# Application of Artificial Neural Network and Decision Tree in A GIS-based Predictive Soil Mapping for Landslide Vulnerability Study

## A Case Study of Hoi Num Rin Sub-watershed, Thailand

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by

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# Abstract

Considering the increasing of land degradation problems caused by deforestion and mismanagement in sloping areas (mountains and hilly surfaces), studies in these problem are quite vita. In these areas, landslide and erorion are very common and fortunately received attention from the planners' side. This means that the demand for high resolution soil mapping is more and more growing, in particular for the landuse planning purpose. The objective of this study focuses on applying the methods for digital soil mapping in inaccessible areas, that is, the land degradation-prone areas. The idea is to look into some the available methods, and/or developing one, which can be used to predictively map the soils. Artificial Neural Network (ANN) and Decision Tree (DT) were employed to comply with the objectives of the study. Geopedologic approach was applied as from the first stage, that is the image interpretation, through the fieldwork (during the phase of data collection). After the geoform map was produced, training areas could be selected, wherein the application of Jenny equation and SCORPAN models could be executed. The major tasks in this exercise are parametrization of the soil forming factors and their integration. A digital soil mapping was done in the study area, Hoi Num Rin sub-watershed, covering an area of about 20 $km^2$. The ANN is based on feedforward-backpropagation learning algorithm determined with one hidden layer. The decision tree is based on the expert system concept. Both methos were applied to integrate the parametrized soil forming factors. The description of soil predictors to train the ANN and to formulate the decision trees: 4 organism types, 7 relief type units, 9 lithological units, 3 time series , 4 landscape units and 8 landform units were extracted from the map and databases. The results: soil mapping derived from ANN, 10 soil classe names showed training error (MSE) below 0.003, 98% training accuracy and 39 mins learning time. The soil map resulted from using decision tree took much more time; more than 2 days: to learn soil and its environments over the the landscape and landform variable and to formalise and generalise 10 statements (formulas). Soil physical property maps used in ANN to predict 32 soil data from sample areas to unsampled areas. For the validation of soil classes with observed data, the results show very high accuracy in Order and Suborder levels, high accuracy in Greatgroup and Subgroup levels and more than 90% matching when compared with decision-tree-derived map. For the validation of soil properties map, there are good accuracy of soil bulk density, shear strength and plasticity index maps; 69, 60 and 70%, respectively. For the relation of soil and landslide, landslide occurred in middle and foot slope complex (facets), and lithological type which plays an important role in landslide in shale, phyllite and andisite-derived materials. Landslides occurred in areas with Typic Paleudalfs, Typic Paleudults and Typic Hapludalfs. While soil shear strength and plasticity index show the good correlation, but no correlation in bulk density. In summary, the geopedological approach is quite valuable to obtain special soil information in inaccessible areas. ANN as well as DT can help to

produce a very high resolution map. The difference, however, is that ANN is faster, thus more recommendable in term of time and cost saving.

**Keyword**: geopedologic approach, predictive soil map, digital soil map, artificial neural network, decision tree, ANN, DT, landslide.

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# Chapter 1: Introduction

## 1.1 General background

Due to ever increasing growth of the world population, land for human habitat and agricultural activities is scarce. As a result, people are moving from the flat areas to the sloping or mountainous areas. This leads to many environmental problems including soil erosion, landslides ……etc. To address these problems, there is a growing need for soil mapping, as soil data is required in land degradation studies. In many countries, including Thailand, most of the available soil maps only cover flat areas. The soil information for the inaccessible areas such as the hilly and mountainous areas either lack or are very general. The traditional soil mapping is said to be expensive, highly subjective, not easily retrievable, and usually with low accuracy and precision (Shi et al., 2004). This means that there is a need for an efficient and inexpensive method of soil mapping. Some problems that are encountered in soil mapping are: the lack of skilled and enthusiastic soil surveyors, the shortage of labour for fieldwork, and the financial shortage.

Soil mapping was done in Thailand more than 60 years ago by Land Development Department (LDD), Ministry of Agriculture & Cooperatives, and Bangkok. These maps are mainly for valley bottoms and other level areas for the agricultural purposes and, to a certain extent, for research purposes, hence some routine soil properties were collected. Only particular areas which belong to the project, such as agricultural and research pilot areas were surveyed in more detailed level, and for specific purpose. However, LDD still believes that the soil map of Thailand can also be used for other purposes, such as engineering planning, infrastructure planning, hazard zonation map, etc. Thailand lies in tropical and sub-tropical zone, which means that climate and vegetation, as soil forming factors, play the dominant role in soil formation. In recent studies, and for larger scale mapping, LDD staff applies soil forming factors, such as climate, topography, biological factors and time in soil survey and classification; following the USDA Soil Survey Manual and Soil Taxonomy.

Soil survey is the process of carrying out soil mapping in an area, including soil description from field observation and examination, classification and verification. Soil classification is the process of putting soils in classes, after having done the soil description in the field ; soil properties are used following the requirements reflected in the classification system (e.g., USDA, or WRB…etc,) to the series level.

GIS and Remote sensing techniques can be useful in the preparation for soil survey. There are some new techniques/ methods (as consequence of the advancements in technology) in soil mapping. Here, it must be added that even the flat areas' soil maps that are available for the whole country are outdated too (considering the changes in the classification system). However, sloping areas (irregular, rugged topography), which were forested by the time soil surveyors mapped soils, are not mapped; no soil information is available. Now, when many mountainous areas are deforested and converted to agricultural land; cause of land degradation, the lack of soil information is felt and has become a serious issue as without soil data no land degradation assessment and/or land use planning can be done.

To prepare the soil map of the study area, which is located in a mountainous area, in the conventional way can be very costly and would take a long time. Considering the objective, concentrated on land degradation/landslide studies beneficial to landuse planning, the required soil properties can be selected and mapped. These maps will be useful for the landuse planning, hazard assessment, and other environmental studies. On the other hand, less budget, labour and, to a certain extent, specialists in soil survey are needed. The methodology (see Chapter 4) could be based on Artificail Neural Nnetwork (ANN) in GIS environment, the output of which being a predictive soil map.

In the context of a growing demand of high-resolution and high accuracy spatial soil information for environmental planning and modelling, fast and accurate prediction methods are needed to provide high-quality digital soil maps (Behrens et al., 2005). So, our intention (in this thesis) is to develop a methodology, which can be suitable to predict, with a reasonably accepted high-quality, soils of the study area. We also strive for efficiency and cost-attractiveness; less time to produce and not so laborious.

## 1.2 Research objective

**General:**

To develop a GIS-based method for soil mapping in inaccessible and landslide prone area .

**Specific:**

1. To produce a geopedologic map applying "decision tree method"
2. To produce a geopedologic and soil attribute maps applying Artificial Neural Network (ANN)
3. To assess the use of decision tree and ANN for soil mapping.
4. To map the landslide prone areas and prepare a map where vulnerable areas to landslide are shown

## 1.3 Research Questions

1. Which soil forming factors play dominant role, and are essential for predictive soil mapping?
2. Which soil properties (data) are needed in landslide study?
3. What is geopedologic approach and how should it be used in predictive (digital) soil mapping?
4. To what extent soils (3-D) can be predicted using ANN, fed by the data obtained from the study of selected training areas?
5. To what extent soils can be predicted using environmental attributes at neighboring sites.

## 1.4 Hypothesis

1. Geopedologic approach is useful to predict soils of unobserved areas.
2. Soil forming factors are important in mapping soil classes and soil properties.
3. Use of GIS and RS techniques in classifying and mapping soils in sloping areas lead to higher accuracy, to time-saving, and speeds up the soil survey.
4. Soil physics (knowledge) is important to landslide study.

# Chapter 2: Literature review

Soil information is very important to land degradation and hazard studies. Particularly, land slide is the big problem in the mountainous and sloping areas, often inaccessible and not surveyed. Northern Thailand is for a great part mountainous and inaccessible. Geopedologic approach has been used to come to the soil map required (Hansakdi, 1998; Udomsri, 2006). The approach is based on understanding the landscape, selection and studying the training areas and/or transects, and on extrapolating the obtained soil information from sample areas to the unsampled parts. Udomsri (2006) applied geopedologic approach to map soils in the sloping areas for soil erosion assessment. Soil forming factors of Jenny (1941) is the supporting theory, which help the procedure (of soil survey and mapping) functioning. Predictive soil mapping is not something new at ITC. What is new is the use of computer and the facilities that the computer software programmes, all GIS-based, offer (Farshad et al., 2005a).

## 2.1 Acquisition of soil data

### 2.1.1 Soil survey data of Thailand

Soil map has been produced in 1935 by R.L. Penlton, the advisor in agricultural and soil technology. He formed the team with Sarot Motrakun. They promoted and supported the study of soil science in Thailand. Many of the soil-oriented disciplines including soil survey were initiated studied in that year. As in many other countries, soil survey in Thailand benefited from several other disciplines, such as soil science, geology, geography, geomorphology, vegetation and climatology. Soil survey procedure includes 4 phases, namely stratification (of landscape), soil description (field observation, soil analysis in laboratory), soil classification and soil survey interpretation (Farshad et al., 2005b). Soil maps were produced applying the modified methods mainly on the basis of the instructed techniques by USDA’s Soil Survey Manual and Soil Taxonomy (Changpri, 1992).

Soil maps have been produced covering the whole country of Thailand only in the areas with slopes less than 35%, at scale 1:100,000 and continue to produce at a scale 1:25,000, still based on the USDA soil classification . Treesuwan (2001) reports that the remaining area is which has no soil map, as 33% in sloping and mountainous area.

Recently LDD is committed to produce soil map at scale 1:4000 for particular projects, such as soil erosion, land slide assessment and other studies where detailed soil map is needed. The need of GIS, Remote sensing and the other newly developed tools and software program can be of quite importance for such a detailed soil survey, especially for mapping inaccessible areas. As Liengsakul et al. (1993)

used GIS for preparation of terrain mapping unit (TMU) map which integrate data from exiting map and satellite image interpretation. This map was produced at scale 1:250,000, including slope, elevation, particle size distribution, soil drainage, soil reaction, soil classification at great group level, and soil depth as a phase. Udomsri (2006) who used decision tree (expert system) to help predictive soil mapping in Ang Khang station, in Chiang Mai is a good example for the Thai surveyors to use, while improving it. Udomsri applied geopedologic approach (Zinck, 1988/89) and terrain analysis (Hengl et al., 2003) to come to soil mapping units.

### 2.1.2 Geopedologic approach to soil survey

Geopedology is a concept or theory approach, which defined and applied the component of soil and its environment, such as, climate, geology, geomorphology, hydrology, vegetation and pedology. It can be considered as science and art of modeling (Farshad et al., 2005b).
The geopedologic approach to soil survey is based on fully understand the landscape genesis and includes:

1. Image interpretation (air photo's and landsat data): The study area is subdivided into workable and meaningful units,
2. Sample areas are selected and studied with the required accuracy, depending on the publication scale, and
3. Extrapolating the soil information (content of each mapping unit, based on the smallest unit- landform) obtained from studying samples.

Hengl and Rossiter (2003) applied geopedological approach to map soils in an area in Croatia. Aerial photo interpretation was used to delineate landforms and also made of DTM to map terrain parameters. Arcak et al. (2002) applied geopedology approach to study and estimate mass movement hazard zones in an area in Turkey. They used the soil information such as slope, geology, land cover and soil properties regardless of mass movement features and types. They concluded that geopedology was useful and provided what they needed for the study of mass movement.

Farshad et al. (2005b) and (Aiman et al., 2004) applied geopedological approach to map soil salinity, in the Northeast of Thailand. They found that geopedology plays an important role in mapping salt-affected soils. The relationship of ground water rising, capillary movement and its height in different soil units (different textures structure, and porosity) have to be modeled in order to predict the salt movement. The geopedological map and an appropriate interpolation technique can be used to map soil salinity in both discrete and continuous models.
Udomsri (2006) applied geopedological approach to characterize the geoform map as one of the layers he needed for digital soil mapping. Here below (Table 2.1) illustrates how categorical the geopedologic legend of a geoform map is (Zinck, 1988/89)

**Table 2. 1: Different categories used in the Geopedologic approach**

| Level | Category | Generic concept | Short description |
|---|---|---|---|
| 6 | Order | Geostructure | Large continental portion characterized by a broad geologic structure (e.g. cordillera, geosyncline, shield.) |
| 5 | Suborder | Morpho genetic environment | Broad type of biophysical medium and controlled by a style of internal external geodynamics (e.g. structural, depositional, erosional, etc.) |
| 4 | Group | Landscape | Large portion of land characterized by a repetition of similar relief types or an association of dissimilar relief types (e.g. valley, plateau, mountain, etc.) |
| 3 | Subgroup | Relief/molding | Relief as determined by a given combination of topography and geologic structure (e.g. cuesta, horst, etc.) Molding as determined by specific morphoclimatic conditions or morphogenetic processes (e.g. glacis, terrace, delta, etc.) |
| 2 | Family | Lithology /facies | Petrographic nature of hard rocks (e.g. periglacial, lacustrine, alluvial, etc.) |
| 1 | Subfamily | Landform | Conspicuous basic geoform type, characterized by a unique combination of geometry, dynamics and history. |

### 2.1.3 Predictive soil mapping

There are several terms in use, sometimes interchangeably. Soil maps are produced applying different methodologies, although all in the context of soil forming factors and the derived processes. Here, the argument that soil maps and their legends are representations of structured knowledge is made and discussed with some examples while an epistemology of soil survey is outlined. The relationship between the mental modelling (often done by soil surveyors), a soil map legend, and a soil map is formally represented. An analogy between knowledge engineers and soil scientists is made to understand how artificial intelligence, logic, and its formalisms can be used in soil survey. Some frameworks for presenting soil surveyors' mental models explicitly are suggested to improve soil survey reporting in the 21st century.

A soil map is a map showing distribution of and/or soil properties in the area. Soil survey is a kind of 'knowledge system' as defined in knowledge engineering (Bui, 2004). Soil mapping is a cognitive process that requires manipulation of symbols and logic. Soil maps as multi-purpose models of spatial soil distribution have a much higher level of aggregation (map units) than the models of soil processes and land-use effects that need input from soil maps (McBratney and Odeh, 1997). Predictive soil mapping or digital Soil Mapping is the computer-assisted production of digital maps of soil type and soil properties. It typically implies use of mathematical and statistical models that combine information from soil observations with information contained in correlated environmental variables and remote sensing images (McBratney et al., 2003). Also, it can be defined as the development of a numerical or statistical model of the relationship among environmental variables and soil properties, which is then applied to a geographic data base to create a predictive map (Sculla et al., 2003).

Recently, GIS and remote sensing are widely used for the digital soil mapping and it can be applied in different ways using different methods and techniques (Farshad et. al., 2005b). There are several methods that were applied in predictive soil mapping. Some examples are; (Burrough et al., 1992) used fuzzy classification compared with conventional Boolean methods to determine land suitability from (1) multivariate point observations of soil attributes, (2) topographically controlled site drainage conditions, and (3) minimum contiguous areas. McBratney and Odeh (1997) applied fuzzy systems, including fuzzy set theory and fuzzy logic for numerical classification of soil and mapping, land evaluation, modelling and simulation of soil physical processes. Zhu and Band (www.solimserver.geography.wise.edu) applied fuzzy logic to the data integration process to accommodate the spatially continuous nature of geographic phenomena. The study presents knowledge-based approach, used an expert system methodology for integrating empirical knowledge with other environmental data for the derivation of information about a given spatial phenomena, for soil inference example. (Zhu, 1997) developed a fuzzy logic based model (called a similarity model) to represent soil spatial information so that soil landscape is perceived as a continuum in both the parameter space and the geographic space. The collection of these similarity values forms an n-element vector called a soil similarity vector. Thereafter, Zhu et al (1997) used SoLIM (Soil Land Inference Model) and applied a fuzzy inference scheme for estimating and representing the spatial distribution of soil types in a landscape.

De Gruijter et al. (1997) developed multi-purpose continuous soil model of soil processes and land-use effects, using statistics. The combination of continuous classification and compositional kriging convincingly bridged the gap between aggregation levels, and with the aid of the pixel mixture technique the resulting soil distribution model could also be visualized at the appropriate level of aggregation. Ziadat (2005) used multiple linear regression models within small watershed subdivisions enabled the prediction of soil depth, surface cover type, erosion type, erosion class, and soil texture. Accurate information about soil attributes, presented in a spatially continuous form, is prerequisite for many land resources management applications.

The artificial neural network approach have been used in soil survey and mapping, such as Zhu (2000) developed a neural network approach to populate a soil similarity model that was designed to represent soil landscape as spatial continua for hydroecological modelling at watersheds of meso-scale size. The approach also included a Geographic Information System procedure for selecting representative training and testing samples and a process of determining the network internal structure. Behrens et al.(2005) studies on the development of a methodology based on artificial neural networks (ANN) was able to spatially predict soil units and describe the occurrence of soil unit and train ANN output, based on feed-forward ANN with the resilient back-propagation learning algorithm.

The other method such as decision tree and Baysain, Bin et al. (2004) applied two approaches for automated building of knowledge bases of soil resources mapping. He used decision tree and Bayesian predictive modelling, respectively to generate knowledge from training data. With these methods, building a knowledge base for automated soil mapping is easier than using the conventional knowledge acquisition approach. The knowledge bases built by these two methods were used for soil type classification of the study area and using TM bi-temporal imageries and GIS data. Udomsri (2006) applied Jenny equation and decision tree (expert system) to predict soil map in GIS environment for soil mapping in slopping area, and its application to erosion hazard.

### 2.1.4 Soil classification and soil physical properties for landslide condition factors in study area

Several factors play vital role in landslide phenomena. From the concept of geotechnique engineering which is widely used to study landslide and many other proposes. This technique includes studying and investigating soil and bedrock (engineering properties) for landslide, earthquake, etc,. Wikipedia (http://en.wikipedia.org/wiki/Geotechnical_engineering). In this study we will focus on soil discipline and soil classification and few of the soil physical properties which are important landslide conditioning factors. Soils are classified with respect to their respective or specific characteristics and properties. The establish of soil classification importance to landslides occurrence, this study will consider in soil sub group, soil texture, cohesion, plasticity and bulk density which are explained that follow:

### A) Soil classification to the level of Sub Groups

According to the classification system used by Soil Survey Staff (2006), three classification levels (order, suborder and great group) precede subgroup. They are focused on categorizing soils based on major features or geological and environmental processes. They noted that the subgroup classification seeks to recognize distinctive soil features across different soils within a given soil great group. The discussion, the subgroup name includes the great group name, modified by one or more descriptive adjectives. These descriptive adjectives fall into three general categories termed Typic, intergrade, and extragrade. A Typic subgroup soil lacks any significant properties that would suggest it is in a transition phase between related great groups or some other soil taxonomic level. Intergraded subgroup soils are those that belong to one soil great group but share various soil properties common to another recognized great group, suborder, or order. Some of soil properties, which can be extracted from soil classification such as soil depth, approximate clay content, etc,.

**B) Soil physical properties: bulk density, shear strength and plasticity properties**

The soil properties are considered in this study, not only the properties for soil classification but the other soil properties about shear strength and swell-shrink potential also are considered for landslide study. Most commonly of soil properties that will be dealt with in this study are: soil bulk density, shear strength and plasticity properties will be collected for predictive soil mapping.

Soil Survey Staff (2006) defined the term Soil texture to designate the proportionate distribution of the sand, silt and clay mineral particles in a soil. They have discussed that these mineral particles vary in size from those easily seen with the unaided eye to those below the range of a high-powered microscope. According to their size, these mineral particles are grouped into "separates."

The soil plasticity index is the numerical difference between its liquid limit and its plastic limit. The liquid limit and plastic limit are both expressed as percent moisture content (Department of Transportation Engineering Service Centre, www.dot.ca.gov).

Soil strength is the capacity of a soil to withstand forces without experiencing failure, whether by rupture fragmentation or flow (Heffernan et al., www.usyd.edu.au). Consideration of the strength of a soil is very important, especially for landslide study.

## 2.2 A few methods for predictive soil mapping

### 2.2.1 Soil forming factors

Soil is developed by several factors, mainly biophysical, but partly social-oriented. Some methods follow the concept of soil forming factors in its environment, such as

**Jenny (equation) Method:**

Jenny (1941) attempted and summarized the knowledge of soil processes that form soil (soil formation) and defined the famous equation of soil forming factor which intended as a mechanistic model for soil development, they are:

$$S=f(cl, o, p, r, t)$$

This equation gives way to understand the soil formation; where *cl* is the represents climate, *o* is the organisms including humans, *p* is the parent material, *r* is the relief or terrain, and *t* is the time of soil development.

SCORPAN Model:

MacBratney et al. (2003) modified Jenney equation to SCORPAN model. This is the formulation approach that explains and describes the relationships between soil and other spatially referenced factors. The soil forming factors that are referred to in SCORPAN are:

$S_{(c,\,a)*} = f(S,C,O,R,P,A,N,)$

S: soil, other properties of the soil at the points;

C: climate, climatic properties of the environment at a point;

O: organism, vegetation or fauna or human activity;

R: topography, landscape attributes;

P: parent material, lithology;

A: age, the time factor;

N: space, spatial position.

* c is soil class and a is soil attribute

### 2.2.2 Artificial Neural networks

Artificial Neural Network is an interconnected group of artificial neuron that uses a mathematical or computational model for information processing based on a "connectionist approach" to computation. Several types of "neural network" are distinguished, such as prediction, classification, data association, data conceptualization and data filtering. In this study we will focus on prediction type. Back propagation is a supervised learning technique used for training artificial neural networks; present a training sample to the neural network and compare the network's input to the desired output from that sample (Wikipedia, www.en.wikipedia.org/wiki/Artificial_neural_network). McBratney et al. (2003) used neural networks to build a mathematical model that supposedly works in an analogous way to the human brain. Artificial Neural Networks (ANN) which are simple mathematical models are inspired from the brain's certain information-processing characteristics including the parallel processing, the ability to learn and generalize, disregard data errors and produce meaningful solutions, which fall beyond the reach of conventional digital computers. Neural Networks are now widely used in the soil science literature, mainly for predicting soil attributes (Nouri et al., 2004). The application of neural networks as "Pedotransfer Functions" for predicting soil hydraulic properties is the most common (McBratney et al., 2003). He defined artificial neural network as the tool for this study. It is the mathematical model of a neural network consisting of a set of simple functions linked together by weights. Neural networks have a system of many elements or 'neurons' interconnected by communication channels or 'connectors' which usually carry numeric data, encoded by a variety of means and organized into layers.

The artificial neural network approach has been used for many purposes. The application of ANN can be found in several studies, such as Skidmore (1997) applied neural network to classify the forest mapping in New South Wales, Australia. Vaiphasa (2001) applied neural network to map salt marsh vegetation. Minasny and McBratney (2002), and Chang and Islam (2000) used ANN models based on physical linkages among space-time distribution of brightness temperature to predicting soil hydraulic properties, soil texture and soil media properties. Kohonen (1982) used Neural Networks to predict the probability of soil classes using multi-logit transformation application of the output. Another type of network is called self-organizing maps. Zhu (2000) applied and developed a neural network approach to predict the probability of soil classes from soil environment factors. He applied a soil similarity model that was designed to represent soil landscape as spatial continua for hydroecological modelling. Fidencio et al. (2001) applied two types of neural networks were applied: a counter propagation neural network (CP-ANN) and a radial basis function network (RBFN) to classify soil samples from different geographical regions. The result of the paper describes how artificial neural networks can be used to classify multivariate data. (Zhu and Band, www.solimserver.geography.wisc.edu).

### 2.2.3 Decision tree (expert system) for predictive soil map

Decision tree is a non-parametric method for analyzing hierarchical relationships. It can identify and express nonlinear and non-additive relationships in a simple form. The idea is to recursively subdivide the training set of examples into homogeneous groups, using “discriminating variables”. The variable selection criterion is based on the entropy measure from information theory (Bin et al., 2004). Decision tree analysis is the original of artificial intelligence research. The aim of this approach is to produce a system, which can identify and recognize similar patterns in the future (Quinlan, 1986) cite by Udomsri (2006).

The advantages of “decision trees analysis” are listed by Moore et al. (1991) as follows:

1. It is easier to interpret when explanatory variables are both nominal and continuous.
2. It is invariant to monotone re-expressions (transformations) of predictor variables.
3. It deals more satisfactorily with missing data values and outliers.
4. It is more adapt at capturing no additive and nonlinear behaviours.
5. It doesn’t make any assumptions about data distributions and
6. It is easily updateable as more data are collected.

Lieng et. al. (online) applied decision tree classification to make a land cover map by using use forest stand map, land inventory map and point observations from numerous sources as reference data. They found that the differences in scale, legend, elapsed time since updating and ambiguities from subjective interpretation can make two maps of the same area almost incomparable.

