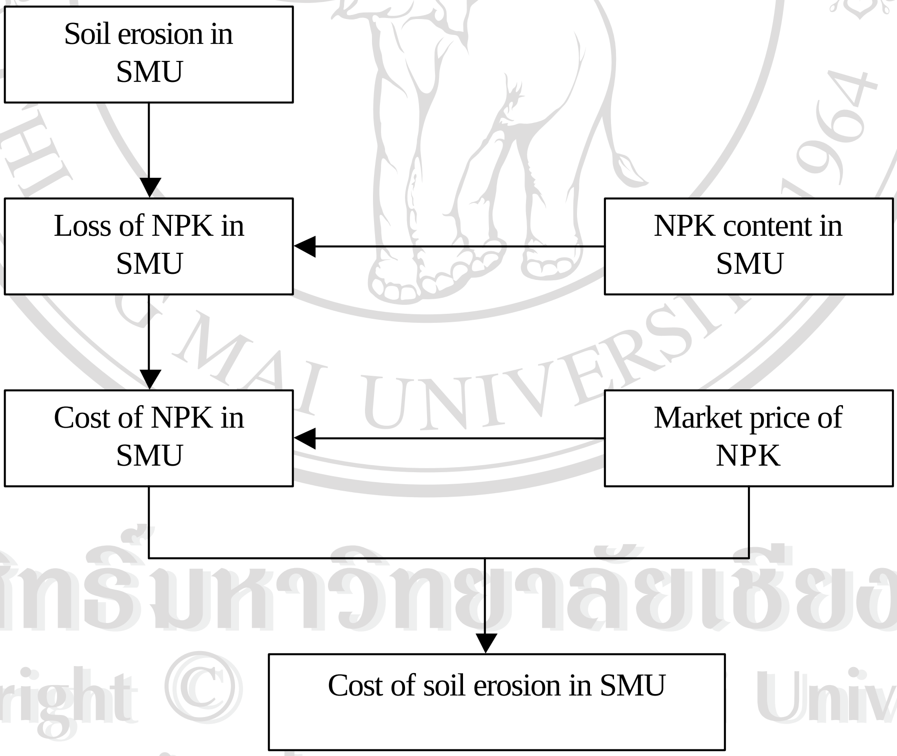

Figure 4-6 Steps in the estimation of cost of NPK in soil mapping units