## 2.3 Landslide

A landslide is a geological phenomenon which includes a wide range of ground movement, such as rock falls, deep failure of slopes and shallow debris flows (Wikipedia, http://en.wikipedia.org/wiki/Landslide). Landslide is a gravitational downward and out word movement of soil masses. Landslides develop in unstratified, homogenous soils or are induced by certain types of stratification, e.g., interposed layers of sand or clay. Other causes are excessive load pressure at the head of slope or undercutting at the foot (Hilbert, 1981). Factor maps, that were considered relevant for the assessment of landslide susceptibility, were also collected, such as lithology, structural geology, surficial materials, slope classes, land use, distance from streams, roads and houses. The weight of evidence method was used to generate statistically derived weights for all classes of the factor maps. The analysis indicated that the use of detailed geomorphological information in the bivariate statistical analysis raised the overall accuracy of the final susceptibility map considerably (Van Westen et al., 2001). Landslide or mass wasting is the movement of the soil, rock and other material by the gravity (Kusky, 2002). The combination factors can lead to landslide event, such as rainfall, geological, morphological, landuse changing, slope etc. Veder (1979) defined the factor that may caused the landslide in to 5 types; geological cause, morphological cause, physical cause, physical structure changes of silt and clay soils and action of water in soil. The materials are very important in the type of landslide. Dikau et al. (1996) classified landslide in 2 main types are rotational and translational and they defined the detail of material of landslide into many types, showing in the table below;

**Table 2. 2: Landslide types**

| Type | Rock | Debris | Soils |
|---|---|---|---|
| Fall | Rock fall | Debris flow | Soil fall |
| Topple | Rock topple | Debris topple | Soil topple |
| Slide (rotational) | Single (slum)<br>Multiple<br>successive | Single<br>Multiple<br>Successive | single<br>multiple<br>successive |
| Slide (translational)<br>Non- rotational | Block slide | Block slide | Slab slide |
| Planar | Rockslide | Debris slide | Mudslide |
| Lateral Spreading | Rock spreading | Debris spread | Soil (debris) spreading |
| Flow | Rock flow | Debris flow | Soil flow |
| Complex (with run out or change of behavior downslope, note that nearly all forms develop complex behavior) | e.g. rock avalanche | e.g. flow slide | e.g. slum earth flow |

: Dikau et al. (1996)

Mostly, landslides occur in the sloping areas; hilly and mountainous. The slope insatiability, caused by several factors, could be considered as the main cause of landslide. Steep area is very week for the effect of gravity. The type of mass movement that Ladd (1935), cited by Moira (1984), the classification of the landslide in terms of mass movement, is:

1. Flow: Mud flow consisting of clay material and mud flow in volcanic ash.
2. Slope readjustment in the following material:
    - soil accumulations originating in situ
    - Talus accumulations.
    - Beds of clay.
    - Sand accumulations.
    - Heterogonous glacial debris.
    - Unconsolidated volcanic products.
    - Aggregates of shattered serpentine, or similar group of serpentine materials.
    - Artificial fills mad of earth material other than boulders and gravel.
3. Undermined strata with horizontal element in movement:
    - Collapse with slide characteristics from squeeze out of either under lying wet clay beds or rounded sand beds.
    - Collapse with side characteristics due to breaking down of underlying weak, poorly consolidated strata, or such areas in igneous rock masses
    - Collapse with slide characteristics due to burning of underlying lignite beds.
4. Structure slides. Movement on and because of:

- Bedding planes
- Joint planes
- Fault planes
- Schistose planes

5. Clay ejection from ancient clay-filled caves opened by cuts

The movement is related with the slope degree. Slope instability assessment is considered in landslide factor and it's very important factor. Crozier (1984) classified slope stability to 6 classes:

1. Slope with active landslide
2. Slope frequently subject to new or renewed landslide activity
3. Slope in frequently subject to new or renewed landslide activity
4. Slope with evidence of previous landslide activity but which have not undergone movement in the proceed 100 years.
5. Slopes with show no evidence or previous landslide activity but which are considered likely to develop landslide in the future
6. Slope which shows no evidence of previous landslide activity.

### 2.3.1 Method for landslide assessment

Several methods are available for landslide assessment, such as the quantitative predictive model is the one method can be used in landslide assessment based on spatial database in digital, which consisting many layer and represent casual factor to generate the landslides. These are listed below. Van Westen (1993) classified the landslide hazard analysis into 4 types:

A. Distribution analysis
B. Qualitative analysis
C. Statistical analysis
D. Deterministic analysis and
E. Landslide frequency analysis

Two types of statistical analysis are Bi-variety analysis and Multi-variate analysis, which are used to prepare the parameters of landslide assessment.

2.1 The Bi-variate method is a simple method, using overlay parameter maps and calculations of landslide densities, each parameter, or specific combinations parameter map can be analyzed individually (Suzen, 2002). This method applies GIS procedure, Van Westen (1993) uses the procedure as follows:

1. Classification the parameter map number
2. Using combination; overlay the specific parameter maps with landslide map.
3. Calculation of weighting values; using cross table.

4. Assignment of weighting value to the parameter maps and classification of the hazard type.

In the method, the landslide distribution map is used the combination of landslide distribution map and weighting values based on landslide densities, and it can be applied several statistical method to calculate the weight of value in term of landslide susceptibility method (Van Westen, 1993) and weight of evidence modelling method.

2.2. Multi-variate method: it is very important to indicate the temporary factors that control the landslide event, to contribute to the factors controlling the degree of hazard within land unit map. (Van Westen, 1993). This method is the interactions between factors and landslide distribution, and defines individual weight factors on landslide event (Komac, www.library.witpress.com). The following GIS procedures are used in multivariate statistics method:

1. The procedure to determine and analysis the list of factors. Create the matrix map by overlaying the parameter maps with the land-unit map.
2. Combination; by overlay land unit map with the landslide map and class the map to two group as stable and unstable units.
3. Export of the matrix to a statistical package for subsequent analysis.
4. Importation of the results per land-unit into the GIS and recoding of the land units. The frequency distribution of stable and unstable classified units is checked to see whether the two groups are separated correctly.
5. Classification of the map into a hazard classes.

### 2.3.2 The GIS and RS techniques for landslide study

The data requirement, considering the procedure of this study, multiple regression and discriminate analysis, are a type of multi-variate analysis, consisting of other statistic method; such as logistic regression or analysis of the parameter maps prior to bivariate analysis by factor analysis (Komac, www.library.witpress.com).

#### 2.3.2.1 GIS approach for landslide study

Several studies applied GIS and Remote Sensing for landslide study. GIS technique includes the tools for collecting, storing, retrieving at will, transforming, and displaying spatial data from the real world for particular set of purposes. GIS-based approach can be used for generate geological map, landuse map, soil map, and slope map. They can be used for landslide zonation. Landslide susceptibility is a fraction of the degree of slope insatiability and other causative factors which can trigger mass movement. Several methods were used for landslide susceptibility mapping, as Manoj and Elmar (2005) applied bivariate statistical analysis in predictive map of landslide susceptibility. This map represents various factors, such as slope, aspect, relative relief, lithology, buffer zones along thrusts, faults and lineaments, drainage density and land cover. Other researcher like Van Westen et al. (www.intranet.itc.nl/papers/2003) applied the weights of evidence method to generate statistically derived weights for all classes of the factor maps. Geomorphogical information, landslide map and slope map were used for the analysis and generation of indicators. Bivariate statistical analysis was used in the final susceptibility map considerably. The limitation of GIS approach is considered to be the price of the GIS software which is very expensive. GIS software needs the specialist and the special training, and due to the changing of the GIS soft ware effected to the price. Saro Lee et al. (2006) developed technique, artificial neural network method for landslide susceptibility. Landslide locations were identified from interpretation of satellite images and field survey data, and a spatial database of the topography, soil, forest, and land use and used with an artificial neural network to analyze landslide susceptibility. Landslide susceptibility indices were calculated using the back-propagation weights, and susceptibility maps were constructed from Geographic Information System (GIS) data for the five cases. He found that artificial neural network can be an effective tool for analyzing landslide susceptibility.

#### 2.3.2.2 RS approach for landslide study

Remote sensing (RS)-based approach is very useful to predict landslide occurrence affecting the earth's surface. RS data include aerial photography, optical and RADAR images, (Brennan, http://geosun.sjsu.edu/pa). . This data can be used to extract landslide information, such as landslide morphology, type of movement and landslide morpho-dynamics, vegetation (land cover) and landuse changes, which can be used for monitoring and mapping landslides (Komac, www.library.witpress.com). Masahiro (2004) used an airborne laser scanner to identify shallow landslides occurrences. Singh (2003) used SAR intherferometry technique for landslide susceptibility assessment. He used InSARS DEM to generate other factor maps such as slope, aspect, relief and slope and the input maps have been used for generation of two susceptibility maps. The limitation of the information of RS data approach; DTM data is low spectral resolution. High-resolution image data is very expensive, and difficult to apply to use in Less Developed countries (LDC). Disadvantages of the result of landslide hazard map are depended on the experience and skill of interpreter. Vohora and Donoghue (http://intranet.itc.nl/papers/2003/peer_jrnl/vanwesten_geo.pdf) used IKONOS high resolution multispectral data apply in landslide mapping. It can be predicted landslide prone terrain in large area of natural terrain and means to investigate specific causative factor. This approach can be used to correlate landslides to areas of disturbed vegetation.

# Chapter 3: Description of the study area

## 3.1 Geographic location

The study area is located 60 kilometres northeast of Chiang Mai (25 km from Mae Ka Chan district, Chaing Rai province), on Tanaosri Mountain, Hoi Num Rin, which lies between 99$^{o}$ 02' and 99$^{o}$ 07' East longitudes, and between 19$^{o}$ 25' and 19$^{o}$ 27' North latitudes, with an altitude varying between 700 and 1,720 meters above sea level. Annual rainfall is about 1,973 mm/year, and average annual temperature is 24$^{o}$ C. Humidity is about 77.5 %. Hoi Num Rin is almost cool all the year round. The weather allows the growth of temperate plants. The pleasant temperature attracts thousands of visitors each year especially during the cool winters. Land use in the past was shifting cultivation-based, which is now prohibited. Because of strict government policy, dense forests exist in some areas while it is degraded elsewhere.

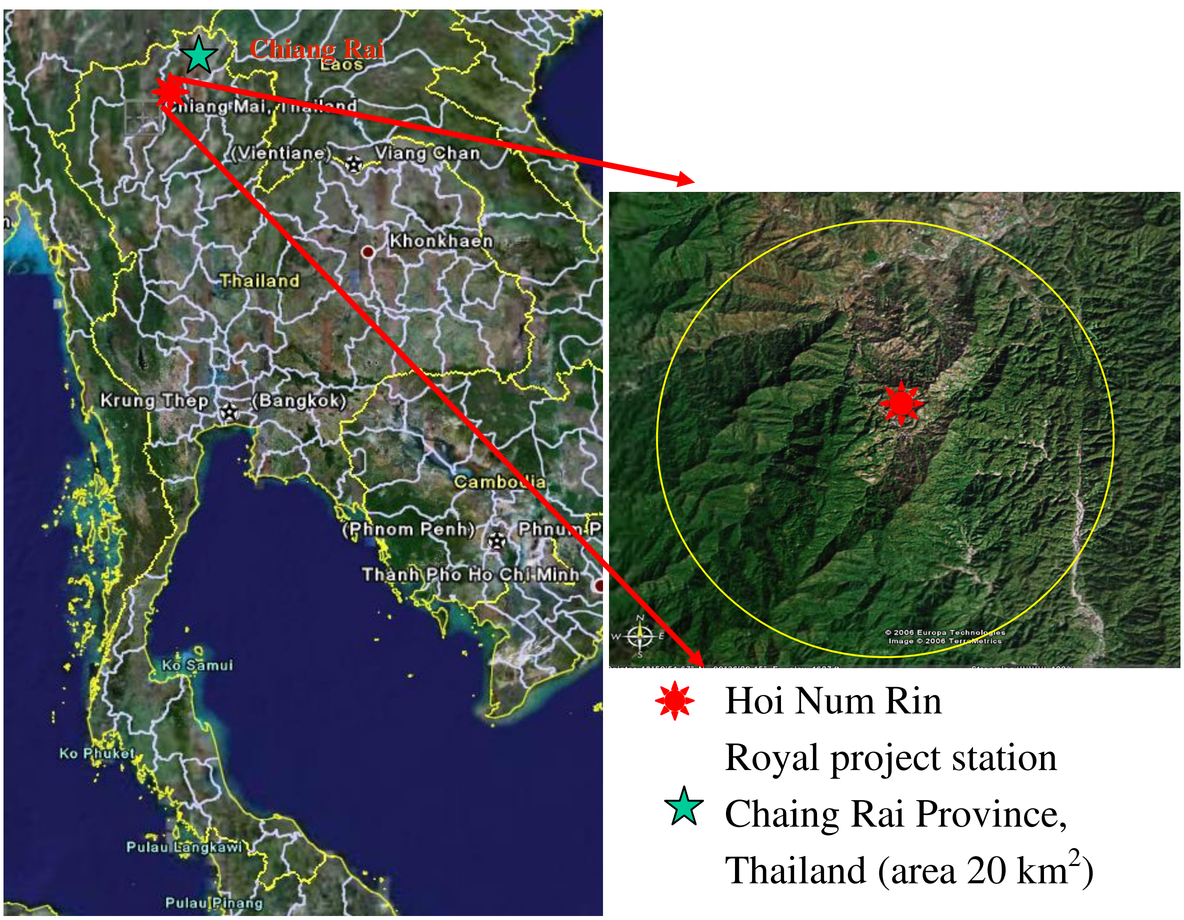
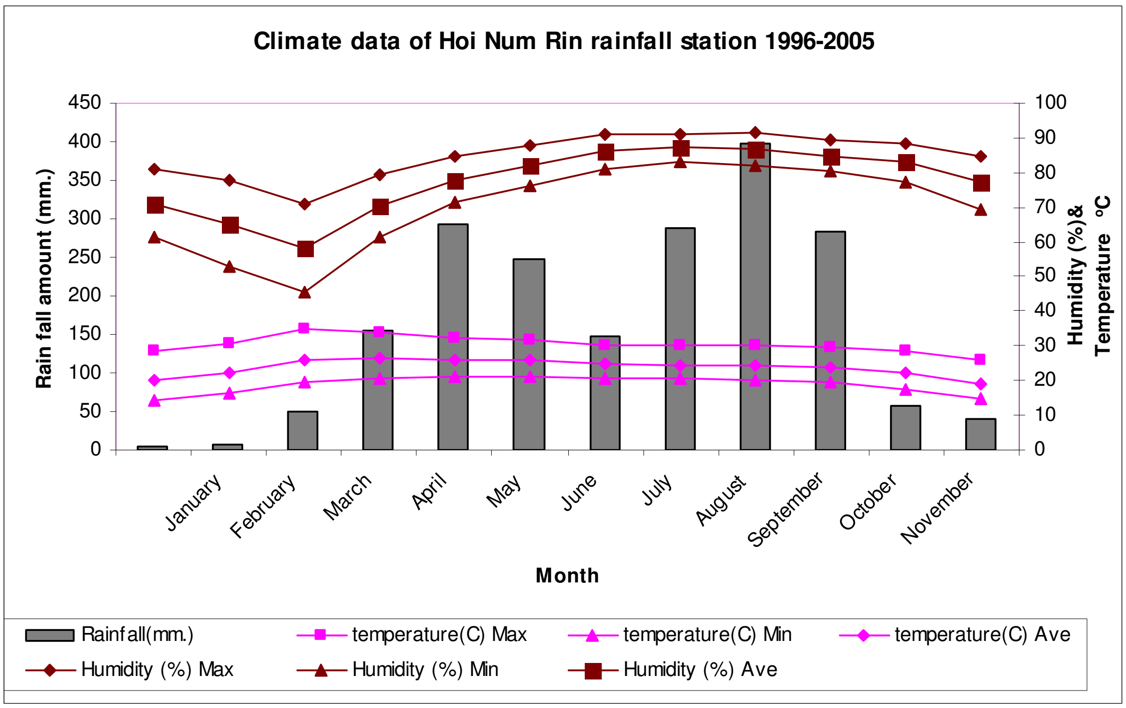



**Figure 3. 1: The study area; Hoi Num Rin Royal station, Chaing Rai province.**

## 3.2 Climate

Climate data was collected from meteorological station of Hoi Num Rin station royal project located at elevation 1,120 meters above sea level. The data collected include daily rainfall, temperature and humidity for the period of 1996-2005. The area can be classified as Tropical Savanna (Aw) (Köppen) with average temperature of year averages 23.8 °C and average temperature of coldest month is under 18.8 °C and the warmest month is 30.5 °C. Three seasons are distinguished; winter, summer and rainy. The winter, cold and dry season starts at late November which lasts until late February. The summer in this area is short, starting in March and continues to April. The rainy season starts at the beginning of May and goes on until late October. During this period, the south-west monsoon and depression carries rain bearing clouds from the Indian Ocean. The average annual rainfall is about 1973 mm.

**Figure 3. 2: Climate data of the study area**




## 3.3 Geology

Geologic study in the area is carried out by the Mineral Resources Department (1976, at 1:50,000 scale, in map sheet number 4847-II. The characteristic rock types were studied and defined in 3 dominant types. The major geological formations defined as Lower Carboniferous, Post Triassic and Triassic formation. The details of geology in Hoi Num Rin has described and shown in the table 3.2 and Figure 3.2.

**Table 3. 1: Description of geological map of Hoi Num Rin Royal sub-watershad**

| Symbol | Age | Description |
|---|---|---|
| $C_1$ | Lower Carboniferous | Sandstone, orthoquartzite and graywacke, white, light gray, fine-medium grain, thin bedded interbedded with white shale and qurtz veins |
| TRgr | Triassic | Porphyritic biotite granite, white, and gray, medium-coarse grained, comprises quartz, feldspar as phenoeryst and biotite, granite, white and gray, medium-coarse grained, comprises quartz, feldspar and biotite, pegmatite; aplite and quartz veins |
| PTRv | Post Triassic | Volcanic rock: andisite and basalt |

## 3.4 Geomorphology

Topography of Hoi Num Rin sub-watershed is the part of the north-east of Tanaosri mountain. The study area subdivides into three main geomorphologic zones: mountain, hilly and valley. The most area are hilly and mountainous areas, slope ranging between 12 to75% in the. Flat to gently sloping area is confined to only a few parts of the vale and valley. The mountains can be subdivided into 3 types, characterized depending on the geological types. Firstly, mountain locates in Lower Carboniferous formation. This formation comprises several rock types such as sandstone, orthoquartzite and graywacke, white, light gray, fine-medium grain, thin bedded interbedded with white shale and quartz veins. In field we found that the dominant rock types are shale and metamorphic rock such as phyllite. The second, mountain locates in Post Triassic formation, which is the volcanic; mainly andesite and basalt. And the third, the mountain locates in Triassic formation. This formation comprises of several rock types such as porphyritic biotite granite, white, and gray, medium-coarse grained, quartz, feldspar as phenocryst and biotite, granite, white and gray, medium-coarse grained, comprises quartz, feldspar and biotite, pegmatite; aplite and quartz veins. In field porphyritic biotite granite and granite are found as dominant rocks (Mineral Resources Department, 1976). Soil Survey Division (2004) reports that the dominant rock types in the west and middle mountain is the metamorphic rock such as Phyllite. In the northern and eastern parts of the study area the dominant rock types are andesite, basalts, tuff and the metamorphic rocks of the previous rock groups. In valley fill or stream fill which is very narrow along the stream or creeks, alluvium and some colluvium material. The main geomorphologic units in study area are reported by Soil Survey Division (2004). The landscapes include:

A. Mountains, the area having the slope more than 12% and locating about 1,200 meters above mean sea level.

B. Narrow valley, the lowlying area with slope less than 12%.

## 3.5 Natural vegetation

The natural vegetation in Hoi Num Rin sub-watershed is mainly forest. Hoi Num Rin sub-watershed is located in Mae Pun Noi, Mae Pun Lhuang and Mar Lao Fung Khua reserve forest area. The area was originally covered by evergreen forest mixed with deciduous forests. According to the report of Soil Survey Division (2004), there are 2 major types of forests namely:

1. Evergreen forest, which is hill evergreen forest.
2. Deciduous forests**,** dry deciduous dipterocarps forest and mixed deciduous forest.

## 3.6 Soil (see chapter 6)

The general soil characteristic in Hoi Num Rin sub-watershed are controlled by 4 types of parent materials, three groups of which fall under group A, developed in C1. Group B is the soil developed on PTRv. Group C is the soil developed on TRv, and group D is the soils developed in the valley.

### 3.6.1 Soil climate

Soil climate includes soil moisture regime and soil temperature regime, one of the factors important to soil development. It is assumed (in the definition) that soil can support vegetation (Jangpri, 1987).

A. Soil moisture regime

Soil Moisture Regime is used for soil classification at Soil Order, Suborder, Great group and Subgroup levels. The soil moisture regimes are defined in terms of the level of ground water and in terms of the seasonal presence or absence of water held at a tension of less than 1500 kPa in the moisture control section (Soil Taxonomy, 2006). Jangpri (1987) reported the classes of soil moisture regimes for Thailand, as follows:

(1) Aquic moisture regime,

(2) Udic moisture regime and

(3) Ustic moisture regime.

According to Soil Survey Staff (2004) the soil moisture regime in Hoi Num Rin sub- watershed is Ustic.

B. Soil Temperature Regime

For the soil classification at family level, soil temperature regime is one important criterion to be considered. Soil Temperature Regimes are 6 classes as follows (Soil Survey Staff, 2006).

**Table 3. 2: Soil temperate regime**

| Average Temperature (year) | Classes of soil temperature regimes | |
|---|---|---|
| | The different of soil temperatures (Summer and Winter) ≥ 6 °C | The different of soil temperatures (Summer and Winter) ≤ 6 °C |
| < 8 | Frigid | Isofigid |
| 8 – 15 | Mesic | Isomesic |
| 15 – 22 | Thermic | Isothemic |
| > 22 | Hyoerthermic | Isohyperthermic |
| < 0 | Pergelic | - |
| 0 – 8 (shallow soil) | Cryic | Isofirgid |

In the Northern Thailand, Kunaporn (1989) had studied the correlation and regression of air temperature, soil temperature and the altitude to class the specific Soil Temperature regime on hilly and mountainous areas. He concluded that;

1. The Soil Temperature Regime in the area with elevation of less than 360 meters above mean sea level is Isohyperthermic.
2. The Soil Temperature Regime in the area with elevation between 360 to 1,045 meters above mean sea level is Hypertermic.
3. The Soil Temperature Regime in the area with elevation between 1,045 to 2,420 meters above mean sea level is Thermic
4. The Soil Temperature Regime in the area with elevation between 2,420 to 2,500 meters above mean sea level is Mesic.

For the soil temperature regime in Hoi Num Rin sub-watershed, he was classified to Hyperthermic.

### 3.6.2 Soil distribution pattern

A. Soil classification (soil in 3D- body) is the group of soil classes and soil body is studied in 3-dimention (horizontal and vertical). In this study, soil will be classed in to great group based on USDA soil taxonomy (Soil Survey Staff, 2006), therefore, several soil properties are collected and use for soil classification. Soil classification will be the name of the soil which studied in the field, resulted from integration of some of the soil properties which are used to define the soil classification name. According to Soil Survey Division (2004) soils of the study area are grouped in to 3 orders, namely Inceptisols, Mollisols and Alfisols and can be further subdivided into 3 sub-orders, 7 great groups and 12 sub-groups based on USDA Soil Taxonomy.

B. Soil attribute is the attribute which show an individual soil property, for instance, depth, texture, moisture and etc. For this study we will consider some of soil physical properties, such as soil plasticity index, soil shear strength (normally not determined in a routine soil survey) and soil particle size class.

## 3.7 Landuse

In this part, Hoi Num Rin sub-watershed was covered by forest. About 50 years ago, people moved into the area and cleared much of the sloping areas from forest for planting and building. The current landuse in study area can be described as follows:

1. Urban area, this landuse consists of hill-tribe villages, Royal Station office, hotel, temple and schools.

2. Agriculture area: this landuse consists of tropical orchard, vegetables, flowers, and field crops.

3. Forest and reforested lands: the study area consists of 4 forest types as ever green forest, Hill ever green forest, pine forest and mixed deciduous forest.

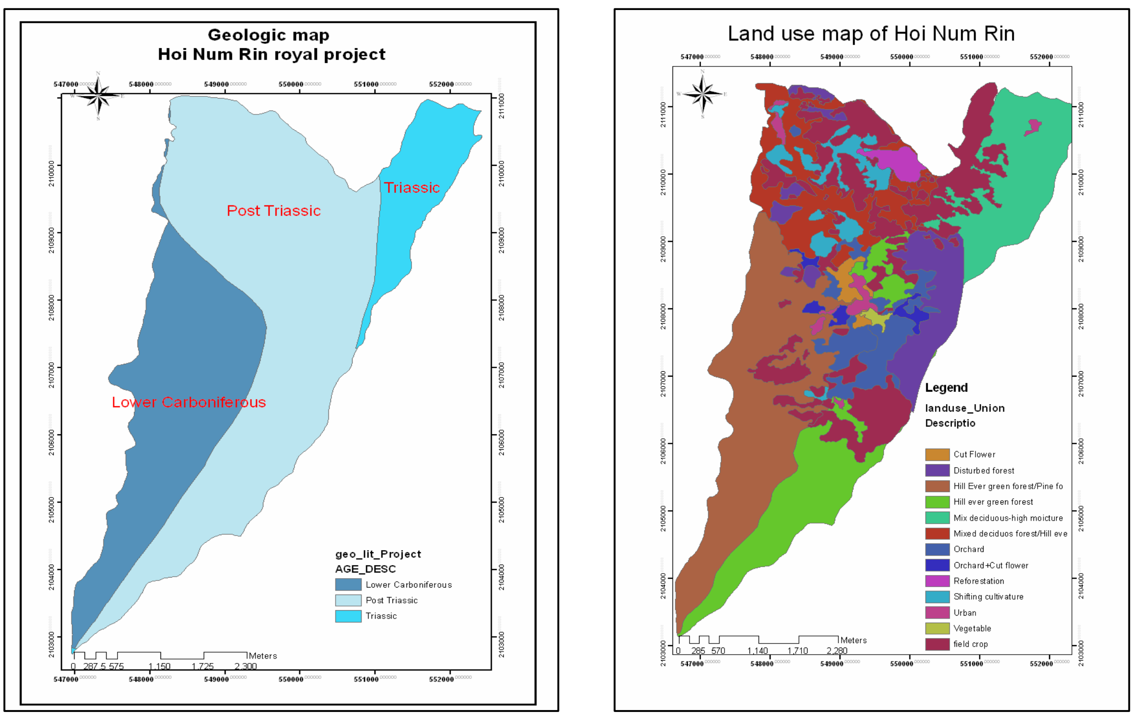



**Figure 3. 3: Geological and landuse map of Hoi Num Rin sub-watershed**

# Chapter 4: Research Methods and techniques

## 4.1 Material used

The following materials were used for this study:

### 4.1.1 Remote sensing images including aerial photographs

- Colour aerial photographs flown in 2003 with the scale of 1:25,000
- Otho-photo mosaic of the study area obtained from Land Development Department (Thailand), at a scale 1:4,000.

### 4.1.2 Map

- Topographic map sheet at scale 1:50,000 (4748-II) by Royal Thai Survey Department (200)
- Geological map at scale 1:50,000 by Mineral Resource Department (1976).
- The various maps of the study area prepared and produced by LDD (Soil Survey Division, 2004).
  - A digital contour map interval of 2.5 meters covering the whole study area
  - Drainage map
  - Road map
  - Pond map
  - Soil map with the description at scale 1:10,000
  - Landuse map covering the whole study area, was produced by LDD

### 4.1.3 Equipments

- Equipments used in the office include; mirror stereoscope and screen-stereoscope,
- Sampling equipments used in the field work include GPS receiver (Garmin etrex legend), borehole book for describing and sampling soils, auger, shear vane tester, plastic bag and other related things for soil sampling
- Equipments used in laboratory include; autenberg equipment, Cylinder for soil particle analysis, digital balance, spatula, cans, oven, etc,.

### 4.1.4 Data

- Climate data of the study area (temperate, rainfall and humidity) obtained from Hoi Num Rin Royal project station
- Laboratory data (soil physical analysis such as soil texture and soil plasticity index) obtained from Office of Agriculture Research and development Region1, Department of Agricultural.

### 4.1.5 Software

- The software's used were; Arc GIS for producing geoform map for field work and producing predictor maps for ENVI.
- Microsoft SPSS for statistic analysis.
- Microsoft Visio for flowchart preparing.

## 4.2 Methods for deriving predictive soil mapping

The methodologies used in the soil predictive processes are Artificial Neural Network (ANN) and Decision tree (expert system) based.

### 4.2.1 Artificial Neural Network (ANN)

Neural network is the main method applied in this study to carry out the predictive soil mapping. Literature review showed that this method has been widely used in many researches and also for soil mapping. Several software programs can be used to run the artificial neural network approach, but in this study ENVI 4.2 was used to carry out the prediction (predictive soil mapping).

The process of ANN consists of two phases: training phase and learning phase (Figure 4.4). The first phase, training phase, is meant to train the program on the condition in a certain feature, for example name of a class and/or soil series, etc. and soil classification. This phase comprises of the training data set, which is soil sample area and the input unit, which is the soil predictors. In this study, soil predictors are the soil forming factors (SCORPAN method) as was explained in chapter 3. This process also used the fed forward step to calculate the weight of the predictor's variable as soil forming factors in the training areas. The output of this phase represents the target variable as the desired output, i.e., the soil classification name in training area. The second phase, learning phase is the process of the calibration in the predictive area, where the same predictors are available, but not soil sampled. The network predicts the soil classification unit based learned weight. The essential algorithms for this study called feed-forward back propagation algorithm.

The neural network-back propagation algorithm comprises of feed-forward and backward steps in the network structure. The feed-forward back propagation algorithm used in this study has multi-layer as input layer, hidden layer and out put layer. The input layer is a GIS raster image, being the layer as image pixel value in linearity scales, stretching between 0.0 and 255, for input to the network. The application of neural net classification, in ENVI 4.2, was modified by Richards and Xiuping (1999) which was used in neural network processes. The essential process node can be explained about the connection between many inputs and with a single output for each single node in the neural network, *O* is the single output from the operation as:

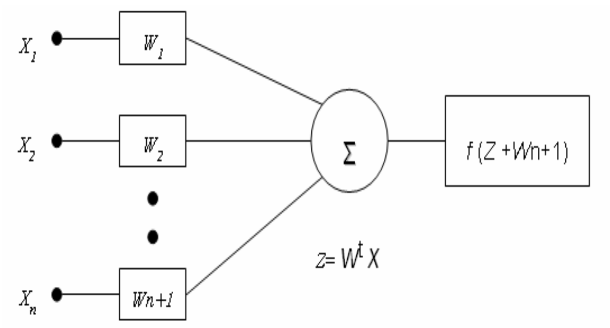



**Figure 4. 1: The representation of a processing element in which the threshold function is generalized.**

$$O = f(w^t x + \theta) \qquad (4.1)$$

Where *w* is a vector of weigh coefficient,

*x* is the vector of inputs,

$\theta$ is a threshold (sometimes set to 0)

And the multilayer percepton of neural network*,* is in the choice of the function *f,* called *the activate* function.

$$f(z) = 1/(1+e^{-z/\theta_o}) \qquad (4.2)$$

Where $z$ is $w^t x + \theta$ as seen in 4.1

*x* is the vector of inputs,

$\theta_o$ is a constant.

*e* is the exponential of base e

The training neural network-back propagation was used multilayer feed forward networks (Figure 4.2) for this study. Each unit of input layer present one organism unit ($O_1$,…, $O_n$), one relief unit ($R_1$,…,$R_n$), one parent material unit ($P_1$,…$P_n$), one time unit ($T_1$,..$T_n$), one landform unit ($L_1$,…,$L_n$), or one landscape unit ($Lc_1$,…$Lc_n$), respectively. The input layer connect to the output layer via hidden units ($H_{N1}$,…$H_{Nn}$), and it representing one soil name. The relationship between input and output layers is saved through the weights (***W***), which are adjusted during the learning process. Input units which present in the network, the symbol is I (i=1,…, n; and n = input unit ×hidden unit), hidden unit symbol is h (h=1,…,n; and n= hidden unit × output unit).

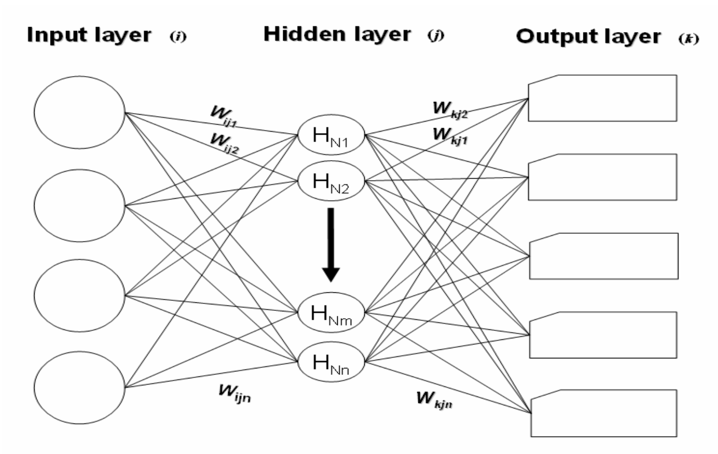



**Figure 4. 2: Exemplified topology of feed-forward Multi-layer neural network used.**

The topology consists of three layers area letters as *i*, *j* , *k* with *k* being the output layer. The set of weight linking layer links by *i*Hns in those layers *j* are represented generally by $W_{ij}$ and those linking layer *j* and *k* are represented by $W_{jk.}$ So, from the general operation at 4.1 can be used to represent all the argument output in the corresponding layer, for *j*, *i* and *k* layer is

$$O_j = f(Zj) \quad \textit{with} \quad Z_j = \sum_j W_{ij}\, O_i + \theta_j \qquad (4.3)$$

$$O_k = f(Zk) \quad \textit{with} \quad Z_k = \sum_k W_{kj}\, O_j + \theta_k \qquad (4.4)$$

The second step, backward pass through the network to calculate the output value compared with the target value (training area). The difference of the value between output and target is called *error*.

The error represents when the network was learning the process, this process generally learning by adjusting the weight in the node to minimize the difference between the output node and the desired output. Throughout the network, the aim is to reduce the error; the total by back-propagation depends on the number of iteration and over the iterations the total error is reduced by two processes of feed-forward and back-propagation (Skidmore et. al., 1997) The error in back propagation is a measure of how well a network is functioning during training. This process can be assessed the outputs (*k*). The individual error can be calculated as follows:

$$E = \tfrac{1}{2} \sum_k (t_k - O_k)^2 \qquad (4.5)$$

Where $t_k$ represents the desired or target output and

$O_k$ represents the training pixel

More detail about using neural network in ENVI 4.2 is given in Richards and Xiuping (1999).

### 4.2.2 Decision tree analysis

Decision tree approach is the supporting tool to help for predictive soil mapping (Udomsri, 2006). Sculla et al. (2005) applied decision tree analysis as a predictive soil map technique for developing a preliminary soil map to neighbouring site by samples extracted from an existing soil map. It can be composed of the spatial data and its capability to integrating a wide range of data sets. Sculla et al. (2005) used decision tree to predict soil map by integrated several materials as a predictors variable (soil forming factors) e.g. remote sensing variables, terrain variables, for the prediction processes. And also this technique could be used in soil survey to extrapolate obvious soil landscape relationships from one site to other site base soil experts.

Decision trees are powerful and popular tools for classification and prediction. It contrasts with the artificial neural network as a decision tree represents rules, which can be expressed that human can directly understand the system or even it can be worked with in a data base language, this is the attractiveness of the decision tree analysis (online, http://dms.irb.hr/tutorial/tut_dtrees.php). The decision tree rule comprises of label, condition, and action (Skidmore et al., 1996) as follows:

Label = If -------> condition

Then -------> Action

The structure or model and the possible consequence of decision tree can be explained in the form of a tree structure (figure 4.3)

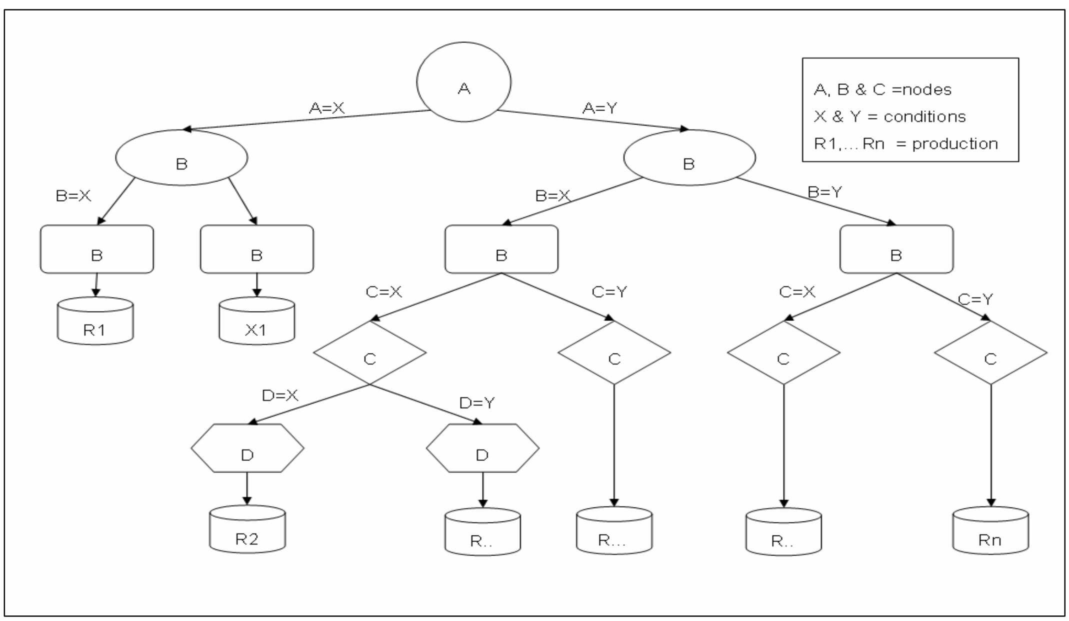



**Figure 4. 3: The exemplifier of a simple decision tree structure**

## 4.3 Study outlines

In order to follow the study objectives, the overall work was divided into three stages; pre-field work, field work and post-field work, as the work flow has shown in figure 4.4.

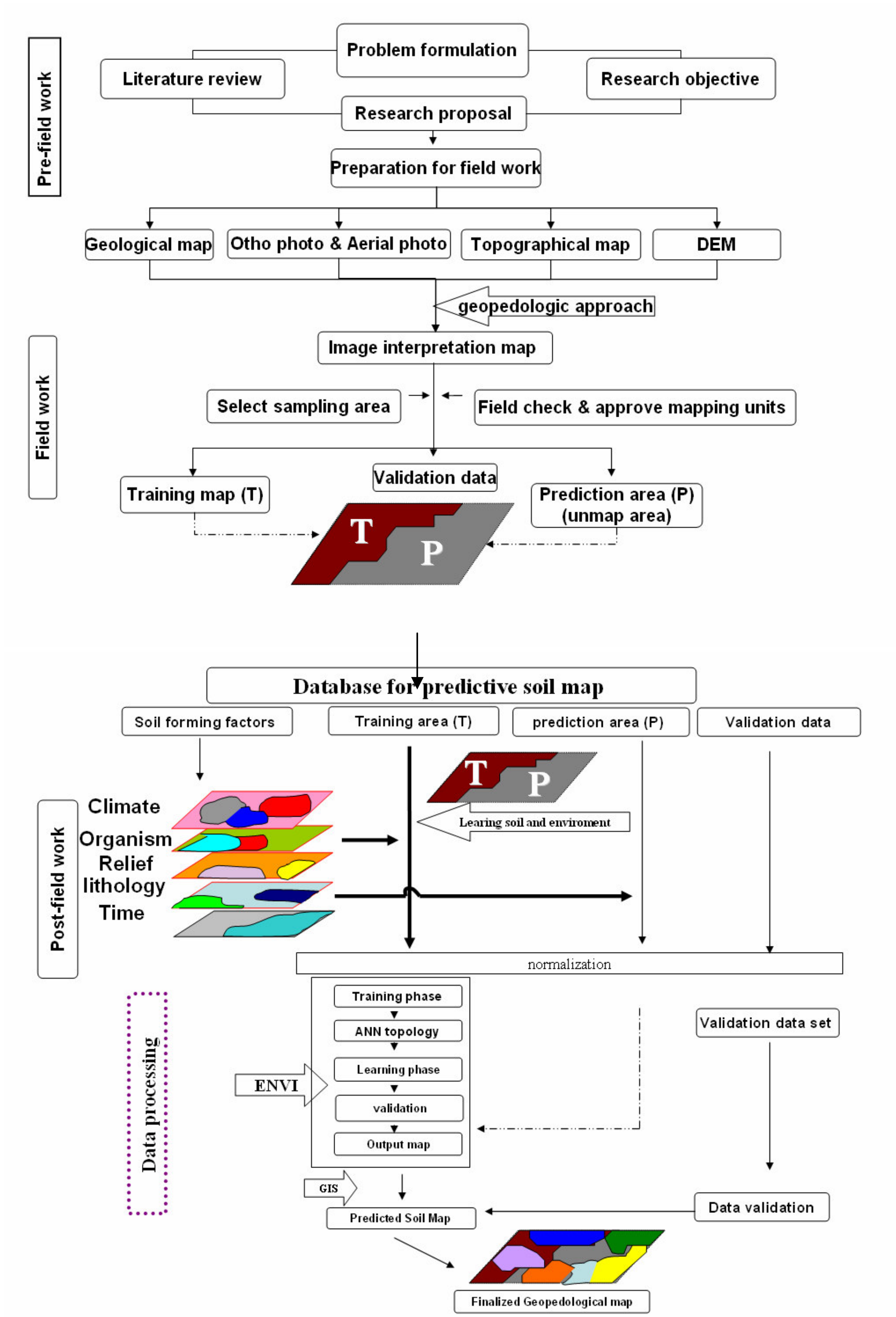



**Figure 4. 4: Methodological framework**

### 4.3.1 Pre-field work

This stage of the study was foreseen to prepare all methods, techniques and materials for fieldwork. This included method and techniques for soil data collection, to be used for soil classification, and for landslide study.

The field work materials are geological map, otho photo & aerial photo, topographical map and DEM.

Image interpretation map at scale 1:25,000(geoform map, see also chapter 5) was prepared applying the geopedologic approach. To produce this map, topographic map, otho-photo, geological map and DEM were required. For this purpose ArcGIS and Ilwis software's were used. This map was used to select the sample area and/or transect line.

A Digital Elevation Model (DEM) was produced using contour interpolation function in ArcGIS 9.1. Contour map had contour interval of 2.5 meters cover whole of the study area.

Landslide mapping was also done in this stage. DEM and contour map were used to interpret the landslide phenomena's.

### 4.3.2 Field work

The field work stage of the study involved collection of primary and secondary data. This stage took place from late August to mid September 2006. The primary data collection included soil data collection for soil classification, determining soil physical properties, landslide phenomena field check and collecting data for landuse and land cover. The secondary data included climate data (8 years return) from the Hoi Num Rin Royal station.

#### 4.3.2.1 Data collection for soil classification

Regarding image interpretation map (geoform map), landform units were used to design the soil sample area and the transection line for soil survey. Soil observation was mainly made in mini pit and some case by auguring. In the sample area in each landform unit detail study was carried out; soil profile description followed by soil classification according to the USDA soil taxonomy. All thee observations were registered, using GPS reading.

#### 4.3.2.2 Soil sampling for soil physicals analysis

Soil shear strength was determined using shear vane tester in undisturbed soil, in depths of 0, 25, 50, 75 and 100 centimetres. Or within B horizon in shallow soils (soil depth less than 50 cm). The results are used to study used to study the role of soil physical properties in landslide occurrences.

#### 4.3.2.3 Soil physical analysis

Soil samples were taken to the laboratory for soil analysis for soil physical properties analysis and in some case for soil mapping itself. The analyses for the study of landslide include soil particle class (sand, silt and clay), soil plasticity index. This property was determined using Atterburg equipment for data measurement.

#### 4.3.2.4 Checking landslide feature

In cases of the recent landslides, which could not be interpreted by imageries, DEM and contour shape were used. Then we recorded recent land slide feature by point checking. Landslide body and scarp were recorded all together with the coordinates (use of GPS).

#### 4.3.2.5 Climate data

Hoi Num Rin Royal station has the rain-gage and small metrological station built in the study area. Rain fall data, temperature and humidity were collected for the last 8 years. These data were used for soil classification and description stage in classes of soil moisture regime and soil temperature regime.

### 4.3.3 Post field work

This stage was to carry out some data gathering for geopedological mapping. After field work, several data and maps were produced and improved for the stage of predictive soil mapping.

Image interpretation (geoform map) was adjusted and improved, such as landscape, landform and relief types map. On the other hand, some of the attributes, for instance, lithology, time, and organism were generated, newly.

Soil sample map, which verified previously from the field observation using the information of sample area, was improved, firstly. Here, the soil data from mini-pit, soil profile and auguring holes description were used. The relationship between soil data and other maps, such as landscape, landform, lithology, and organism map layer was studied.

# Chapter 5: Data Processing and analysis

The data collected before and during the field work were imported to ArcGIS software, all of raster format.

## 5.1 Geoform map (Image interpretation map)

Geoform was produced applying geopedologic approach to visual image interpretation. The materials used to do the interpretation were aerial photo at scale 1:25,000, and the otho photo (available digitally) with accuracy of 1 meter. There were other data used to support the process of interpretation, such as topographic map, geological map, contour line map, some spatial data derived from DEM (see 5.2.2), road and stream maps, some of which available in digital format and some in hard copy. Arc GIS was the software used to delineate the geoform boundaries. The output map is a map with 4 landscape units, 11 relief type units, 16 lithological units and 32 landform units, shown in Table 5.1 and Figure 5.1, below.

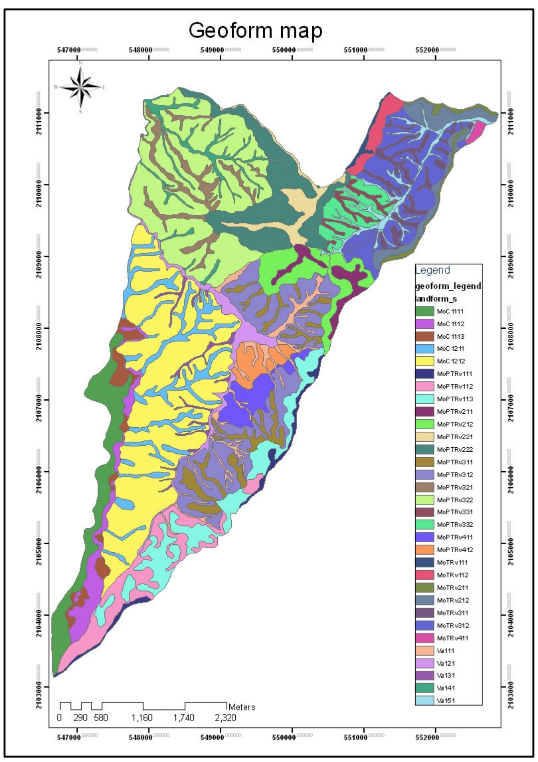



**Figure 5. 1: Geoform map of Hoi Num Rin sub-watershed**

### Table 5. 1: The geoform unit in Hoi Num Rin sub-watershed

| Landscape | Relief | lithology | landform | Symbol |
|---|---|---|---|---|
| Mountain in Carboniferous | Ridge | RS and CV from Shale and phyllite | Summit and Shoulder complex | MOC1111 |
| | | | Steep/very steep of slope com | MOC1112 |
| | | | Gentle/moderately of slope complex | MOC1113 |
| | Spur | RS and CV from Shale and phyllite | Summit and Shoulder complex | MOC1211 |
| | | | Middle and foot slope complex | MOC1212 |
| Mountain in Post Triassic volcanic rocks | High Ridge | RS and CV from Andisite | Summit and Shoulder complex | MOPTRv111 |
| | | | Steep/very steep of slope complex | MOPTRv112 |
| | | | Gentle/moderately of slope complex | MOPTRv113 |
| | Low Ridge | RS and CV from Andisite | Summit and Shoulder complex | MOPTRv211 |
| | | | Middle and foot slope complex | MOPTRv212 |
| | | RS and CV from Shale/Phyllite | Summit and Shoulder complex | MOPTRv221 |
| | | | Middle and foot slope complex | MOPTRv222 |
| | Spur | RS and CV from Andisite | Summit and Shoulder complex | MOPTRv311 |
| | | | Middle and foot slope complex | MOPTRv312 |
| | | RS and CV from Shale/Phyllite | Summit and Shoulder complex | MOPTRv321 |
| | | | Middle and foot slope complex | MOPTRv322 |
| | | RS and CV from Granite | Summit and Shoulder complex | MOPTRv331 |
| | | | Middle and foot slope complex | MOPTRv332 |
| | Glacies surface | CV from Andisite | Erosional surface | MOPTRv411 |
| | | | Accumulation surface | MOPTRv412 |
| Mountain in Triasic volcanic rocks | High Ridge | RS and CV from Shale/Phyllite | Summit and Shoulder complex | MOTRg111 |
| | | | Middle and foot slope complex | MOTRg112 |
| | Low Ridge | RS and CV from Granite | Summit and Shoulder complex | MOTRg211 |
| | | | Middle and foot slope complex | MOTRg212 |
| | Spur | RS and CV from Granite | Summit and Shoulder complex | MOTRg311 |
| | | | Middle and foot slope complex | MOTRg312 |
| | hill | RS and CV from Granite | Slope facet complex | MOTRg411 |
| Valley | Vale | Alluviocolluvium from Andisite | Bottom side complex | Va111 |
| | | Alluvium from Andisite and Shale | Bottom side complex | Va121 |
| | | Alluviocolluvium from Shale | Bottom side complex | Va131 |
| | | Alluviocolluvium from Shale and phyllite | Bottom side complex | Va141 |
| | | Alluviocolluvium from Granite | Bottom side complex | Va151 |

RS = Residuum
CV = Colluvium

## 5.2 Digital Elevation Model (DEM)

### 5.2.1 Generation and improving the DEM

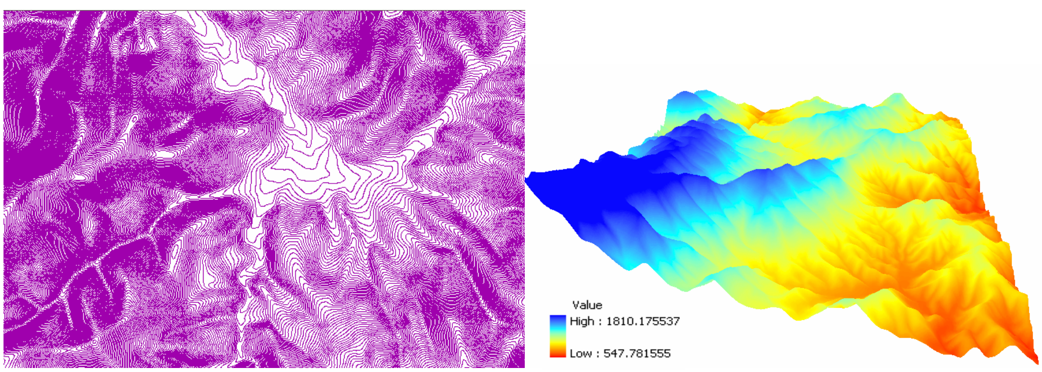
Digital Elevation Model (DEM) represents a continuous elevation values over a topographic surface by a regular array of z-values, referenced to a common datum.

Contour line is a line feature class that represents elevation contours map. The algorithm to generate DEM; the algorithm first generates a generalized morphology of the contours, thereafter implements the contours as a source of elevation information (ArcGIS 9.2 help, www.webhelp.esri.com/arcgisdesktop/9.2).

This study transforms DEM from contour line map, with contour interval of 2 meters, . ArcGIS software was used to create DEM, as follows:

1. Add contour line of Hoi Num Rin area in Arc GIS window.
2. Open ArcToolbox, select spacial analysis tool, Interpolation and Topo to Raster.

Input feature data as the contour map and give the pixel size and set default for the other properties option (ArcGIS Destop help, www.webhelp.esri.com/arcgisdesktop/9.2).

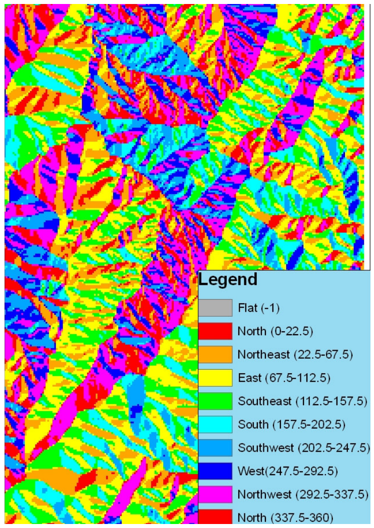


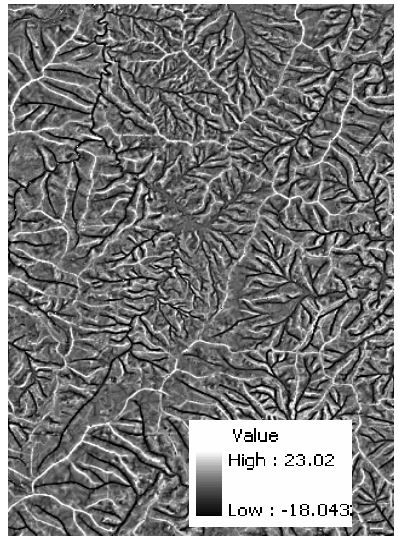

(a) (b)

**Figure 5. 2: The material for DEM interpolation (a) Contour map interval 2 meters (b) Out put DEM by using Arc GIS**

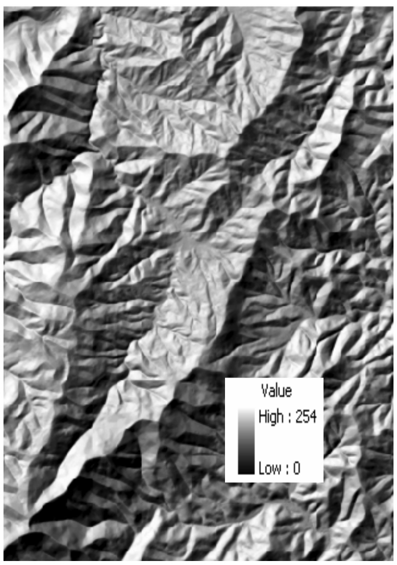
### 5.2.2 The data derived from DEM

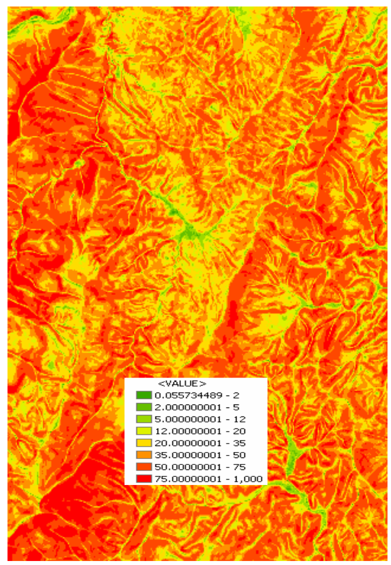
After the DEM was generated, some of the spatial data such as aspect, curvature and hill- shade were generated, this is a basic technique in digital soil mapping. These spatial data contributed to the preparation of the geoform map (see 5.1).




**(a) Aspect** **(b) Curvature**




**(c) Hill shade** **(d) Slope percentage**

**Figure 5. 3: The aspect derived from DEM**

## 5.3 Data input for geopedolgical map (predictive soil mapping)

In this stage, remembering the Jenny equation (soil forming factors), parametrization of the factors asks for data. For each of the “Clorpt” layers proper data are to be the predictors variable. The steps followed are explained hereafter:

### 5.3.1 Soil sample map

Sample area selection based on landscape, relief-type, lithology and landform map, that is, to make use of the interpretation map, where geopedologic approach is applied. Selection of the sample areas is an important step, as these are the areas where landforms are examined for their soils. Several observations are done in these areas, in order to get acquainted with the soil-landform relationships. In this study, three sample areas were selected, labled as A, B and C. Area A is located in the northern part of the study area. This area crosses two dominant types of lithologic formation symboled on the geology map as PTRv and TRv. The second area, B is located in the middle part of the study area. Here too, there are two dominant types of lithologic formation indicated on the geology map as $C_1$ and PTRv. The third area, C is located in the southern part of the study area and crosses 2 dominant types of lithologic formation on the geology map labeled as C and PTRv. Actually, these sample areas are used to get trained or to learn about the soil and environment relationship, elaborated in the SCORPAN model (McBrathney et al., 2003), a deriviation of the Jenny equation (Jenny, 1941). The idea is, however, to become able to predict soils of unsampled areas.

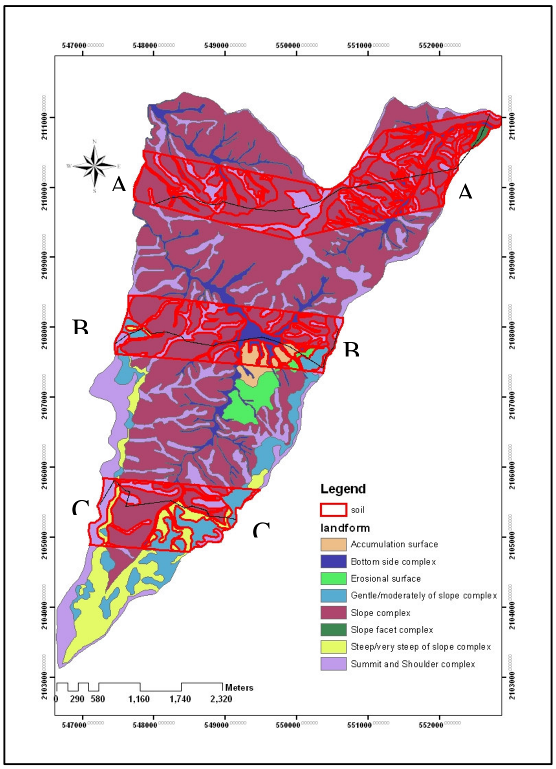



**Figure 5. 4: The sample area A, B and C cross the study area**

### 5.3.2 Climate (the first factor in the "*clorpt*" equation) map

Climate is one of the factors of soil profile development, which can be explained in terms of soil moisture regime and temperature regime, generally. Soil moisture regime used to classify the soil to suborder and soil temperature regime used to classify the soil at family level (USDA Soil taxonomy). In this study, climate data from Hoi Num Rin Royal Station were used to determine the moisture regime and temperature regime. To identify soil moisture regime, control section must be considered. Soil moisture control section is determined using particle size class of soil in certain part of the soil profile. According to the USDA soil taxonomy (Soil survey staff, 2006) the control section (for soil moisture regime) is determined (for fine-loamy, coarse-silty, fine-silty, or clayey particle-size class) at

10 to 30 cm below the soil surface; for fine-loamy, coarse-silty, fine-silty, or clayey particle-size class at 20 to 60 cm ,and for sandy soil particle-size class at 30 to 90 cm.

To identify moisture regime in the study climate data of Hoi Num Rin Royal station, average year 1996-2005 (Table 5.2) was used. To define soil moisture regime interpretation in Thailand based on climatological data and particle size class (Soil survey staff, 2006 and Treesuwan, 2002). The accumulative dry day is 85 days and the consecutive dry day is 40 days, while the cumulative wet day is 280 days and consecutive wet day is 197 days. As a result, the study area can be classified to have a udic moisture regime. Udic moisture regime was identified by Soil survey staff (2006) which is common to the soils of humid climates that have well distributed rainfall; have enough rain in summer so that the amount of stored moisture plus rainfall is approximately equal to, or exceeds, the amount of evapotranspiration; or have adequate winter rains to recharge the soils and cool, foggy summers, as in coastal areas. Water moves downward through the soils at some time in normal years. Soil moisture control section of udic moisture regime is not dry in any part for as long as 90 cumulative days in normal years. If the mean annual soil temperature is lower than 22 $^{o}$C and if the mean winter and mean summer soil temperatures at a depth of 50 cm from the soil surface differ by 6 $^{o}$C or more, the soil moisture control section, in normal years, is dry in all parts for less than 45 consecutive days in the 4 months following the summer solstice.

**Table 5. 2: Climate characteristics of Hoi Num Rin Agriculture Royal Station**

| Rainy day | Total Rain (mm) | PET | MS | Consecutive dry day | Consecutive wet day | Total surplus rain | Total effective rain | Total dry day | Total wet day |
|---|---|---|---|---|---|---|---|---|---|
| 84 | 1996-2005 | 1287 | 399 | 40 | 197 | 1255 | 282 | 85 | 280 |
| PET = potential evapotranspiration during the day<br>MS = constant number (2.3889 mm/day) | | | | | | | | | |

Other types of the moisture regime such as ustic, could not be found in this area. However, it is always difficult to tell about the dominant vegetation or forest types when the soil has been developed. Anyway, to obtain the organism map for the study area, we consider the data of the primary forest that is reported by Land Development Department and Hoi Num Rin Royal project Soil Survey Division (2004). From the report, the main forest type is the primary forest, cover 41% of the study area. The concept to identify temperature regime of Soil survey staff (2006), the control section of soil temperature is at soil depth of 50 cm from soil surface or at the upper boundary of root limiting layer in shallow soil (densic, lithic and paralithic contact). Kunaporn (1989) reported the relationship between air temperature and soil temperature in the report of "The assessment of Soil Temperature Regime Classes on Hilly and Mountains Area in Northern Thailand study" as the equation below.

$$\text{Soil Temperature} = 2.14151+0.942383\ (\text{Air temperature}) \quad (5.1)$$

### 5.3.3 Organism (the O in the "*clorpt*" equation) map

In this study organism (living matter) is related to native vegetation, the primary forest of the study area. Because vegetation is the most important soil forming factor, the best indicator of the environment wherein the soil has formed. However, it is always difficult to tell about the dominant vegetation or forest types when the soil was developed. Anyway, to obtain the organism map for the study area, we consider the data of the primary forest that is reported by Land Development Department and Hoi Num Rin Royal project Soil Survey Division (2004). The geologic types were considered to obtain the organism map, its behaviour represents in the difference, and including the field observation and the native people's interview, according to the data in 5.2.2. The flow chart represents how to generate organism map and variation of native forest as shown in Figure 5.5.

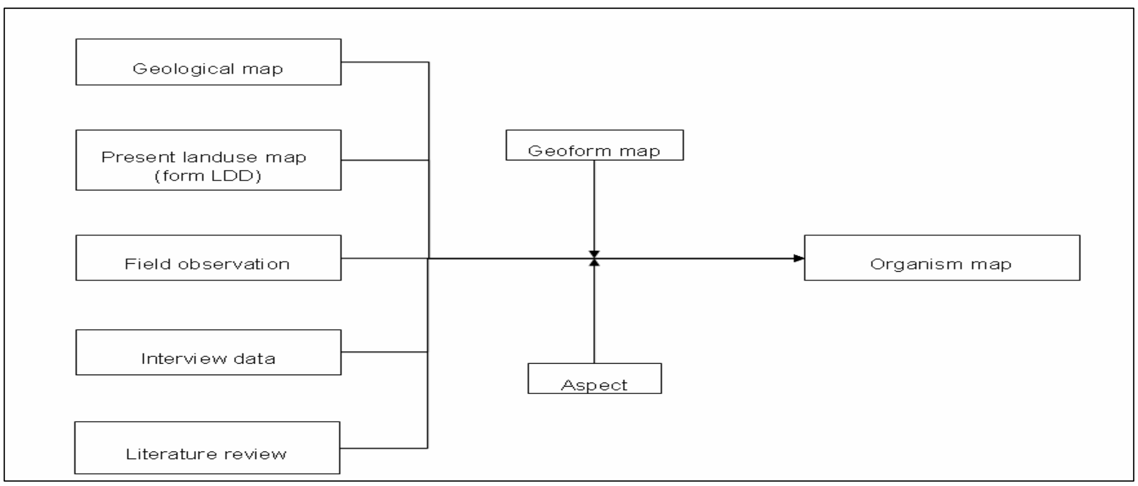



**Figure 5. 5: Flow chart to generate organism map**

**Table 5. 3: Organism of Hoi Num Rin**

| Organism | Area | |
|---|---|---|
| | Hectares | Percent |
| Hill evergreen forest | 641 | 30 |
| Hill evergreen forest mix with Pine forest | 621 | 30 |
| Mix deciduous forest-high moisture | 344 | 16 |
| Mix deciduous forest mix with Hill evergreen forest | 498 | 24 |

### 5.3.4 Relief-type (the R of the "*clorpt*") map

Relief represents earth surface and the position where the soils occur, the combination of topographic system and geological structure (Zinck, 1988/1989). It actually explains about the details of topography in terms of the process, system and characteristics. The aerial photo and othophoto were used to interpret the criteria and integrate with the other data such as slope percentage map. In this study, most of the area locates in the high and very high positions in the mountains. Therefore relief unit can be explained and interpreted as in the figure below.

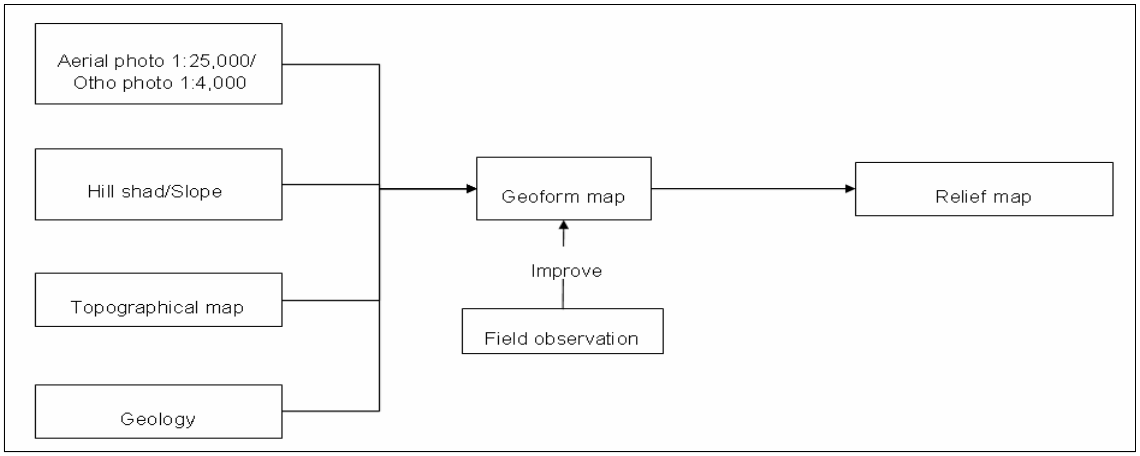



**Figure 5. 6: Flow chart to generate relief type map**

**Table 5. 4: Relief type of Hoi Num Rin**

| Relief | Area | |
|---|---|---|
| | Hectares | Percent |
| Glacies surface | 64 | 3 |
| High ridge | 217 | 10 |
| Hill | 4 | 1 |
| Low ridge | 300 | 14 |
| Ridges in C1 | 162 | 8 |
| Spur | 1194 | 56 |
| Vale | 164 | 8 |

### 5.3.5 Lithological (parent material; the P in the "*clorpt*") map

Geological map, aerial photo, othophoto, the slope aspect and field observation data were used to create lithological map. The boundaries or polygons were based on geoform map. The step to create lithological map is explained in the figure 5.7.

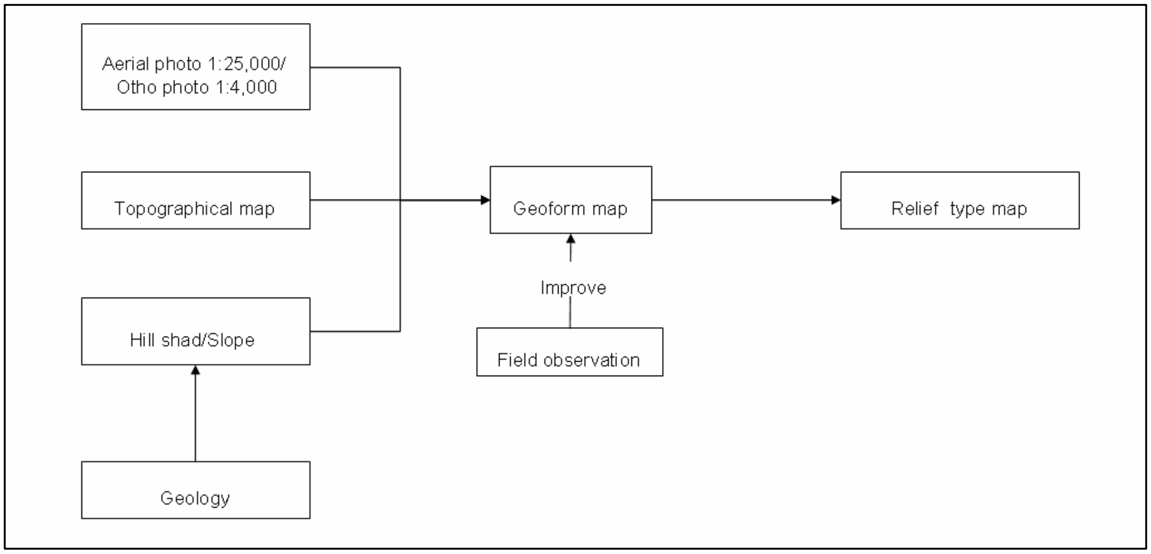



**Figure 5. 7: Flow chart to generate lithological map**

**Table 5. 5: Lithology of Hoi Num Rin**

| Lithology | Area | |
|---|---|---|
| | Hectares | Percent |
| Alluvio-colluvium from andisite | 39 | 2 |
| Alluvio-colluvium from granite | 35 | 2 |
| Alluvio-colluvium from shale | 15 | 1 |
| Alluvio-colluvium from shale and phyllite | 36 | 2 |
| Alluvio-colluvium from andisite and shale | 39 | 2 |
| Colluviums from andisite | 64 | 3 |
| Residuum and colluviums from andisite | 505 | 24 |
| Residuum and colluviums from granite | 265 | 12 |
| Residuum and colluviums from shale | 607 | 28 |
| Residuum and colluviums from shale and phylite | 500 | 24 |

### 5.3.5 Time (soil forming age; T in the "clorpt")

Time map or soil age map is the map representing the age of the soil, that is different from the geological time appearing in the geological map. In this study, the development stage of soil was taken into account. The materials and the step to create time map are shown in figure 5.8.

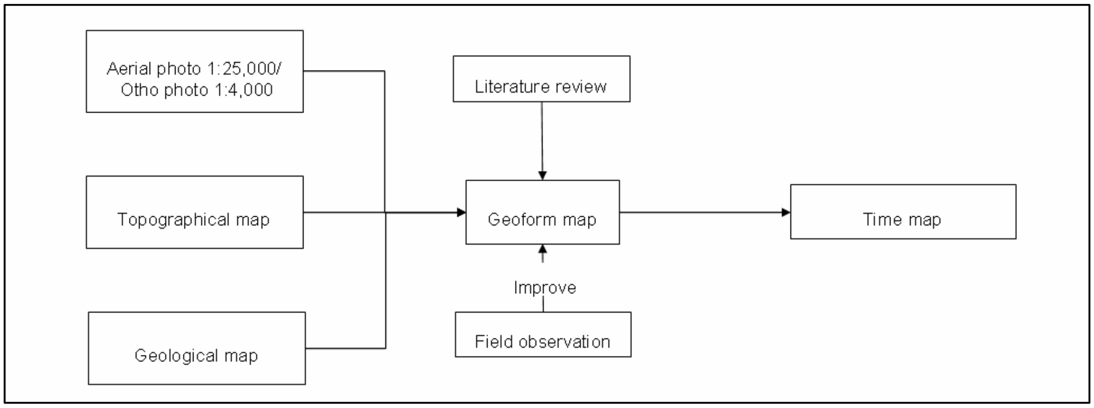



**Figure 5. 8: Flow chart to generate time map**

**Table 5. 6: Time of Hoi Num Rin**

| Time | Area | |
|---|---|---|
| | Hectares | Percent |
| Old | 607 | 29 |
| Young | 164 | 8 |
| Mature | 1334 | 63 |

### 5.3.7 Spatial position map (Landscape and Landform; N in of SCORPAN)

The SCORPAN equation, derived from Jenney equation, also includes spatial position. The spatial position in this study considered in terms of landscape and landform, which are the position and pattern of surface at the soil phenomena. Landscape is the pattern of earth surface representing the soil system in a large dynamic. It can be interpreted by grouping soils with similar morphological and hydrological characteristics (online, http://www.sfwmd.gov)

Landform represents the position on landscape, a part on terrain, and comprises the geological unit, and the slope section. Landform comprises several characteristics such as elevation, slope, orientation, stratification, rock exposure, relief unit, facet and soil type. Sometimes it can be extracted from a digital elevation model using given techniques. And depend on the skill of interpretater because landform unit is varied scale (online, http://en.wikipedia.org/ wiki/Landform). The process to create and produce landscape and landform map explain as a figure below

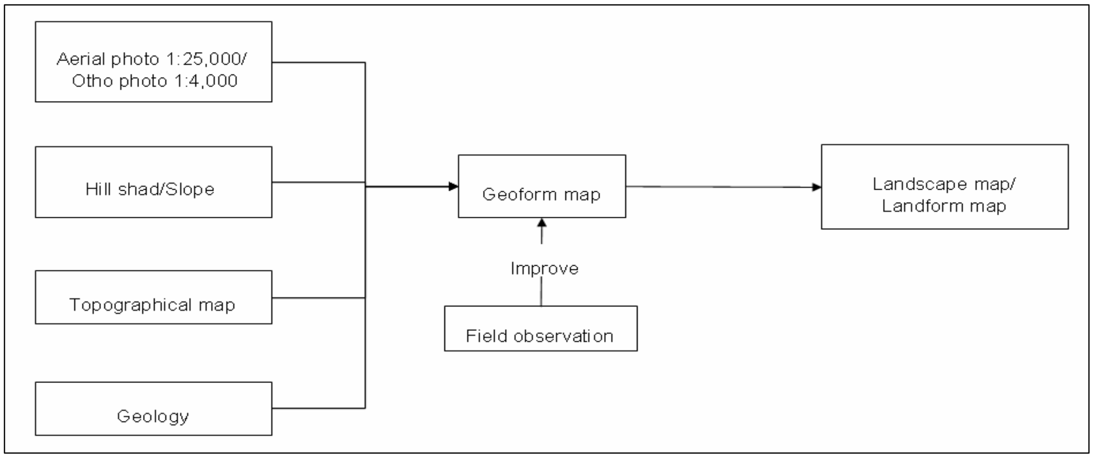


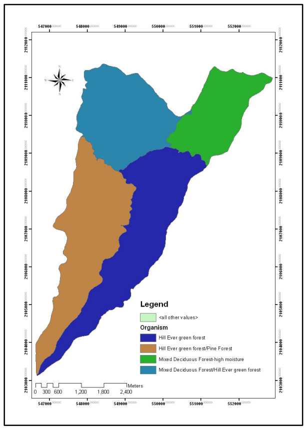

**Figure 5. 9: Flow chart to generate landscape and landform map**

## Table 5. 7: Landscape of Hoi Num Rin

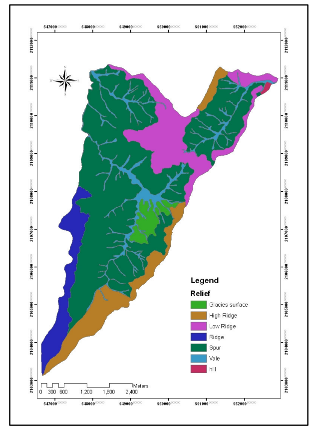
| Landscape | Area | |
|---|---|---|
| | Hectares | 40 |
| Mo in C1 | 607 | 29 |
| Mo in PTRv | 1101 | 52 |
| Mo in TRg | 233 | 11 |
| Valley | 164 | 8 |

## Table 5. 8: Landform of Hoi Num Rin

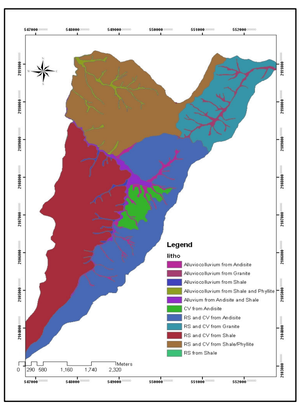
| Landform | Area | |
|---|---|---|
| | Hectares | Percent |
| Accumulation surface | 26 | 1 |
| Bottom side complex | 164 | 8 |
| Erosional surface | 38 | 2 |
| Gentle/Moderately of slope complex | 127 | 6 |
| Middle and foot slope complex | 1197 | 56 |
| Slope facet complex | 4 | 1 |
| Steep/ very steep slope complex | 123 | 6 |
| Summit and shoulder complex | 436 | 20 |



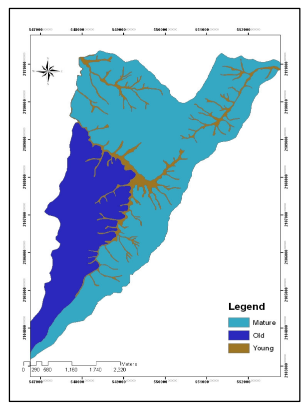

**(a) organism**



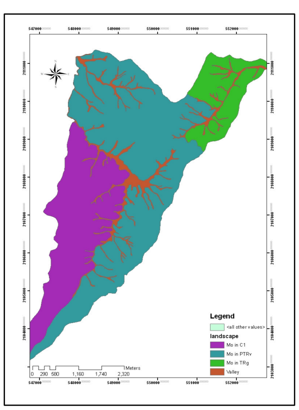

**(b) relief type**



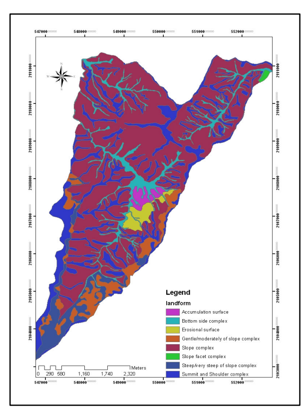

**(c) lithological**




**(d) time**




**(e) landscape**




**(e) landform**

**Figure 5. 10: The out put: the parameter map in Hoi Num Rin sub-watershed**

## 5.4 Geopedologic map (predictive soil map)

The knowledge based on soil forming factors can be used if the geopedologic setting of the area under study is understood. SCORPAN model modified from the Jenney equation, can be used to predict soils of inaccessible areas.

### 5.4.1 Artificial Neural Network

The stage for predictive geopedologic map is the integration of variable maps used as predictors; in other words the soil forming factors. Regarding soil forming factors of SCORPAN model, soil sample, climate, organism, relief type, lithotogy, time and spatial position (landscape and landform) contributed to the process of predictive mapping using neural network in ENVI (4.2) software. This process ignored climate map because only one soil moisture class was found in this study (5.3.7), therefore it was not necessary to include this map. The ANN topology is explained in chapter 4. The data preparing steps to carry out ANN work are explained as follows;

Step 1 The predictor variable maps and sample area were generated in vector data. using ArcGIS.

Step 2 All predictor maps were exported to raster data, using ArcGIS.

Step 3 All raster maps were imported and transformed to ENVI standard file, using ENVI.

Step 4 The predictor maps were stacked together, using layer stacking tool.

Step 5 Regional of interests were generated from sample area, by overlay the vector map on the predictor maps (step 5) .

Step 6: Training the area using neural network in supervise classification tool.

Step 7 Learn about how to adjust the network parameters such as training threshold, training rate, traing RMS, number of training iteration and the number of hidden later. Together this step used the neural network algorithm, developed by Henk van Oosten and Tolpekin (2006) to learn the result of the training process such as learning time, training accuracy and training, to decide the parameter which fit for the training process.

Step 8 Export raster map to vecter

A brief explanation of the ANN process is shown in figure 5.10.

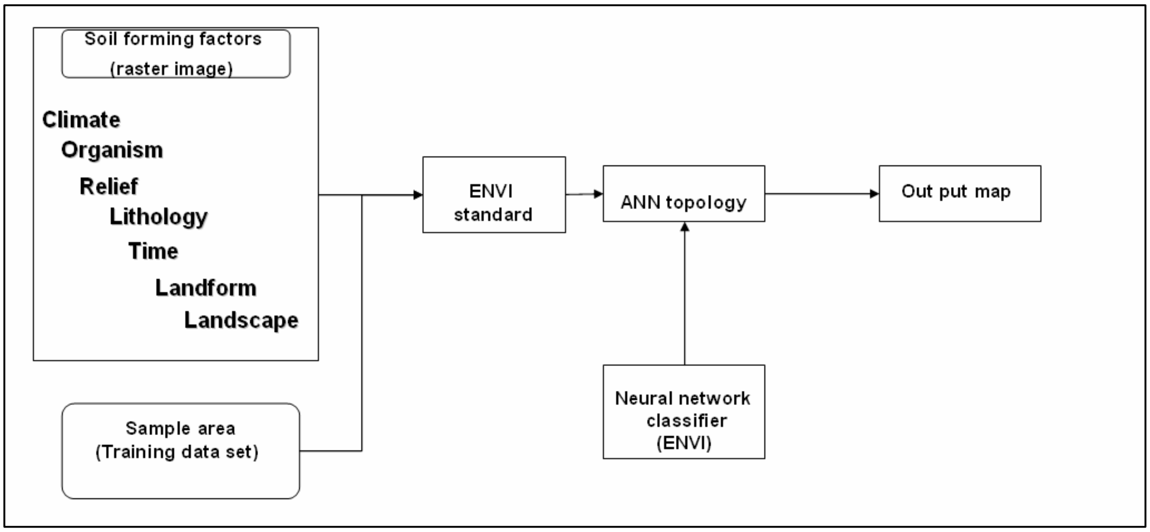



**Figure 5. 10: Neural network flow chart**

### 5.5.2 Decision tree

In this method, the predictors' maps from 5.3.1 were used to make the decision tree in ArcGIS soft ware. Learning the soil conditions based on soil forming factors of SCORPAN model, using raster calculator in spatial analysis tool was used to calculate the algorithms. The flow chart of figure 5.11 explains the step of soil prediction using decision tree.

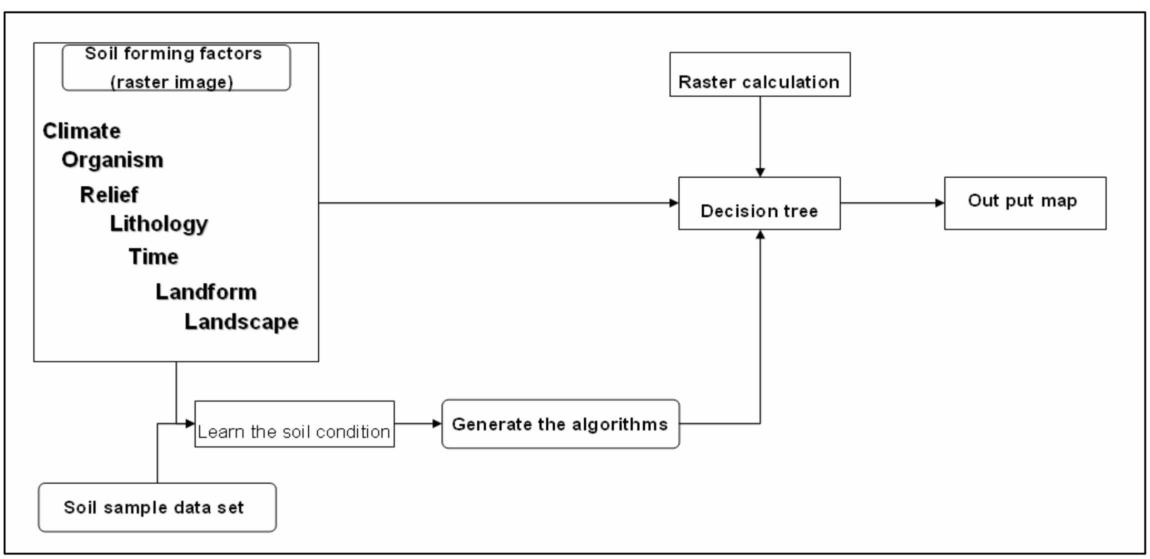



**Figure 5. 11: Decision tree flow chart**

## 5.5 Landslide map

Landslide map was made from image interpretation. The recent and old landslides were extracted from aerial photo, othophoto in year 2004, hillshade and contour map. Generally speaking, it is difficult to identify the occurrence of old landslides from aerial photos because landslide areas are often covered by dense vegetation. Sekiguchi et al. (http://www.gsi.go.jp) identified micro landslide characteristics such as scar, scarp or landslide body by using contour maps based on airborne laser scanning and aerial photo interpretation technique (see figure 5.15). In this study, the landslide locations were collected in the field usingGPS.

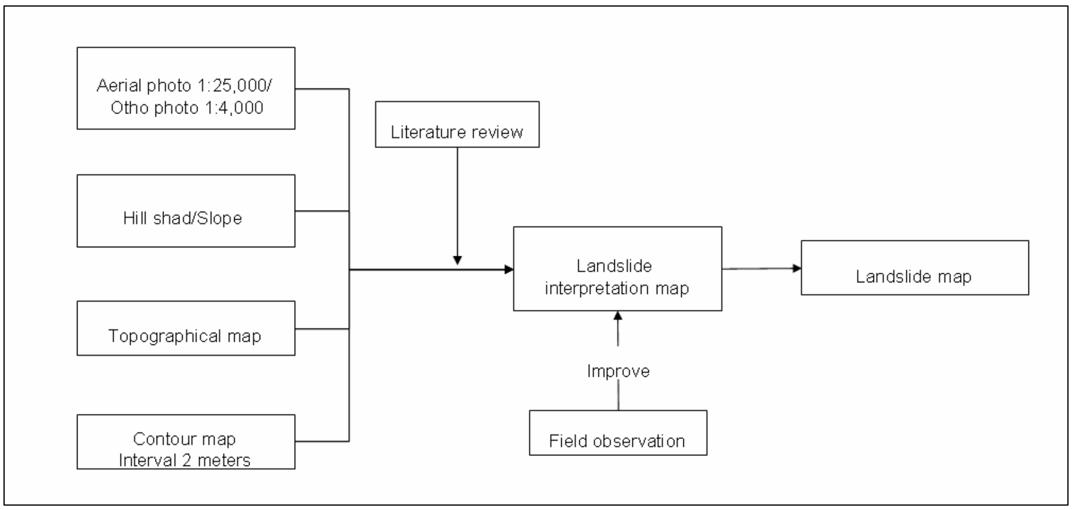



**Figure 5. 12: Landslide map flow chart**

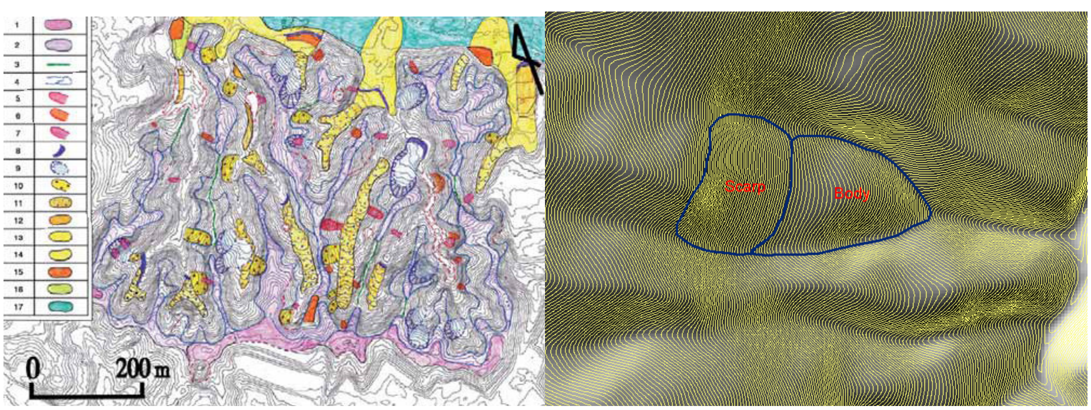



**Figure 5. 13: Landslide character interpretation (a) micro landslide characteristics map overlapped on a laser contour map (Sekiguchi et al, http://www.gsi.go.jp) (b) landslide interpretation map overlapped on contour map and hillshade in Hoi Num Rin sub watershade**

# Chapter 6: Results and Discussion

## 6.1 Soil mapping using geopedological approch

Geoform map was generated by applying aerial photo interpretation technique using geopedologic approach and fieldwork. The resulting map is shown in figure….. (figure 5.1).

### 6.1.1 Geoform units

The process in chapter 5 (5.1) was carried out to obtain the geoform map (see the legend; table 5.1). The results are discussed below.

#### 6.1.1.1 Mountain in Carboniferous geological type ($MoC_1$)

This is characterized by ridges/hills from northeast to southwest direction. The unit ($MoC_1$) covers about 28 percent (606 hectares) of the total area. The elevation ranges from 858 to 1264 meters above mean sea level. Two relief types are mainly ridge ($MoC_1$1) and spur ($MoC_1$2). Parent material type plays dominant role in this landscape; residuum and colluvium from shale and phyllite. At landform level, summit and shoulder complex, steep/very steep of slope com, gentle/moderately of Middle and foot slope complex, middle and foot slope complex can be determined.

#### 6.1.1.2 Mountain in Triassic volcanic rock (MoTRv)

This landscape covers about 233 hectares or 11 % of the total study areas. The altitude varies from 754 to 1058 meters above mean sea level. Four relief types namely high ridge (MoTRg1), low ridge (MoTRg2), spur (MoTRg3) and glacies surface (MoTRg4) can be separated. Four types of parent material play dominant role, residuum and colluviums from andisite residuum and colluviums from shale/phyllite, residuum and colluviums from granite and colluvium from andisite. At landform level, summit and shoulder complex, steep/very steep of slope complex, gentle/moderately of Middle and foot slope complex and slope facet complex.

#### 6.1.1.3 Mountain in Post-Triassic volcanic rock (MoPTRv)

This landscape covers about 1101 hectares or 52 % of the total study area. The altitude varies from 864 to 1636 m above mean sea level. Four relief types, namely high ridge (MoPTRv1), low ridge (MoPTRv2), spur (MoPTRv3) and hill (MoPTRv4) can be separated. Two types of parent material play dominant role; residuum and colluvium from shale/phyllite, granite. At landform level, summit and shoulder complex, middle and foot slope complex and slope facet complex

#### 6.1.1.4 Valley (Va)

This landscape covers about 164 hectares or 8 % of the total study area. The altitude varies from 700 to 1120 m above mean sea level. Only one relief type, namely vale (Va1) can be determined. There are five types of parent materials that play dominant role; alluvio-colluvium from andisite, alluvio-colluvium from andisite&shale, alluviocolluvium from shale, alluviocolluvium from shale&phyllite and alluviocolluvium from granite. At landform level, bottom side complex can be determined.

### 6.1.2 Soils in the selected sample areas

The three sample areas; A, B, and C (see chapter 5), covered 40% of the study area. Soils were studied using 57 profiles and mini-pits. The three sample areas have 32 landform units. Soils were studied and classified at subgroup level using USDA Soil Taxonomy System (Soil Survey Staff, 2006).

#### 6.1.2.1 Sample area A

Area A crosses through landform units in Mo in PTRv and Mo in TRg landscape; MoPTRv221, MoPTRv222, MoPTRv321, MoPTRv322, MoPTRv331, MoPTRv332, TRg211, TRg212, TRg311, TRg312, TRg411, Va141 and Va151. The area covers 20 % the northern part of the study area. The main 6 soil units, classified into soil subgroup level, were found in this sample area. The abridged description of the soil in the area “A” can be summarized as follows.

a) Typic Hapludalfs: differentiated into two groups using the parent material: residuum and colluvium derived from shale associated with phyllite had found in MoPTRv221, MoPTRv321, and MoPTRv331, and the parent material derived from granite had found in TRg211 and TRg311. Generally, this soil is shallow to moderately deep (not more than 150 cm). This soil contains clay skins in subsoil.

b) Typic Paleudalfs: differentiated into two groups by the parent material: the parent material is residuum and colluvium derived from shale associate with phyllite, found in MoPTRv322 and MoPTRv332, the parent material derived from granite had found in TRg212 and TRg312. Generally, this soil is a deep to very deep and this soil contains clay skins in subsoil.

c) Typic Paleudalfs/ Typic Hapludalfs: parent material is residuum and colluvium derived from shale associated with phyllite. There are deep to very deep soil associate with shallow to moderately deep soils, found in MoPTRv222.

d) Typic Hapludalf/ Typic Paleudalfs, the parent material is residuum and colluviums derived from granite. There are shallow soil associate with deep to very deep soil, has found in MoTRg411.

e) Typic Udifluvents, parent material is alluvio-colluvium.

f) Typic Udifluvents/ Typic Argiudolls, the parent material is alluvio-colluvium.

#### 6.1.2.1 Sample area B

Area B crosses through landform units in Mo in $C_1$ and Mo in PTRv landscape; $MoC_1111$, $MoC_1112$, $MoC_1113$, $MoC_1211$, $MoC_1212$, MoPTRv411, MoPTRv412, MoPTRv113, MoPTRv111, MoPTRv411, MoPTRv211, MoPTRv212, MoPTRv212, Va131 and Va121. It covers 2 % of the middle part. The main 7 soil units, classified into soil subgroup level, were found in this sample area. “B” The abridged descriptive of the soils in the area can be summarized as follows.

a) Lithic Halpludults: the parent material is residuum and colluvium derived from shale. This soil is very shallow to shallow soil, had lithic contact with in 50 cm, found in $MoC_1111$.

a) Typic Hapludults: the parent material is residuum and colluvium derived from shale. This soil is shallow to moderately deep soil, found in $MoC_1112$ and $MoC_1211$.

b) Typic Paleudults: the parent material is residuum and colluvium derived form shale. This soil is deep to very deep soil, found in $MoC_1113$ and $MoC_1212$.

c) Rhodic Paleudalfs: the parent material is residuum and colluvium derived from andisite. This soil is deep to very deep soil, had dark-red color through the soil profile, found in MoPTRv111 and MoPTRv411.

d) Typic Hapludalfs: the parent material is residuum and colluvium derived form andisite. This soil is shallow to moderately deep soil, had found in MoPTRv211.

e) Typic Paleudalfs: the parent material is residuum and colluvium derived from andisite. This soil is deep to very deep soil, found in MoPTRv113, MoPTRv212 and MoPTRv412.

f) Typic Udifluents: the parent material is aluuvio-colluvium, found in Va131 and Va121.

#### 6.1.2.2 Sample area C

Area C crosses through landform units in Mo in $C_1$ and Mo in PTRv landscape; $MoC_1111$, $MoC_1112$, $MoC_1113$, $MoC_1211$, $MoC_1212$, MoPTRv411, MoPTRv311, MoPTRv112, MoPTRv113, Va131, Va121 and Va111. The area covers 9 % of the southern part. The main 7 soil units, which classify into soil subgroup level, were found in this sample area. The abridged description of the soils in the area “C”can be summarized as follows.

a) Lithic Hapludults: the parent material is residuum and colluvium derived from shale. This soil is very shallow to shallow soil, found lithic contact with in 50 cm, found in $MoC_1111$.

b) Typic Hapludults: the parent material is residuum and colluvium derived from shale. This soil is shallow to moderate deep soil, found in $MoC_1$112 and $MoC_1$211.

c) Typic Paleudults: the parent material is residuum and colluvium derived form shale. This soil is deep to very deep soil, found in $MoC_1$113 and $MoC_1$212.

d) Rhodic Paleudalfs: the parent material is residuum and colluvium derived from andisite. This soil is deep to very deep soil, had dark-red colour through the soil profile, and had found in MoPTRv113.

e) Typic Hapludalfs, the parent material is residuum and colluviums derived form andisite. This soil is shallow to moderately deep soil, found in MoPTRv112.

f) Typic Paleudalfs: the parent material is residuum and colluviums derived from andisite. This soil is deep to very deep soil, found in MoPTRv311.

h) Typic Udifluents, the parent material is aluuvio-colluvium, h found in Va111 and Va131.

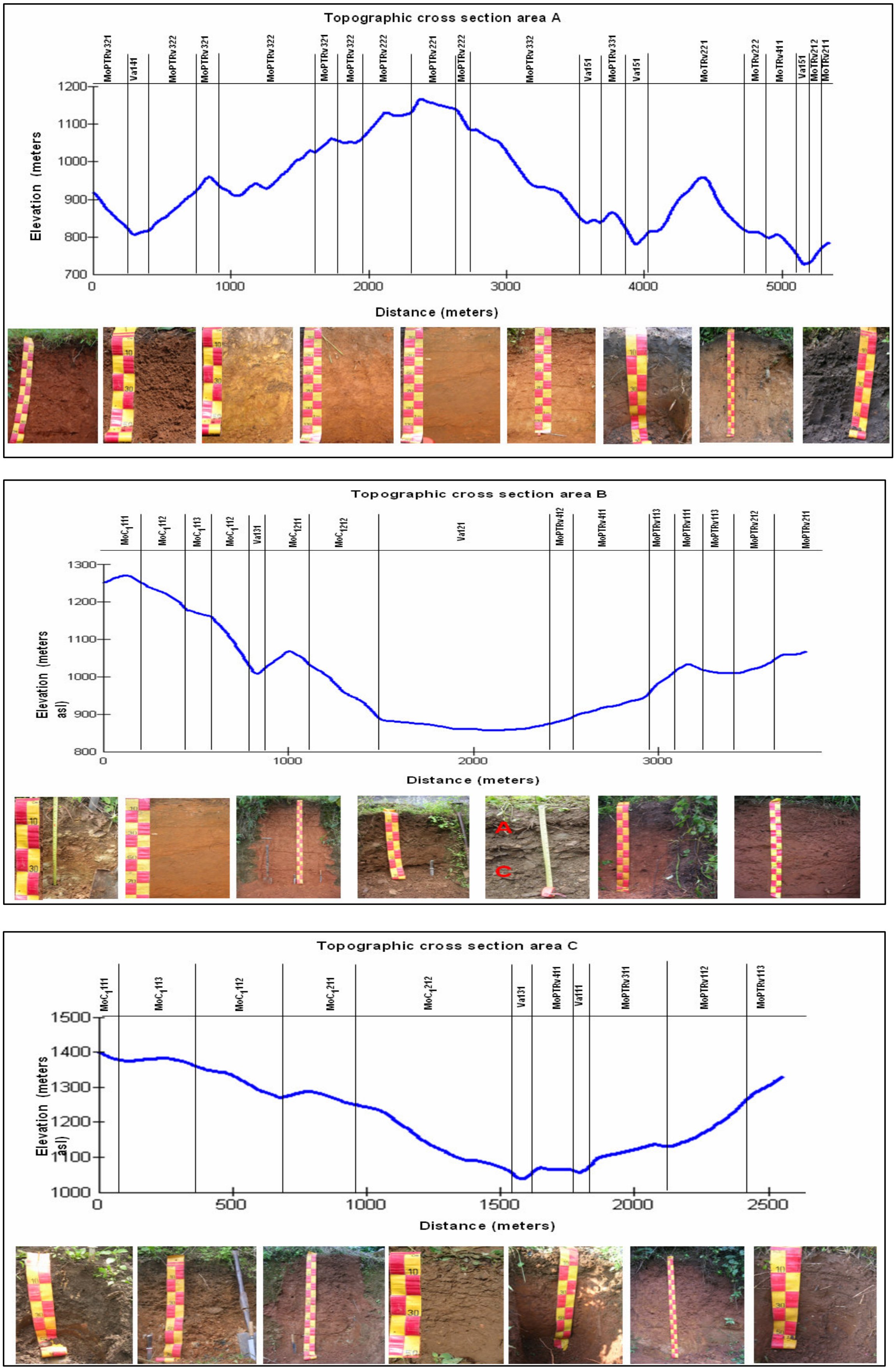



**Figure 6. 1: Topographic cross section of the three sample area A, B and C.**

**Table 6. 1: The summary of soil profiles and mini-pits in sample areas for soil prediction.**

| Climate | Landscape | Relief type | lithology | Landfrom | Vegetation | Time | SOIL_CLASS | Geoform | Profile-minipit- no. |
|---|---|---|---|---|---|---|---|---|---|
| Udic | Mo in C1 | Ridge | RS and CV from Shale | Summit and Shoulder complex | Hill Ever green forest/Pine Forest | Old | Lithic Hapludults | MOC1111 | 15, 42 |
| Udic | Mo in C1 | Ridge | RS and CV from Shale | Steep/very steep of slope com | Hill Ever green forest/Pine Forest | Old | Typic Hapludults | MOC1112 | 57, 58 |
| Udic | Mo in C1 | Ridge | RS and CV from Shale | Gentle/moderately of slope comp | Hill Ever green forest/Pine Forest | Old | Typic Paleudults | MOC1113 | 33, 56, 73 |
| Udic | Mo in C1 | Spur | RS and CV from Shale | Summit and Shoulder complex | Hill Ever green forest/Pine Forest | Old | Typic Hapludults | MOC1211 | 45, 46, 47 |
| Udic | Mo in C1 | Spur | RS and CV from Shale | Middle and foot slope complex | Hill Ever green forest/Pine Forest | Old | Typic Paleudults | MOC1212 | 32, 43, 70 |
| Udic | Mo in PTRv | High Ridge | RS and CV from Andisite | Summit and Shoulder complex | Hill Ever green forest | Mature | Rhodic Paleudalfs | MOPTRv111 | 6, 29, 50, 79 |
| Udic | Mo in PTRv | High Ridge | RS and CV from Andisite | Steep/very steep of slope com | Hill Ever green forest | Mature | Typic Hapludalfs | MOPTRv112 | 77 |
| Udic | Mo in PTRv | High Ridge | RS and CV from Andisite | Gentle/moderately of slope comp | Hill Ever green forest | Mature | Rhodic Paleudalfs | MOPTRv113 | 3, 9, 49 |
| Udic | Mo in PTRv | Low Ridge | RS and CV from Andisite | Summit and Shoulder complex | Hill Ever green forest | Mature | Typic Hapludalfs | MOPTRv211 | 10 |
| Udic | Mo in PTRv | Low Ridge | RS and CV from Andisite | Middle and foot slope complex | Hill Ever green forest | Mature | Typic Paleudalfs | MOPTRv212 | 61 |
| Udic | Mo in PTRv | Low Ridge | RS and CV from Shale/Phyllite | Summit and Shoulder complex | Mixed Deciduous Forest/Hill Ever green forest | Mature | Typic Hapludalfs | MOPTRv221 | 11, 53 |
| Udic | Mo in PTRv | Low Ridge | RS and CV from Shale/Phyllite | Middle and foot slope complex | Mixed Deciduous Forest/Hill Ever green forest | Mature | Typic Paleudalfs/ Typic Hapludalfs | MOPTRv222 | 12, 21, 35, 54 |
| Udic | Mo in PTRv | Spur | RS and CV from Andisite | Summit and Shoulder complex | Hill Ever green forest | Mature | Typic Hapludalfs | MOPTRv311 | 24, 37 |
| Udic | Mo in PTRv | Spur | RS and CV from Andisite | Middle and foot slope complex | Hill Ever green forest | Mature | Typic Paleudalfs | MOPTRv312 | 31, 63, 68 |
| Udic | Mo in PTRv | Spur | RS and CV from Shale/Phyllite | Summit and Shoulder complex | Mixed Deciduous Forest/Hill Ever green forest | Mature | Typic Hapludalfs | MOPTRv321 | 7, 52 |
| Udic | Mo in PTRv | Spur | RS and CV from Shale/Phyllite | Middle and foot slope complex | Mixed Deciduous Forest/Hill Ever green forest | Mature | Typic Paleudalfs | MOPTRv322 | 44 |
| Udic | Mo in PTRv | Spur | RS and CV from Andisite | Summit and Shoulder complex | Mixed Deciduous Forest-high moisture | Mature | Typic Hapludalfs | MOPTRv331 | 76 |
| Udic | Mo in PTRv | Spur | RS and CV from Andisite | Middle and foot slope complex | Mixed Deciduous Forest-high moisture | Mature | Typic Paleudalfs | MOPTRv332 | 75 |
| Udic | Mo in PTRv | Glacies surface | RS and CV from Andisite | Erosional surface | Hill Ever green forest | Mature | Rhodic Paleudalfs | MOPTRv411 | 8 |

* Old = soil developed as Ultisoils Mature = soil developed as Alfisols Young = soil developed as Entisoil and mollisols

**Table 6. 2: The summary of soil profiles and mini-pits in sample areas for soil prediction.**

| Climate | Landscape | Relief type | lithology | Landfrom | Vegetation | Time | SOIL_CLASS | Geoform | Profile-minipit- no. |
|---|---|---|---|---|---|---|---|---|---|
| Udic | Mo in C1 | Ridge | RS and CV from Shale | Summit and Shoulder complex | Hill Ever green forest/Pine Forest | Old | Lithic Hapludults | MOC1111 | 15, 42 |
| Udic | Mo in C1 | Ridge | RS and CV from Shale | Steep/very steep of slope com | Hill Ever green forest/Pine Forest | Old | Typic Hapludults | MOC1112 | 57, 58 |
| Udic | Mo in C1 | Ridge | RS and CV from Shale | Gentle/moderately of slope comp | Hill Ever green forest/Pine Forest | Old | Typic Paleudults | MOC1113 | 33, 56, 73 |
| Udic | Mo in C1 | Spur | RS and CV from Shale | Summit and Shoulder complex | Hill Ever green forest/Pine Forest | Old | Typic Hapludults | MOC1211 | 45, 46, 47 |
| Udic | Mo in C1 | Spur | RS and CV from Shale | Middle and foot slope complex | Hill Ever green forest/Pine Forest | Old | Typic Paleudults | MOC1212 | 32, 43, 70 |
| Udic | Mo in PTRv | High Ridge | RS and CV from Andisite | Summit and Shoulder complex | Hill Ever green forest | Mature | Rhodic Paleudalfs | MOPTRv111 | 6, 29, 50, 79 |
| Udic | Mo in PTRv | High Ridge | RS and CV from Andisite | Steep/very steep of slope com | Hill Ever green forest | Mature | Typic Hapludalfs | MOPTRv112 | 77 |
| Udic | Mo in PTRv | High Ridge | RS and CV from Andisite | Gentle/moderately of slope comp | Hill Ever green forest | Mature | Rhodic Paleudalfs | MOPTRv113 | 3, 9, 49 |
| Udic | Mo in PTRv | Low Ridge | RS and CV from Andisite | Summit and Shoulder complex | Hill Ever green forest | Mature | Typic Hapludalfs | MOPTRv211 | 10 |
| Udic | Mo in PTRv | Low Ridge | RS and CV from Andisite | Middle and foot slope complex | Hill Ever green forest | Mature | Typic Paleudalfs | MOPTRv212 | 61 |
| Udic | Mo in PTRv | Low Ridge | RS and CV from Shale/Phyllite | Summit and Shoulder complex | Mixed Deciduous Forest/Hill Ever green forest | Mature | Typic Hapludalfs | MOPTRv221 | 11, 53 |
| Udic | Mo in PTRv | Low Ridge | RS and CV from Shale/Phyllite | Middle and foot slope complex | Mixed Deciduous Forest/Hill Ever green forest | Mature | Typic Paleudalfs/ Typic Hapludalfs | MOPTRv222 | 12, 21, 35, 54 |
| Udic | Mo in PTRv | Spur | RS and CV from Andisite | Summit and Shoulder complex | Hill Ever green forest | Mature | Typic Hapludalfs | MOPTRv311 | 24, 37 |
| Udic | Mo in PTRv | Spur | RS and CV from Andisite | Middle and foot slope complex | Hill Ever green forest | Mature | Typic Paleudalfs | MOPTRv312 | 31, 63, 68 |
| Udic | Mo in PTRv | Spur | RS and CV from Shale/Phyllite | Summit and Shoulder complex | Mixed Deciduous Forest/Hill Ever green forest | Mature | Typic Hapludalfs | MOPTRv321 | 7, 52 |
| Udic | Mo in PTRv | Spur | RS and CV from Shale/Phyllite | Middle and foot slope complex | Mixed Deciduous Forest/Hill Ever green forest | Mature | Typic Paleudalfs | MOPTRv322 | 44 |
| Udic | Mo in PTRv | Spur | RS and CV from Andisite | Summit and Shoulder complex | Mixed Deciduous Forest-high moisture | Mature | Typic Hapludalfs | MOPTRv331 | 76 |
| Udic | Mo in PTRv | Spur | RS and CV from Andisite | Middle and foot slope complex | Mixed Deciduous Forest-high moisture | Mature | Typic Paleudalfs | MOPTRv332 | 75 |
| Udic | Mo in PTRv | Glacies surface | RS and CV from Andisite | Erosional surface | Hill Ever green forest | Mature | Rhodic Paleudalfs | MOPTRv411 | 8 |

* Old = soil developed as Ultisoils

Mature = soil developed as Alfisols   Young = soil developed as Entisoil and mollisols

## 6.2 Predictive soil mapping using ANN and decision tree

To carry out soil mapping in this study, artificial neural network (ANN) and decision tree methods were applied not only to map selected soil attribute but also to map soil. Total of 43 soil profile descriptions (from soil profile and mini-pit) together with some environmental data along the three sample areas were used to generate the soil map (6.2). The concept of soil forming factors of SCORPAN model was used.

### 6.2.1 Parameterization of soil forming factors (see also chapter 5)

Study is inspired by Jenney equation (clorpt) and the SCORPAN models were used to be the function to predict soil map. It can be summarized as: soil is the interaction between climate (C), organisms/vegetation (O), relief (R), parent material (P) age/time (A) and spatial position or geographic space (N). Therefore, some of the parameters which play important role were selected and integrated to be the predictors.

a. To parameterize climate, soil moisture regime was taken that is udic moisture regime.

b. To parameterize organism, native vegetation was taken as the indicator of the organism.

c. To parameterize relief type, the landform from geoform map was taken as the indicator.

d. To parameterize parent material, lithology obtained from geological map, slope aspect and field observation was taken as the indicators.

e. To parameterize time, soil profile descriptions in combination with lithology were taken as the indicators.

f. To parameterize spatial position, landscape and landform from geoform map were taken as the indicator of the spatial position.

### 6.2.2 Geopedological map derived from ANN

A total of 56 descriptions (from soil profile and mini-pit), together with some environmental data along the three sampled areas were used to generate the soil map (figure 6.2a).

Using the standard back-propagation algorithm in ENVI software, a number of three layer ANNs as input layer, hidden layer and output layer were trained for the soil map prediction. In the input layer the number of input nodes was fixed as the number of predictors, which are soil forming factors parameters that are 6 maps. The number of hidden layer is 1. And the number of output nodes was fixed by the soil class that is 10 classes. The other network parameters were adjusted after stage of learned to train the network and selected the parameters which give the best fit with the result as follows:

- Training threshold contribution is 0.9

- Training rate is 0.2, training momentum is 0.9
- Training RMS exit criteria (error) is 0.0001
- Number of training iteration is 1000 (see also the table 6.3 below, the best result is when the iteration of 1000 is selected.

The networks were trained until the error calculated over the testing data was judged to have reached a minimum. From the table, the best parameters which fitted for the prediction used 38.93 minutes to train the network, training accuracy is 98 % and training error is 0.003.

**Table 6. 3: Confusion matrix (overall) from different iteration of the training process**

| Iteration | Class 1 | Class 2 | Class 3 | Class 4 | Class 5 | Class 6 | Class 7 | Class 8 | Class 9 | Class 10 | Learning Time (mins) | Training Accuracy (%) | Training Error |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 500 | 94 | 100 | 100 | 93 | 100 | 93 | 97 | 100 | 100 | 100 | 21.91 | 97 | 0.005 |
| 1000 | 94 | 100 | 100 | 97 | 100 | 93 | 97 | 100 | 100 | 100 | 38.92 | 98 | 0.003 |
| 5000 | 94 | 100 | 100 | 97 | 100 | 93 | 97 | 100 | 100 | 100 | 231.23 | 98 | 0.003 |

The resulted geopedological map derived from ANN is shown in Figure 6.2. Soils of Hoi Num Rin were classified according to Soil Taxonomy System (Soil Survey Staff, 2006); 4 orders, 4 suborders, 6 great groups and 10 subgroups. Phase of the soil unit such as rocky area was ignored because in this area only a small past in the valley landscape is rocky. ANN could predict and transfer the soil from the sampled sites to unsampled areas. The result: Lithic Hapludults cover 85 ha or 4%, Typic Paleudults cover 378 ha or 18%, Rhodic Paleudalfs cover 135 ha or 6%, Typic Hapludults cover 144 ha or 7%, Rhodic Paleudalfs cover 134 ha or 6 %, Typic Hapludalfs cover 322 ha or 15%, Typic Paleudalfs cover 743 ha or 35%, Typic Paleudalfs/Typic Hapludalfs cover 124 ha or 6%, Typic Hapludalfs/Typic Paleudalfs cover 9 ha or 6%, Typic Udifluvents cover 135 ha or 6% and Typic Udifluvents/Typic Argiudolls cover 34 ha or 2%.

### 6.2.3 Geopedological map derived from the decision tree

The other method used in soil prediction is the used of decision tree. In order to implement the decision process, the parameter was the same with ANN's data. The required algorithm is a available in several softwares. But in this study, ArcGis was used to establish decision tree. There are 10 soil classification names in three sample areas. On the basics of which was established to predict soil of unsampled areas. The basic is to search the area with the similar environment as the know sites in the sample areas.

#### 6.3.2.1 Data integration

There are 6 parameter maps, comprised of landscape, relief type, lithology, landform, organism and time (table 6.3), used in the data integration and formula creation.

**Table 6. 4: Data integration to construct the decision tree formula**

| Soil | SOIL_Name | landscape | Relief type | lithology | landform | Organism | Time |
|---|---|---|---|---|---|---|---|
| A | Lithic Hapludults | Mo in $C_1$ | Ridge | RS and CV from Shale | Summit and Shoulder complex | Hill Ever green forest/Pine Forest | Old |
| B | Typic Hapludults | Mo in $C_1$ | Ridge | RS and CV from Shale | Steep/very steep of slope com | Hill Ever green forest/Pine Forest | Old |
| | | Mo in $C_1$ | Spur | RS and CV from Shale | Summit and Shoulder complex | Hill Ever green forest/Pine Forest | Old |
| C | Typic Paleudults | Mo in $C_1$ | Ridge | RS and CV from Shale | Gentle/moderately of slope complex | Hill Ever green forest/Pine Forest | Old |
| | | Mo in $C_1$ | Spur | RS and CV from Shale | Middle and foot slope complex | Hill Ever green forest/Pine Forest | Old |
| D | Rhodic Paleudalfs | Mo in PTRv | High Ridge | RS and CV from Andisite | Summit and Shoulder complex | Hill Ever green forest | Mature |
| | | Mo in PTRv | High Ridge | RS and CV from Andisite | Gentle/moderately of slope complex | Hill Ever green forest | Mature |
| | | Mo in PTRv | Glacies surface | RS and CV from Andisite | Erosional surface | Hill Ever green forest | Mature |
| E | Typic Hapludalfs | Mo in PTRv | High Ridge | RS and CV from Andisite | Steep/very steep of slope complex | Hill Ever green forest | Mature |
| | | Mo in PTRv | Low Ridge | RS and CV from Andisite | Summit and Shoulder complex | Hill Ever green forest | Mature |
| | | Mo in PTRv | Low Ridge | RS and CV from Shale/Phyllite | Summit and Shoulder complex | Mixed Deciduous Forest/Hill Ever green forest | Mature |
| | | Mo in PTRv | Spur | RS and CV from Andisite | Summit and Shoulder complex | Hill Ever green forest | Mature |
| | | Mo in PTRv | Spur | RS and CV from Andisite | Summit and Shoulder complex | Mixed Deciduous Forest/Hill Ever green forest | Mature |
| | | Mo in PTRv | Spur | RS and CV from Granite | Summit and Shoulder complex | Mixed Deciduous Forest-high moisture | Mature |
| | | Mo in TRg | High Ridge | RS and CV from Shale/Phyllite | Summit and Shoulder complex | Mixed Deciduous Forest-high moisture | Mature |
| | | Mo in TRg | High Ridge | RS and CV from Shale/Phyllite | Middle and foot slope complex | Mixed Deciduous Forest-high moisture | Mature |
| | | Mo in TRg | Low Ridge | RS and CV from Granite | Summit and Shoulder complex | Mixed Deciduous Forest-high moisture | Mature |
| | | Mo in TRg | Spur | RS and CV from Granite | Summit and Shoulder complex | Mixed Deciduous Forest-high moisture | Mature |

**Table 6.3: Data integration to construct the decision tree formula (continue..)**

| Soil | SOIL_Name | landscape | Relief type | lithology | landform | Organism | Time |
|---|---|---|---|---|---|---|---|
| F | Typic Paleudalfs | Mo in PTRv | Low Ridge | RS and CV from Andisite | Middle and foot slope complex | Hill Ever green forest | Mature |
| | | Mo in PTRv | Spur | RS and CV from Andisite | Middle and foot slope complex | Hill Ever green forest | Mature |
| | | Mo in PTRv | Spur | RS and CV from Shale/Phyllite | Middle and foot slope complex | Mixed Deciduous Forest/Hill Ever green forest | Mature |
| | | Mo in PTRv | Spur | RS and CV from Shale/Phyllite | Middle and foot slope complex | Mixed Deciduous Forest/Hill Ever green forest | Mature |
| | | Mo in PTRv | Spur | RS and CV from Granite | Middle and foot slope complex | Mixed Deciduous Forest-high moisture | Mature |
| | | Mo in PTRv | Glacies surface | RS and CV from Andisite | Accumulation surface | Hill Ever green forest | Mature |
| | | Mo in TRg | Low Ridge | RS and CV from Granite | Middle and foot slope complex | Mixed Deciduous Forest-high moisture | Mature |
| | | Mo in TRg | Spur | RS and CV from Granite | Middle and foot slope complex | Mixed Deciduous Forest-high moisture | Mature |
| G | Typic Paleudalfs/ Typic Hapludalfs* | Mo in PTRv | Low Ridge | RS and CV from Shale/Phyllite | Middle and foot slope complex | Mixed Deciduous Forest/Hill Ever green forest | Mature |
| H | Typic Hapludalfs/f, Typic Paleudalfs* | Mo in TRg | hill | RS and CV from Granite | Slope facet complex | Mixed Deciduous Forest-high moisture | Mature |
| I | Typic Udifluvents | Valley | Vale | Alluviocolluvium from Andisite | Bottom side complex | Hill Ever green forest | Young |
| | | Valley | Vale | Alluvium from Andisite and Shale | Bottom side complex | Hill Ever green forest | Young |
| | | Valley | Vale | Alluviocolluvium from Shale | Bottom side complex | Hill Ever green forest/Pine Forest | Young |
| | | Valley | Vale | Alluviocolluvium from Shale and Phyllite | Bottom side complex | Mixed Deciduous Forest/Hill Ever green forest | Young |
| J | Typic Udifluvents/ Typic Argiudolls | Valley | Vale | Alluviocolluvium from Granite | Bottom side complex | Mixed Deciduous Forest-high moisture | Young |

**Table 6. 5: The classes of the parameter map, shown in each class used to the formula procedure**

| class | Landscape | Relief | Lithology | Landform | Organism | Time |
|---|---|---|---|---|---|---|
| 1 | Mo in $C_1$ | Glacies surface | Alluviocolluvium from Andisite | Accumulation surface | Hill Ever green forest/Pine Forest | Old |
| 2 | Mo in PTRv | High Ridge | Alluviocolluvium from Granite | Bottom side complex | Mixed Deciduous Forest-high moisture | Young |
| 3 | Mo in TRg | hill | Alluviocolluvium from Shale | Erosional surface | Mixed Deciduous Forest/Hill Ever green forest | Mature |
| 4 | Valley | Low Ridge | Alluviocolluvium from Shale and Phyllite | Gentle/moderately of Middle and foot slope complex | Hill Ever green forest | - |
| 5 | - | Ridge | Alluvium from Andisite and Shale | Middle and foot slope complex | - | - |
| 6 | - | Spur | CV from Andisite | Slope facet complex | - | - |
| 7 | - | Vale | RS and CV from Andisite | Steep/very steep of Middle and foot slope complex | - | - |
| 8 | - | - | RS and CV from Granite | Summit and Shoulder complex | - | - |
| 9 | - | - | RS and CV from Shale | - | - | - |
| 10 | - | - | RS and CV from Shale/Phyllite | - | - | - |
| 11 | - | - | RS from Shale | - | - | - |

* RS = residuum
CV = colluvium

To integrate the data in order to implement the decision tree formulas, using the data from table 6.4. A series of formula were written to used in ArcGIS raster , which used for calculation procedure, they are as follows:

***soilA****=con(([landscape] == 1) & ([relief] == 5) & ([litho] == 9) & ([landform] == 8) & ([organ] == 1) & ([time] == 1),1,0)*

***soilB****=con(([landscape] == 1) & ([relief] == 5) & ([litho] == 9) & ([landform] == 7) & ([organ] == 1) & ([time] == 1),1,0) | con(([landscape] == 1) & ([relief] == 6) & ([litho] == 9) & ([landform] == 8) & ([organ] == 1) & ([time] == 1),1,0)*

***soil****C=con(([landscape] == 1) & ([relief] == 5) & ([litho] == 9) & ([landform] == 4) & ([organ] == 1) & ([time] == 1),1,0) | con(([landscape] == 1) & ([relief] == 6) & ([litho] == 9) & ([landform] == 5) & ([organ] == 1) & ([time] == 1),1,0)*

***soilD****=con(([landscape] == 2) & ([relief] == 2) & ([litho] == 7) & ([landform] == 8) & ([organ] == 4) & ([time] == 3),1,0) | con(([landscape] == 2) & ([relief] == 2) & ([litho] == 7) & ([landform] == 4) & ([organ] == 4) & ([time] == 3),1,0) | con(([landscape] == 2) & ([relief] == 1) & ([litho] == 6) & ([landform] == 3) & ([organ] == 4) & ([time] == 3),1,0)*

```
soilE=con(([landscape] == 2)  & ([relief] == 2)  & ([litho] == 7)   & ([landform] == 7) & ([organ] == 4)
&  ([time] == 3),1,0)
| con(([landscape] == 2)  & ([relief] == 4)  &  ([litho] == 7)  &  ([landform] == 8)  &  ([organ] == 4)
&  ([time] == 3),1,0)
| con(([landscape] == 2)  & ([relief] == 4)  &  ([litho] == 10)  &  ([landform] == 8)  &  ([organ] == 3)  &
([time] == 3),1,0)
| con(([landscape] == 2)  & ([relief] == 6)  &  ([litho] == 7)  &  ([landform] == 8)  &  ([organ] == 4)  &
([time] == 3),1,0)
| con(([landscape] == 2)  & ([relief] == 6)  &  ([litho] == 7)  &  ([landform] == 10)  &  ([organ] == 3)
&  ([time] == 3),1,0)
| con(([landscape] == 2)  & ([relief] == 6)  &  ([litho] == 8)  &  ([landform] == 8)  &  ([organ] == 2)  &
([time] == 3),1,0)
| con(([landscape] == 3)  & ([relief] == 2)  &  ([litho] == 10)  &  ([landform] == 8)  &  ([organ] == 2)
&  ([time] == 3),1,0)
| con(([landscape] == 3)  & ([relief] == 2)  &  ([litho] == 10)  &  ([landform] == 5)  &  ([organ] == 2)
&  ([time] == 3),1,0)
| con(([landscape] == 3)  & ([relief] == 4)  &  ([litho] == 8)  &  ([landform] == 8)  &  ([organ] == 2)  &
([time] == 3),1,0)
| con(([landscape] == 3)  & ([relief] == 6)  &  ([litho] == 8)  &  ([landform] == 8)  &  ([organ] == 2)  &
([time] == 3),1,0)
| con(([landscape] == 2)  & ([relief] == 6)  &  ([litho] == 10)  &  ([landform] == 8)  &  ([organ] == 3)
&  ([time] == 3),1,0)
```

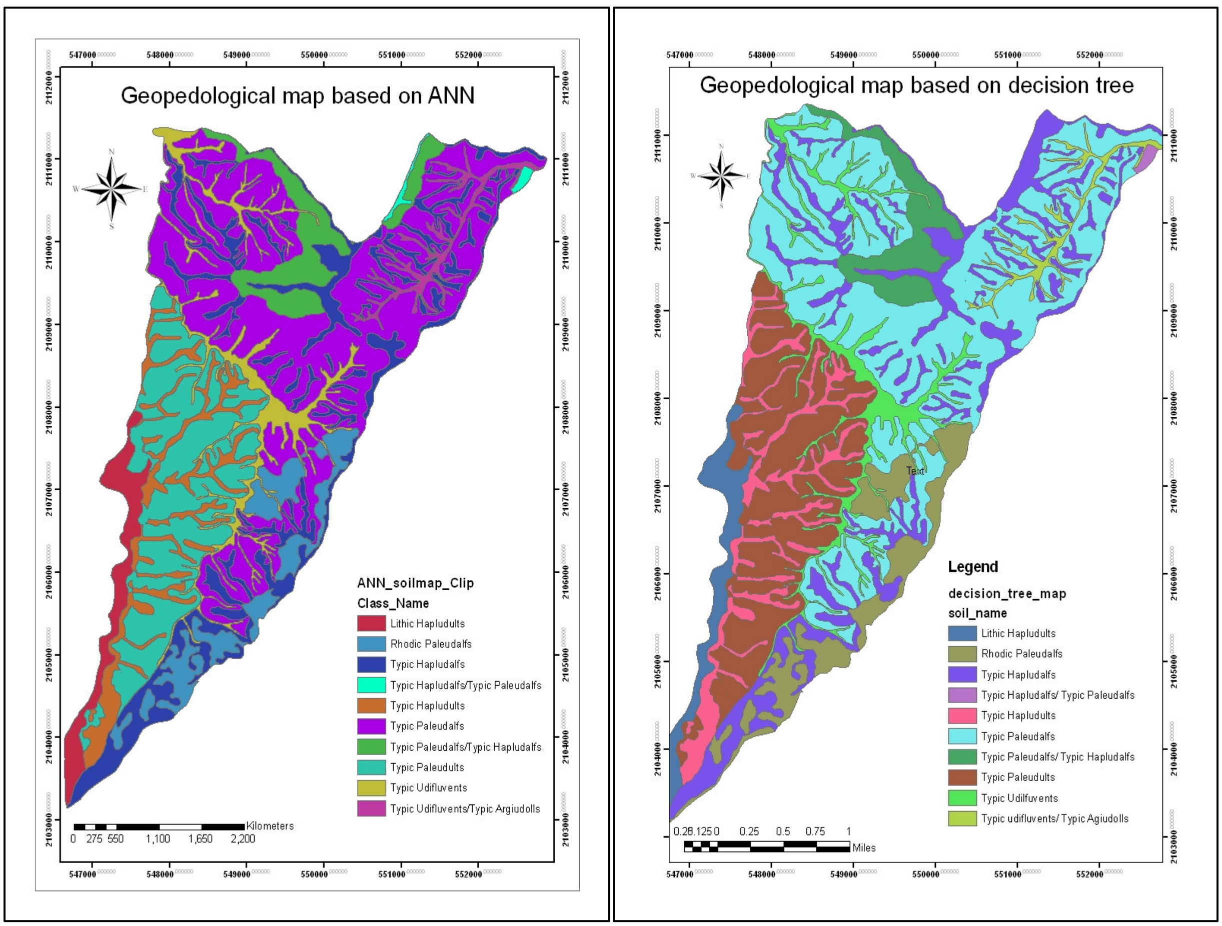
```
soilF=con(([landscape] == 2)  & ([relief] == 4)  & ([litho] == 7)   & ([landform] == 5) & ([organ] == 4)
&  ([time] == 3),1,0)
| con(([landscape] == 2)  & ([relief] == 6)  &  ([litho] == 7)  &  ([landform] == 5)  &  ([organ] == 4)
  &  ([time] == 3),1,0)
| con(([landscape] == 2)  & ([relief] == 6)  &  ([litho] == 10)  &  ([landform] == 5)  &  ([organ] == 3)  &
([time] == 3),1,0)
| con(([landscape] == 2)  & ([relief] == 6)  &  ([litho] == 10)  &  ([landform] == 5)  &  ([organ] == 3)  &
([time] == 3),1,0)
| con(([landscape] == 2)  & ([relief] == 6)  &  ([litho] == 8)  &  ([landform] == 5)  &  ([organ] == 2)  &
([time] == 3),1,0)
| con(([landscape] == 2)  & ([relief] == 1)  &  ([litho] == 6)  &  ([landform] == 1)  &  ([organ] == 4)  &
([time] == 3),1,0)
| con(([landscape] == 3)  & ([relief] == 4)  &  ([litho] == 8)  &  ([landform] == 5)  &  ([organ] == 2)  &
([time] == 3),1,0)
| con(([landscape] == 3)  & ([relief] == 6)  &  ([litho] == 8)  &  ([landform] == 5)  &  ([organ] == 2)  &
([time] == 3),1,0)

con(([landscape] == 2)  & ([relief] == 4)  &  ([litho] == 10)  &  ([landform] == 5)  &  ([organ] == 2)  &
([time] == 3),1,0)
```

```
soilG=con(([landscape] == 2)  & ([relief] == 4)  & ([litho] == 10)   & ([landform] == 5)  & ([organ] ==
3)  &  ([time] == 3),1,0)
```

Thereafter, in the individual soil map came out from the processes. The map integration used data management tool, append in ArcTool box for the combination map, the result map show in Figure 6.2b.

From the geopedological map, the prediction of soils in Hoi Num Rin sub-water shade were classified ; 4 orders, 4 suborders, 6 great groups and 10 subgroups cover whole of the area. Decision tree could predict and transfer the soil from the sampled sites to unsampled areas. The result: Lithic Hapludults cover 85 ha or 4%, Typic Paleudults cover 378 ha or 18%, Typic Hapludults cover 144 ha or 7%, Rhodic Paleudalfs cover 157 ha or 7%, Typic Hapludalfs cover 326 ha or 15%, Typic Paleudalfs cover 743 ha or 35%, Typic Paleudalfs/ Typic Hapludalfs cover 104 ha or 5%, Typic Hapludalfs/Typic Paleudalfs cover 4ha or 1%, Typic Udifluvents cover 129 ha or 6% and Typic Udifluvents/ Typic Argiudolls cover 35 ha or 2%.




**(a)** **(b)**

**Figure 6. 2: The predictive map (a) geopedological map derived from ANN method (b) geopedological map derived from decision tree method**

## 6.3 Generation of soil attribute maps (soil physical properties )

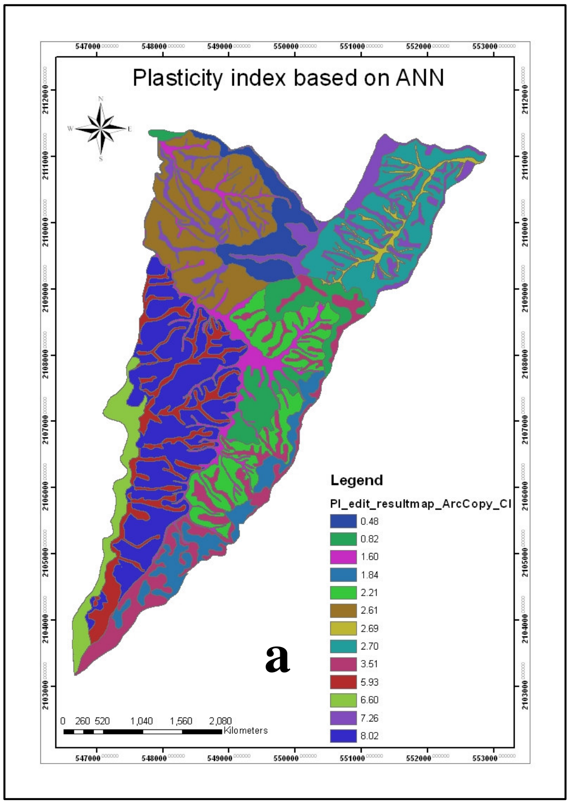
Some of soil physical properties were collected, in addition to the regular one, from the field, to use for landslide study. There are soil bulk density, soil shear strength and soil plasticity index. All the information were collected belong to the landform units that is 32 units for the prediction (Table 6.6) and 15 samples for the validation purpose. For soil shear strength data was collected in the field in B horizon. On the other hand soil for bulk density and plasticity index samples were taken to analyse in the soil physical laboratory. Thereafter, these data were taken to predict soil properties map. This process applied ANN method, following the same procedure as used in 5.4.1 and 6.2.2. The reason why the ANN method is used is because the comparison of the timing, as ANN is shorter than decision tree method, and it also lies on a more solid mathematical base.

**Table 6. 6: Soil attribute table for soil physical properties belong to landform unit**

| No. | Landform symbol | BD | LL | PL | PI | Shear | Landform description | Soil |
|---|---|---|---|---|---|---|---|---|
| 1 | MOC1111 | 1.36 | 33.11 | 26.51 | 6.60 | 3.34 | Summit and Shoulder complex | Lithic Hapludults |
| 2 | MOC1112 | 1.33 | 30.96 | 25.03 | 5.93 | 5.15 | Steep/very steep of slope com | Typic Hapludults |
| 3 | MOC1113 | 1.49 | 29.52 | 21.50 | 8.02 | 4.78 | Gentle/moderately of slope comp | Typic Paleudults |
| 4 | MOC1211 | 1.33 | 30.96 | 25.03 | 5.93 | 5.15 | Summit and Shoulder complex | Typic Hapludults |
| 5 | MOC1212 | 1.49 | 29.52 | 21.50 | 8.02 | 4.78 | Middle and foot slope complex | Typic Paleudults |
| 6 | MOPTRv111 | 1.34 | 39.36 | 37.52 | 1.84 | 4.00 | Summit and Shoulder complex | Rhodic Paleudalfs |
| 7 | MOPTRv112 | 1.35 | 22.35 | 28.84 | 3.50 | 4.00 | Middle and foot slope complex | Typic Hapludalfs |
| 8 | MOPTRv113 | 1.34 | 39.36 | 37.52 | 1.84 | 4.28 | Gentle/moderately of slope comp | Rhodic Paleudalfs |
| 9 | MOPTRv211 | 1.47 | 38.59 | 31.33 | 7.26 | 4.58 | Summit and Shoulder complex | Typic Hapludalfs |
| 10 | MOPTRv212 | 1.51 | 33.82 | 33.00 | 0.82 | 5.60 | Middle and foot slope complex | Typic Paleudalfs |
| 11 | MOPTRv221 | 1.47 | 38.59 | 31.33 | 7.26 | 4.58 | Summit and Shoulder complex | Typic Hapludalfs |
| 12 | MOPTRv222 | 1.41 | 30.90 | 30.42 | 0.48 | 4.26 | Middle and foot slope complex | Typic Paleudalfs/ Typic Hapludalfs |
| 13 | MOPTRv311 | 1.47 | 38.59 | 31.33 | 7.26 | 4.58 | Summit and Shoulder complex | Typic Hapludalfs |
| 14 | MOPTRv312 | 1.51 | 33.82 | 33.00 | 0.82 | 5.60 | Middle and foot slope complex | Typic Paleudalfs |
| 15 | MOPTRv321 | 1.47 | 38.59 | 31.33 | 7.26 | 4.58 | Summit and Shoulder complex | Typic Hapludalfs |
| 16 | MOPTRv322 | 1.44 | 31.45 | 28.84 | 2.61 | 3.04 | Middle and foot slope complex | Typic Paleudalfs |
| 17 | MOPTRv331 | 1.47 | 38.59 | 31.33 | 7.26 | 4.58 | Summit and Shoulder complex | Typic Hapludalfs |
| 18 | MOPTRv332 | 1.56 | 31.45 | 28.84 | 2.21 | 5.08 | Middle and foot slope complex | Typic Paleudalfs |
| 19 | MOPTRv411 | 1.51 | 33.82 | 33.00 | 0.82 | 5.60 | Erosional surface | Rhodic Paleudalfs |
| 20 | MOPTRv412 | 1.51 | 33.82 | 33.00 | 0.82 | 5.60 | Accumulation surface | Typic Paleudalfs |
| 21 | MOTRg111 | 1.47 | 38.59 | 31.33 | 7.26 | 4.58 | Summit and Shoulder complex | Typic Hapludalfs |
| 22 | MOTRg112 | 1.47 | 38.59 | 31.33 | 7.26 | 4.58 | Middle and foot slope complex | Typic Hapludalfs |
| 23 | MOTRg211 | 1.47 | 38.59 | 31.33 | 7.26 | 4.58 | Summit and Shoulder complex | Typic Hapludalfs |
| 24 | MOTRg212 | 1.42 | 18.52 | 15.82 | 2.70 | 4.26 | Middle and foot slope complex | Typic Paleudalfs |
| 25 | MOTRg311 | 1.47 | 38.59 | 31.33 | 7.26 | 4.58 | Summit and Shoulder complex | Typic Hapludalfs |
| 26 | MOTRg312 | 1.42 | 18.52 | 15.82 | 2.70 | 4.26 | Middle and foot slope complex | Typic Paleudalfs |
| 27 | MOTRg411 | 1.35 | 38.59 | 31.33 | 7.26 | 4.58 | Slope facet complex | Typic Hapludalfs/ Typic Paleudalfs |
| 28 | Va111 | 1.52 | 32.19 | 30.59 | 1.60 | 4.20 | Bottom side complex | Typic Udifluvents |
| 29 | Va121 | 1.52 | 32.19 | 30.59 | 1.60 | 4.20 | Bottom side complex | Typic Udifluvents |
| 30 | Va131 | 1.52 | 32.19 | 30.59 | 1.60 | 4.20 | Bottom side complex | Typic Udifluvents |
| 31 | Va141 | 1.52 | 32.19 | 30.59 | 1.60 | 4.20 | Bottom side complex | Typic Udifluvents |
| 32 | Va151 | 1.33 | 25.23 | 22.54 | 2.69 | 2.48 | Bottom side complex | Typic Udifluvents/ Typic Argiudolls |

### 6.3.1 Soil bulk density map

Soil bulk density data obtained form the field and laboratory can be classed into 13 values. Thereafter, the result map derived from ANN lets predict soil bulk density in unsampled area (Figure 6.3).

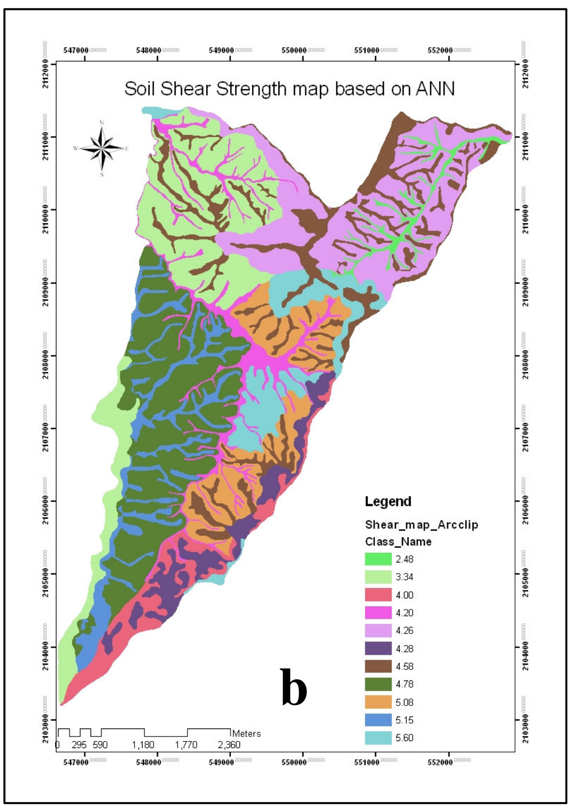



### 6.3.2 Soil shear strength

Soil shear strength data obtained form the field can be classed into 11 values. Thereafter, the result map derived from ANN lets predict soil bulk density in unsampled area (Figure 6.3).

### 6.3.3 Soil plasticity index

Soil plasticity index obtain form the field and laboratory can be classed into 12 values. Thereafter, the result map derived from ANN lets predict soil bulk density in unsampled area (Figure 6.3).



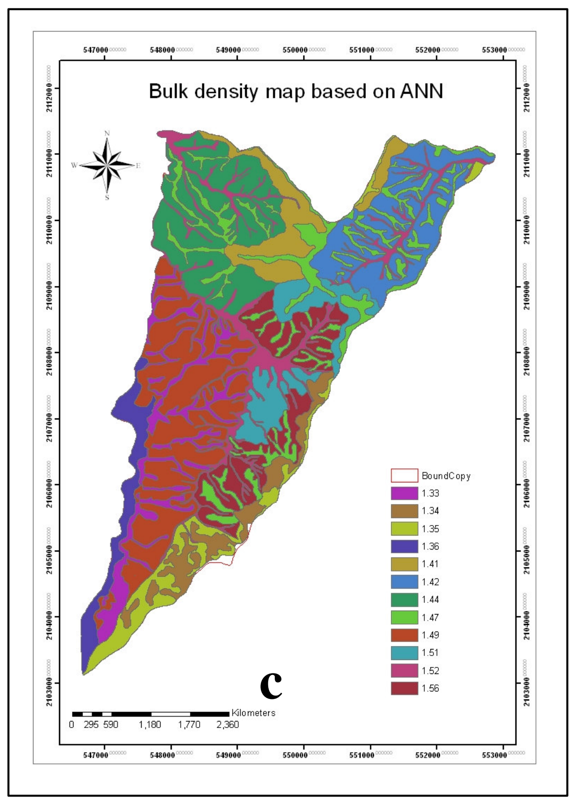




**Figure 6. 3: Soil properties map derived from ANN (a) soil bulk density map(b) soil shear strength map and (c) soil plasticity index map**

## 6.4 Map validation

As the output, geopedological map and soil physical property maps were produced in a predictive way. The results of the extrapolation of what is it learnt in the three sample areas? There are 69 soil profiles and mini-pits, in 32 landform units. Validation data of geopedological map was collected by augur hole, 57 augers, separately. The data was taken to validate the result of the predictive soil mapping, and compared with the result from geopedological map derived from ANN. The validations were performed in three way as follows:

a) Comparing the 54 auger hole descriptions versus geopedological map derived from ANN.

b) Comparing the geopedological map derived from decision tree versus geopedological map derived from ANN.

c) Comparing the LDD versus geopedological map derived from ANN.

The results of the validation are shown in the table 6.6.

On the other hand, the validation data of soil physical properties was observed and collected with the coordinate, there are only 15 data was collected due to the limitation of soil analysis cost. The soil data was crossed over the soil map. In the same point which had both of the observation and soil map data, exported to SPSS software for the statistic analysis, using linear regression. The results are shown in figure 6.4.

### 6.4.1 Comparing the 57 auger hole descriptions versus ANN predictive geopedological map

The observed point data covered in the study area. The validation result as table 6.6 shows that, order and suborder level are very high degree of accuracy. Particularly in suborder, the matching is 100% that is the key to determine the moisture regime (udic moisture regime) was used to classify to suborder. Concerning the greatgroup and subgroup level, the result is high accuracy there are about 75.44% and 89.47 %, respectively. Due to, it is difficult to make sure about the correct data of soil chemical data.

### 6.4.2 Comparing the decision tree predictive soil map versus neural network predictive geopedological map

The high percentage (100%) of accuracy had found in soil order and suborder level. As the same parameter predictors were used to predict the soil in the same area. In great group and subgroup levels represent the good result there are 97 and 95 %, respectively.

### 6.4.3 Comparing the neural network predictive predictive geopedological map versus the LDD soil map

The low percentages of the accuracy were found in all of order, suborder, great group and subgroup levels (47.7, 53.0, 26 and 46).

The order, suborder and subgroup level, the result of the comparison was moderately accuracy. The previous map represents a lot of different order, such as Ultisols versus Alfisols, Alfisols versus Entisols and Alfisols versus Mollisols. As we see the difference, in the previous map classified to Ultisols but in a new map gave Altisols in the area in Mo of C1. Generally, the morphology of Ultisols is similar to Alfisols, but only the percentages of base saturation in Ultisols is lower than Alfisol (lower than 35% in Ultisols, and 35-70% in Alfisols). The percentages of base saturation can be assumed from the pH as Kunaporn (1988) studied about the correlation of soil pH and percentage of base saturation in the difference soil moisture regime, Thailand. The results shown that, soil pH in udic moisture regime pH is 5 and the particle size class is clayey and percentage of base saturation is 11%. According to the data from field observation in all of the part in the area which derived form shale. The pH in the control section (180 cm or upper densic, lithib or paralithic contact) is 5.0 or lower and this area has udic moisture regime (chepter 5), and then we assumed that in this area can be classified to order level is Ultisols. The same difficulty is when we want to differentiate between Alfisols and Entisols. Alfisol has B horizon (argillic) but Entisols do not contain this horizon. Entisols which found in the study area in the relief type is vale and the landfrom is bottom side complex, in the low lying area as vale, all most of the year this area has the transportation and sedimentation. Therefore soil in this area can not develop B horizon, argillic horrizon. Another difficulty is the differentiatation between Alfisols and Mollisols, the color of soil in Mollisols should has dark or very dark, mollic epipedon. The dominant colousr are hue value and croma is 3 or less, and has 18 cm thickness. In the field check, the colour is may be the error during the study. The suborder, the soil moisture regime was considered to class to greatgroup level. Some part of the study area of the previous map classified greatgroup level to ustic moisture regime, but the new map classified to udic moisture regime (chepter 5). The subgroup has to differentiate several of soil morphology which used to classify to subgroup level. The difference of two maps was found such as typic versus aeric, typic versus oxyaquic, typic versus lithic, typic versus rhodic, rhodic versus aeric, and rhodic versus oxyaquic. It really difficult to differentiate the soil colour to define the dark reddish or red soil, it may be the mistake during the field check of soil colour with munshell colour book and the skill of soil surveyor. The differentiation of lithic and typic, is difficult to check by auguring and in the area which has wavy horizon. Generally, lithic soil should have lithic contact within 50 cm from the soil surface. And it is very difficult to define the saturated day by field check, which can be tested by tensiometer. Therefore sometimes we have to classify to typic.

**Table 6. 7: Data validation conclusion for the geopedological map of Hoi Num Rin sub-watershed**

| Validation | Percent matching level | | | |
|---|---|---|---|---|
| | Order | Suborder | Great group | Subgroup |
| Auger hole& ANN geopedological map | 94.74 | 100.00 | 75.44 | 89.47 |
| Decission tree& ANN geopedological map | 100.00 | 100.00 | 96.51 | 95.35 |
| LDD&ANN geopedological map | 47.17 | 53.00 | 26.00 | 42.00 |
| Overall | 63.03 | 68.55 | 42.76 | 57.50 |
| *after combined Alfisols&Ultisols, Inceptisols&Entisols | | | | |

### 6.4.4 Relationship of soil bulk density map from prediction map and observation data

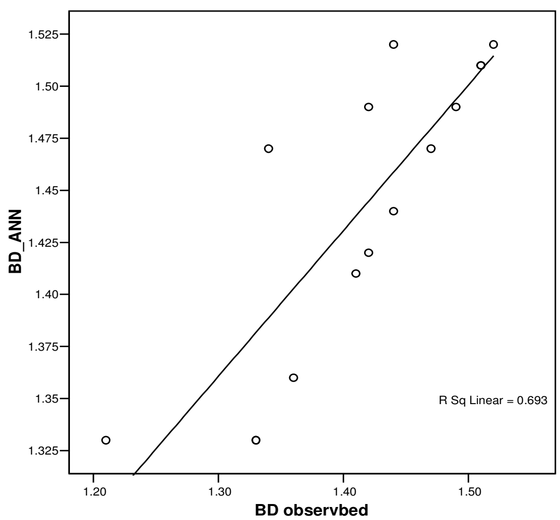
This part studied about the relationship of soil bulk density which derived from predictive map versus the separate validation data from the observation. The observation data of soil bulk density were taken as 15 data with the coordinate. The data were taken to the validation process, using the intersection tool in ArcGIS to join the data in the same area. Thereafter, join table data was imported the to SPSS software. The correlation of two data sets was calculated using linear regression correlation. The result shows that, the predictive soil map has a good correlation with the observation data, $R^2$ =0.69 (Figure 6.4).

### 6.4.5 Relationship of soil shear strength map from predictive soil map and soil shear strength from observed point data

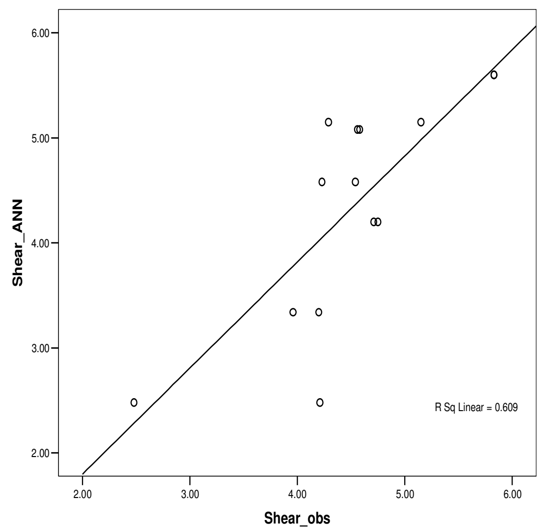
Soil shear strength data from the observed data was taken as 15 data, with the coordinate in the study area. The procedure which used to calculate is the same with the soil bulk density (6.4.4), but used shear strength map. The result, the linear regression correlation was calculated and the result shows that predictive map has a good correlation with the observation data, $R^2$ =0.60 (Figure 6.4).

### 6.4.6 Relationship of soil plasticity index map from predictive soil map and plasticity index from observed point data

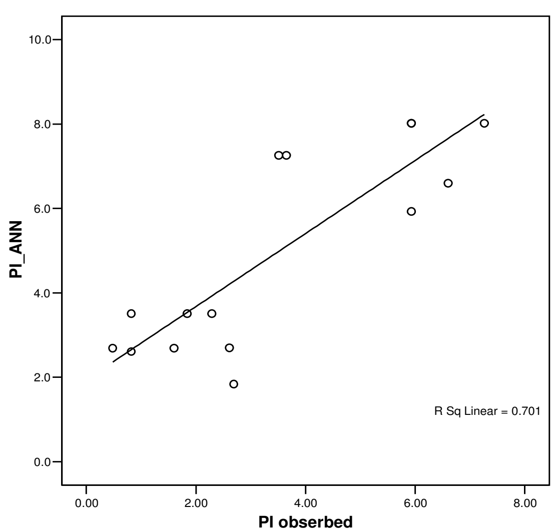
Soil plasticity index data for the validation part were taken as 15 data with the coordinate in the study area. The observation data used the same process with the soil bulk density (6.4.4), but join the data with plasticity index map. The result, the linear regression correlation was calculated and the result shows that predictive map has a good correlation with the observation data, $R^2$ =0.70 (Figure 6.4).




(a)




(b)




(c)

**Figure 6. 4: Scatter plots of soil properties from predictive soil map versus observation data soil bulk density (b) soil shear strength (c) Plasticity Index**

## 6.5 Relationship between soil and landslide

The study of the relationship between soil maps and landslide feature used 15 landslide features in the study area (see 5.4). Thereafter landslide coordinate was taken to overlay on the predictive soil map to evaluate the relation. The results of the relation of landslide and soil are follows.

**Table 6. 8: Relation of landslide and soil**

| Landslide No. | Landform | lithology | Soil name | Soil bulk density (g/soil 100 g) | Shear strength | Plasticity index |
|---|---|---|---|---|---|---|
| 1 | Middle and foot slope complex | RS and CV from Shale/Phyllite | Typic Paleudalfs | 1.44 | 3.34 | 2.61 |
| 2 | Middle and foot slope complex | RS and CV from Shale/Phyllite | Typic Paleudalfs | 1.44 | 3.34 | 2.61 |
| 3 | Middle and foot slope complex | RS and CV from Shale/Phyllite | Typic Paleudalfs | 1.44 | 3.34 | 2.61 |
| 4 | Middle and foot slope complex | RS and CV from Shale/Phyllite | Typic Paleudalfs | 1.44 | 3.34 | 2.61 |
| 5 | Middle and foot slope complex | RS and CV from Shale/Phyllite | Typic Paleudalfs | 1.44 | 3.34 | 2.61 |
| 6 | Middle and foot slope complex | RS and CV from Shale/Phyllite | Typic Paleudalfs | 1.44 | 3.34 | 2.61 |
| 7 | Middle and foot slope complex | RS and CV from Andisite | Typic Paleudalfs | 1.56 | 5.08 | 2.21 |
| 8 | Middle and foot slope complex | RS and CV from Andisite | Typic Paleudalfs | 1.56 | 5.08 | 2.21 |
| 9 | Middle and foot slope complex | RS and CV from Shale | Typic Paleudults | 1.49 | 4.78 | 8.02 |
| 10 | Middle and foot slope complex | RS and CV from Shale | Typic Paleudults | 1.49 | 4.78 | 8.02 |
| 11 | Middle and foot slope complex | RS and CV from Shale | Typic Paleudults | 1.49 | 4.78 | 8.02 |
| 12 | Middle and foot slope complex | RS and CV from Andisite | Typic Paleudalfs | 1.56 | 5.08 | 2.21 |
| 13 | Summit and Shoulder complex | RS and CV from Andisite | Typic Hapludalfs | 1.47 | 4.58 | 3.51 |
| 14 | Middle and foot slope complex | RS and CV from Shale | Typic Paleudults | 1.49 | 4.78 | 8.02 |
| 15 | Middle and foot slope complex | RS and CV from Shale | Typic Paleudults | 1.49 | 4.78 | 8.02 |

### 6.5.1 Relation between soil, landform and lithology and landslide features

The results from table 6.7 show that mostly landslide occurred in middle and foot slope complex and lithological type with play important role to landslide is shale, phyllite and andisite. Landslides occurred in soil name are Typic Paleudalfs, Typic Paleudults and Typic Hapludalfs ; 53%, 40 and 7 %, respectively.

### 6.5.2 Relation between soil bulk density and landslide

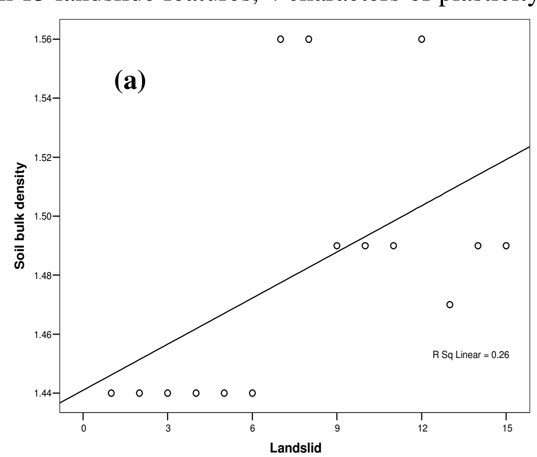
The relation of landslide and soil bulk density from 15 landslide features 4 characters of bulk density form 13 (1.44, 1.47, 1.49 and 1.56, see Table 6.8), 6 features or 40% occurred in the area which has soil bulk density is 1.44, 5 features or 33% occurred in the area which has bulk density is 1.49, 3 features or 20% occurred in the area which has bulk density is 1.56 and 1 feature or 7% occurred in the area which has bulk density is 1.47. The correlation of landslide and bulk density, $R^2$ = 0.26 (Figure 6.5).

### 6.5.3 Relation between soil shear strength and landslide

The relation of landslide and soil shear strength from 15 landslide features, 4 characters of bulk density from 13 (2.21, 2.61, 3.51 and 8.02, see Table 6.8), 6 features or 40% occurred in the area which has shear strength is, 1.44, 5 features or 33% occurred in the area which has shear strength is 8.02, 3 features or 20% occurred in the area which has shear strength is 2.21 and 1 feature or 7% occurred in the area which has shear strength is 3.51. The correlation of landslide and shear strength, $R^2$ =0. 63 (Figure 6.5).

### 6.5.4 Relation between plasticity index and landslide

The relation of landslide and soil plasticity index from 15 landslide features, 4 characters of plasticity index form 13 (3.34, 4.58, 4.47 and 5.08, see Table 6.8), 6 features or 40% occurred in the area which has plasticity index is, 3.34, 5 features or 33% occurred in the area which has plasticity index is 4.78, 3 features or 20% occurred in the area which has plasticity index is 5.08 and 1 feature or 7% occurred in the area which has shear strength is 4.58. The correlation of landslide and plasticity index, $R^2$ = 0.42 (Figure 6.5).



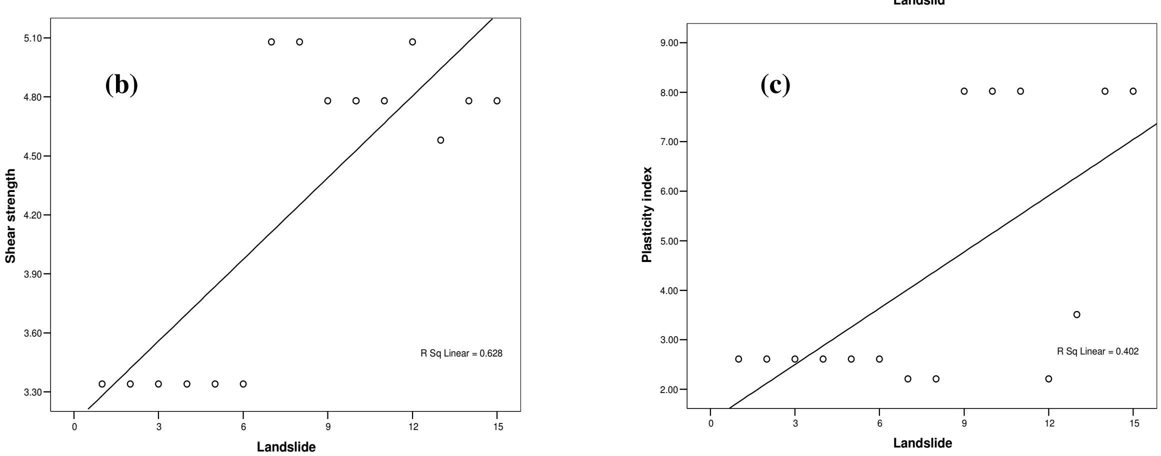




**Figure 6. 5: Scatter plots of landslide feature and soil properties from predictive soil map (a) soil bulk density (b) soil shear strength (c) Plasticity index**

# Chapter 7: Conclusions and Recommendations

## 7.1 Conclusion

In this study, we apply some of the techniques to predictive geopedological mapping (soil map) and try to highlight the role of soil in the study of landslide occurrence in an area in Thailand with a set of geopedologic settings and climatic conditions, as described under "The study area". From the result, the following conclusions can be drawn.

Regarding the soil forming factors, from Jenny equation and the SCORPAN model, the major parameters which play important role in the study area are organism (O), relief ®, parent material (lithology=P), time (soil profile development), and spatial geographic position (landscape and landform).

Geopedological map (soil map) in inaccessible areas can be produced in a predictive way using geopedologic approach applying artificial neural network (ANN) methods.

Artificial neural network method, three multi-layer feedforward-backpropagation networks were constructed; the input layer was the soil forming factors, the output layers were the set of soil classification names. The representatives of the sample areas were select from geoform map, over the landform units. The idea was to learn the relationship between soils and their invironments (based on soil forming factors) in sample areas, thereafter predicted (extrapolatedt) to unsampled area. Three ways were used to evaluate the geopedological map derived from ANN. The validation data were:

a. 57 observations (the data from auger holes),

b. decision tree-derived map,

c. the previous map from LDD (scale 1:10,000).

The validation was done at the level of subgroups only. Results of a. and b (see above) show high accuracy, however, more than the matching with the c. (see above).

The ANN methos was also used to produce the soil physical properties' maps. The same input layers (to prdict soil classication names= classes; mentioned above) were used to come to classes of bulk density, shear strength, and plastic index (all as output layer). The collected data in the field on the mentioned properties were used to train the network. The data were collected in landform units, as the landform is believed to be the best indicator of the soil attributes; the soils developed in the different positions are different. To evaluate the soil physical property maps derived from ANN (soil bulk density, shear strength and plasticity index map), the (validation) data was collected from sites spread over the whole study area. Linear regression was used to validate and learn the correlation. The result is quite satisfactory, showing high correlation between soil property maps (soil bulk density, shear strength and plasticity index map) and the (validation) data; as high as 69, 60 and 70%, respectively.

The advantage of applying ANN to predictive soil mapping is clear from this study. The resulted soil map is considerably accurate (a high accuracy in the case of soil classification names (classes), and a fair results in the case of soil attribute maps). Moreover, the ANN proved to be fast; important in terms of time-saving and cost effectiveness. As compared to the results of method, where DT were used, remarkable results were obtained using ANN. On the other hand, the disadvantage of ANN is that it is difficult in the training phase in the ANN process. As a very important conclusion it should be said that a skilled operator is a must.

The relation between landslide occurrence and geopedological soil map derived from ANN, soil physical properties (soil bulk density, soil shear strength and soil plasticity index). The most landslides have occurred in middle (backslope) and foot slope complex, and to a lesser extent, in submit and shoulder complex. Lithological types which play important role to landslide are shale, phyllite and andesite. It is also concluded that landslides have occurred in Typic Paleudalfs, Typic Paleudults and Typic Hapludalfs. The soil bulk density values impact to landslide is 1.44 to 1.56 g/soil 100 g, but the correlation is very low, that is, 26%. The soil shear strength values with impact on landslide are about 2.21to 8.02, with high correlation, that is, 63%. The soil plastic index values with impact on landslide are 3.34 to 5.08 with a moderate correlation, that is, 42%.

## 7.2 Recommendation

Based on the conclusions, it is recommended that:

1. The geopedologic approach considerably helps predictive soil mapping in inaccessible area.
2. The decision tree method must be generated and well understood when applied to a different area.
3. The artificial neural network can be processed in several software programs, and not only in ENVI. It is still recommendable to apply and compare the result with the other software programs.
4. More attention should be paid to the application of ANN in the predictive soil mapping, particularly, in the case of soil physical properties. The results seemed not as satisfactory as those of soil classification names (classes) map. Here, it should also be said that to collect data in field on shear strength in different soil depth (using auger holes) is problematic. The limitation of the software "ENVI" should be considered too. Attention should be paid on learning how to proceed about the

network parameters (examples: iteration, maximum error, and momentum…etc). Futhermore, it may need to apply another software, for instance, matlab and/or java neural network to produce soil attribute map. In addition, it may be so that landform unit (what we did in this study) is not a good entry for the soil physical properties, but for soil classes (classification names).

5. For the landslide vulnerability study, more information is required. It is not only soils that can have effect on landslide, but also the other parameters such as goundwater, rainfall intensity, slope, landuse changing, etc,.

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# 9 Appendices

**Appendix 1 : Temperature, Humidity and Rainfall**

| Month | temperature(C) | | | Humidity (%) | | | Rainfall |
|---|---|---|---|---|---|---|---|
| | Max | Min | Ave | morning | afternoon | Ave | (m.) |
| January | 28.4 | 14.1 | 20.2 | 80.8 | 61.3 | 71.1 | 4.3 |
| February | 30.6 | 16.2 | 22.3 | 77.6 | 52.8 | 65.2 | 8.2 |
| March | 34.8 | 19.4 | 26.0 | 71.0 | 45.6 | 58.3 | 50.0 |
| April | 33.8 | 20.8 | 26.2 | 79.3 | 61.3 | 70.3 | 154.0 |
| May | 32.5 | 20.9 | 25.9 | 84.4 | 71.2 | 77.8 | 293.7 |
| June | 32.0 | 21.0 | 25.7 | 88.0 | 76.0 | 82.0 | 248.3 |
| July | 30.2 | 20.7 | 24.8 | 90.9 | 81.1 | 86.0 | 148.4 |
| August | 29.9 | 20.4 | 24.5 | 91.0 | 83.3 | 87.2 | 288.8 |
| September | 30.2 | 20.1 | 24.4 | 91.5 | 82.2 | 86.8 | 398.6 |
| October | 29.4 | 19.6 | 23.8 | 89.6 | 80.2 | 84.9 | 282.2 |
| November | 28.8 | 17.6 | 22.3 | 88.4 | 77.5 | 83.0 | 57.2 |
| December | 25.7 | 14.6 | 19.3 | 84.9 | 69.4 | 77.1 | 39.7 |
| Total | - | - | - | - | - | - | 1973.4 |
| average | 30.5 | 18.8 | 23.8 | 84.8 | 70.2 | 77.5 | - |

Source: Hoi Num Rin Royal project station

**Appendix 2 : Cliamate data**

| Year | Rain day | Rain | PET | MS | Consecutive dry day | Est. (MS) | Total surplus rain | Total ffective rain | Total dry day | Total wet day | Moisture regimes |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1996 | 6 | 95.4 | 1287.2 | 397.2 | 110 | 89 | 28 | 67.4 | 240 | 126 | Ustic |
| 1997 | 6 | 95.4 | 1287.2 | 399.9 | 110 | 85 | 0.7 | 94.7 | 243 | 122 | Ustic |
| 1998 | 12 | 217.8 | 1287.2 | 399.9 | 25 | 85 | 0.7 | 217.1 | 139 | 226 | Ustic |
| 1999 | 118 | 2245 | 1287.2 | 399.9 | 1 | 248 | 1842.9 | 402.1 | 1 | 364 | Udic |
| 2000 | 122 | 2469.4 | 1287.2 | 397.2 | 13 | 260 | 2093 | 376.4 | 20 | 346 | Udic |
| 2001 | 99 | 2325.1 | 1287.2 | 399.9 | 38 | 214 | 2026 | 299.1 | 50 | 315 | Udic |
| 2002 | 118 | 2729.6 | 1287.2 | 399.9 | 35 | 263 | 2377.6 | 352 | 38 | 327 | Udic |
| 2003 | 132 | 1668.9 | 1287.2 | 399.9 | 21 | 234 | 1333.3 | 335.6 | 46 | 319 | Udic |
| 2004 | 114 | 1597.3 | 1287.2 | 397.2 | 32 | 248 | 1278.8 | 318.5 | 49 | 317 | Udic |
| 2005 | 110 | 1934.7 | 1287.2 | 399.9 | 13 | 249 | 1574.4 | 360.3 | 25 | 340 | Udic |

# Appendix 2: Comparision between the auger hole description and the geopedological map derived from ANN

| Auger no. | Auger hole | Geopedological map from ANN | Order | Suborder | Greatgroup | Subgroup |
|---|---|---|---|---|---|---|
| 1 | Typic Paleudalfs | Typic Paleudalfs | 1 | 1 | 1 | 1 |
| 2 | Typic Paleudults | Typic Paleudalfs | 1 | 1 | 1 | 1 |
| 3 | Typic Hapludalfs | Typic Hapludalfs | 1 | 1 | 1 | 1 |
| 4 | Rhodic Peleudalfs | Typic Paleudalfs | 1 | 1 | 1 | 0 |
| 5 | Typic Hapludults | Typic Paleudalfs | 1 | 1 | 0 | 1 |
| 6 | Typic Peleudultfs | Typic Paleudults | 1 | 1 | 1 | 1 |
| 7 | Typic Hapludults | Typic Hapludalfs | 1 | 1 | 1 | 1 |
| 8 | Typic Paleudalfs | Typic Paleudalfs | 1 | 1 | 1 | 1 |
| 9 | Typic Hapludalfs | Typic Paleudalfs | 1 | 1 | 0 | 1 |
| 10 | Typic Hapludalfs | Typic Hapludalfs | 1 | 1 | 1 | 1 |
| 11 | Typic Hapludalfs | Typic Paleudalfs | 1 | 1 | 0 | 1 |
| 12 | Typic Hapludalfs | Typic Hapludalfs | 1 | 1 | 0 | 1 |
| 13 | Typic Udifluvents | Typic Udifluvents | 1 | 1 | 1 | 1 |
| 14 | Rhodic Paleudalfs | Typic Paleudults | 0 | 1 | 1 | 0 |
| 15 | Typic Hapludalfs | Typic Paleudults | 0 | 1 | 0 | 1 |
| 16 | Typic Paleudults | Typic Hapludults | 1 | 1 | 0 | 1 |
| 17 | Typic Udifluvents | Typic Udifluvents | 1 | 1 | 1 | 1 |
| 18 | Typic Udifluvents | Typic Udifluvents | 1 | 1 | 1 | 1 |
| 19 | Typic Paleudalfs | Typic Paleudalfs | 1 | 1 | 1 | 1 |
| 20 | Rhodic Paleudalfs | Rhodic Paleudalfs | 1 | 1 | 1 | 1 |
| 21 | Rhodic Paleudalfs | Rhodic Paleudalfs | 1 | 1 | 1 | 0 |
| 22 | Typic Hapludalfs | Typic Hapludults | 0 | 1 | 1 | 1 |
| 23 | Typic Hapludalfs | Rhodic Paleudalfs | 1 | 1 | 0 | 0 |
| 24 | Typic Paleudults | Typic Paleudults | 1 | 1 | 1 | 0 |
| 25 | Typic Paleudults | Typic Paleudults | 1 | 1 | 1 | 1 |
| 26 | Typic Hapludalfs | Typic Hapludalfs | 1 | 1 | 1 | 1 |
| 27 | Typic Hapludalfs | Typic Hapludalfs | 1 | 1 | 1 | 1 |
| 28 | Typic Paleudalfs | Typic Paleudalfs | 1 | 1 | 1 | 1 |
| 29 | Typic Argiudolls | Typic Udifluvents/Typic Argiudolls | 1 | 1 | 1 | 1 |
| 30 | Typic Argiudolls | Typic Udifluvents/Typic Argiudolls | 1 | 1 | 1 | 1 |
| 31 | Typic Udifluvent | Typic Udifluvents/Typic Argiudolls | 1 | 1 | 1 | 1 |
| 32 | Typic Argiudolls | Typic Udifluvents/Typic Argiudolls | 1 | 1 | 1 | 1 |
| 33 | Typic Paleudalfs | Typic Paleudalfs | 1 | 1 | 1 | 1 |
| 34 | Typic Hapludalfs | Typic Paleudalfs | 1 | 1 | 0 | 1 |
| 35 | Typic Paleudults | Typic Paleudults | 1 | 1 | 1 | 1 |
| 36 | Lithic Happludults | Lithic Hapludults | 1 | 1 | 1 | 1 |
| 37 | Typic Paleudalfs | Typic Hapludalfs | 1 | 1 | 0 | 1 |
| 38 | Typic Hapludults | Typic Hapludults | 1 | 1 | 1 | 1 |
| 39 | Typic Paleudults | Typic Paleudults | 1 | 1 | 1 | 1 |
| 40 | Typic Udifluvents | Typic Udifluvents | 1 | 1 | 1 | 1 |
| 41 | Typic Paleudalfs | Typic Hapludalfs | 1 | 1 | 0 | 1 |
| 42 | Typic Paleudalfs | Typic Hapludalfs | 1 | 1 | 0 | 1 |
| 43 | Typic Paleudalfs | Typic Paleudalfs | 1 | 1 | 1 | 1 |
| 44 | Typic Paleudalfs | Typic Hapludalfs | 1 | 1 | 0 | 1 |
| 45 | Typic Hapludults | Typic Hapludults | 1 | 1 | 1 | 1 |
| 46 | Lithic Hapludults | Lithic Hapludults | 1 | 1 | 1 | 1 |
| 47 | Typic Paleudults | Typic Paleudults | 1 | 1 | 1 | 1 |
| 48 | Typic Hapludalfs | Typic Hapludalfs | 1 | 1 | 1 | 1 |
| 49 | Oxyaquic Udifluents (Typic Udifluvents) | Typic Udifluvents | 1 | 1 | 1 | 1 |

| Auger no. | Auger hole | Geopedological map from ANN | Order | Suborder | Greatgroup | Subgroup |
|---|---|---|---|---|---|---|
| 50 | Typic Hapludults | Typic Hapludults | 1 | 1 | 1 | 1 |
| 51 | Typic Udicfluvents | Typic Udifluvents | 1 | 1 | 1 | 1 |
| 52 | Rhodic Paleudalfs | Rhodic Paleudalfs | 1 | 1 | 1 | 1 |
| 53 | Rhodic Paleudalfs | Rhodic Paleudalfs | 1 | 1 | 1 | 1 |
| 54 | Typic Paleudalfs | Typic Hapludalfs | 1 | 1 | 0 | 1 |
| 55 | Rhodic Paleudalfs | Rhodic Paleudalfs | 1 | 1 | 1 | 1 |
| 56 | Rhodic Paleudalfs | Rhodic Paleudalfs | 1 | 1 | 1 | 1 |
| 57 | Rhodic Paleudalfs | Typic Hapludalfs | 1 | 1 | 0 | 0 |
| Total | | | 54 | 57 | 43 | 51 |
| % area matching | | | 94.74 | 100.00 | 75.44 | 89.47 |
| Remake: 1= Matching, 0 = Unmatching | | | | | | |

## Appendix 3: Comparision between the geological map derived from decision tree and ANN methods

| Geopedological map from Desion tree | Geopedological map from ANN | Order | Sub-order | Great-group | Sub-group |
|---|---|---|---|---|---|
| Typic Paleudalfs | Typic Paleudalfs | 1 | 1 | 1 | 1 |
| Typic Paleudalfs | Typic Paleudalfs | 1 | 1 | 1 | 1 |
| Typic Paleudalfs | Typic Paleudalfs | 1 | 1 | 1 | 1 |
| Typic Paleudalfs | Typic Paleudalfs | 1 | 1 | 1 | 1 |
| Typic Paleudalfs | Typic Paleudalfs | 1 | 1 | 1 | 1 |
| Typic Paleudalfs | Typic Paleudalfs | 1 | 1 | 1 | 1 |
| Typic Paleudalfs | Typic Paleudalfs | 1 | 1 | 1 | 1 |
| Typic Paleudalfs | Typic Paleudalfs | 1 | 1 | 1 | 1 |
| Typic Paleudalfs | Typic Paleudalfs | 1 | 1 | 1 | 1 |
| Typic Paleudalfs | Typic Paleudalfs | 1 | 1 | 1 | 1 |
| Typic Paleudalfs | Typic Paleudalfs | 1 | 1 | 1 | 1 |
| Typic Paleudalfs | Typic Paleudalfs | 1 | 1 | 1 | 1 |
| Typic Paleudalfs | Typic Paleudalfs | 1 | 1 | 1 | 1 |
| Typic Paleudalfs | Typic Paleudalfs | 1 | 1 | 1 | 1 |
| Typic Udilfuvents | Typic Udifluvents | 1 | 1 | 1 | 1 |
| Typic Udilfuvents | Typic Udifluvents | 1 | 1 | 1 | 1 |
| Lithic Hapliudults | Lithic Hapludults | 1 | 1 | 1 | 1 |
| Typic Hapludults | Typic Hapludults | 1 | 1 | 1 | 1 |
| Typic Hapludults | Typic Hapludults | 1 | 1 | 1 | 1 |
| Typic Hapludults | Typic Hapludults | 1 | 1 | 1 | 1 |
| Typic Hapludults | Typic Hapludults | 1 | 1 | 1 | 1 |
| Typic Hapludults | Typic Hapludults | 1 | 1 | 1 | 1 |
| Typic Hapludults | Typic Hapludults | 1 | 1 | 1 | 1 |
| Typic Hapludults | Typic Hapludults | 1 | 1 | 1 | 1 |
| Typic Hapludults | Typic Hapludults | 1 | 1 | 1 | 1 |
| Typic Hapludults | Typic Hapludults | 1 | 1 | 1 | 1 |
| Typic Hapludults | Typic Hapludults | 1 | 1 | 1 | 1 |
| Typic Paleudults | Typic Paleudults | 1 | 1 | 1 | 1 |
| Typic Paleudults | Typic Paleudults | 1 | 1 | 1 | 1 |
| Typic Paleudults | Typic Paleudults | 1 | 1 | 1 | 1 |
| Rhodic Paleudalfs | Rhodic Paleudalfs | 1 | 1 | 1 | 1 |
| Rhodic Paleudalfs | Rhodic Paleudalfs | 1 | 1 | 1 | 1 |
| Rhodic Paleudalfs | Rhodic Paleudalfs | 1 | 1 | 1 | 1 |
| Rhodic Paleudalfs | Rhodic Paleudalfs | 1 | 1 | 1 | 1 |
| Rhodic Paleudalfs | Rhodic Paleudalfs | 1 | 1 | 1 | 1 |
| Rhodic Paleudalfs | Typic Hapludalfs | 1 | 1 | 0 | 0 |

| Geopedological map from Desion tree | Geopedological map from ANN | Order | Sub-order | Great-group | Sub-group |
|---|---|---|---|---|---|
| Rhodic Paleudalfs | Rhodic Paleudalfs | 1 | 1 | 1 | 1 |
| Rhodic Paleudalfs | Typic Hapludalfs | 1 | 1 | 0 | 0 |
| Rhodic Paleudalfs | Rhodic Paleudalfs | 1 | 1 | 1 | 1 |
| Rhodic Paleudalfs | Rhodic Paleudalfs | 1 | 1 | 1 | 1 |
| Rhodic Paleudalfs | Rhodic Paleudalfs | 1 | 1 | 1 | 0 |
| Rhodic Paleudalfs | Typic Hapludalfs | 1 | 1 | 0 | 0 |
| Typic Hapludalfs | Typic Hapludalfs | 1 | 1 | 1 | 1 |
| Typic Hapludalfs | Typic Hapludalfs | 1 | 1 | 1 | 1 |
| Typic Hapludalfs | Typic Hapludalfs | 1 | 1 | 1 | 1 |
| Typic Hapludalfs | Typic Hapludalfs | 1 | 1 | 1 | 1 |
| Typic Hapludalfs | Typic Hapludalfs | 1 | 1 | 1 | 1 |
| Typic Hapludalfs | Typic Hapludalfs | 1 | 1 | 1 | 1 |
| Typic Hapludalfs | Typic Hapludalfs | 1 | 1 | 1 | 1 |
| Typic Hapludalfs | Typic Hapludalfs | 1 | 1 | 1 | 1 |
| Typic Hapludalfs | Typic Hapludalfs | 1 | 1 | 1 | 1 |
| Typic Hapludalfs | Typic Hapludalfs | 1 | 1 | 1 | 1 |
| Typic Hapludalfs | Typic Hapludalfs | 1 | 1 | 1 | 1 |
| Typic Hapludalfs | Typic Hapludalfs/Typic Paleudalfs | 1 | 1 | 1 | 1 |
| Typic Hapludalfs | Typic Paleudalfs/Typic Hapludalfs | 1 | 1 | 1 | 1 |
| Typic Hapludalfs | Typic Hapludalfs | 1 | 1 | 1 | 1 |
| Typic Hapludalfs | Typic Hapludalfs | 1 | 1 | 1 | 1 |
| Typic Hapludalfs | Typic Hapludalfs | 1 | 1 | 1 | 1 |
| Typic Hapludalfs | Typic Hapludalfs | 1 | 1 | 1 | 1 |
| Typic Hapludalfs | Typic Hapludalfs | 1 | 1 | 1 | 1 |
| Typic Hapludalfs | Typic Hapludalfs | 1 | 1 | 1 | 1 |
| Typic Hapludalfs | Typic Hapludalfs | 1 | 1 | 1 | 1 |
| Typic Hapludalfs | Typic Hapludalfs | 1 | 1 | 1 | 1 |
| Typic Hapludalfs | Typic Hapludalfs | 1 | 1 | 1 | 1 |
| Typic Hapludalfs | Typic Hapludalfs | 1 | 1 | 1 | 1 |
| Typic Hapludalfs | Typic Hapludalfs | 1 | 1 | 1 | 1 |
| Typic Hapludalfs | Typic Hapludalfs | 1 | 1 | 1 | 1 |
| Typic Hapludalfs | Typic Hapludalfs | 1 | 1 | 1 | 1 |
| Typic Hapludalfs | Typic Hapludalfs | 1 | 1 | 1 | 1 |
| Typic Hapludalfs | Typic Hapludalfs | 1 | 1 | 1 | 1 |
| Typic Hapludalfs | Typic Hapludalfs | 1 | 1 | 1 | 1 |
| Typic Hapludalfs | Typic Hapludalfs | 1 | 1 | 1 | 1 |
| Typic Hapludalfs | Typic Hapludalfs | 1 | 1 | 1 | 1 |
| Typic Hapludalfs | Typic Hapludalfs | 1 | 1 | 1 | 1 |
| Typic Hapludalfs | Typic Hapludalfs | 1 | 1 | 1 | 1 |
| Typic Hapludalfs | Typic Hapludalfs | 1 | 1 | 1 | 1 |
| Typic Hapludalfs | Typic Hapludalfs | 1 | 1 | 1 | 1 |
| Typic Hapludalfs | Typic Hapludalfs | 1 | 1 | 1 | 1 |
| Typic Hapludalfs | Typic Hapludalfs | 1 | 1 | 1 | 1 |
| Typic Hapludalfs | Typic Hapludalfs | 1 | 1 | 1 | 1 |
| Typic Hapludalfs | Typic Hapludalfs | 1 | 1 | 1 | 1 |
| Typic Hapludalfs | Typic Hapludalfs | 1 | 1 | 1 | 1 |
| Typic Hapludalfs | Typic Hapludalfs | 1 | 1 | 1 | 1 |
| Typic Hapludalfs | Typic Hapludalfs | 1 | 1 | 1 | 1 |
| Typic Paleudalfs/ Typic Hapludalfs | Typic Paleudalfs/Typic Hapludalfs | 1 | 1 | 1 | 1 |
| Typic udifluvents/ Mollic Udifluvents | Typic Udifluvents/Typic Argiudolls | 1 | 1 | 1 | 1 |
| Total | | 86 | 86 | 83 | 82 |
| % area matching | | 100.00 | 100.00 | 96.51 | 95.35 |
| Remake: 1= Matching, 0 = Unmatching | | | | | |

# Appendix 4: The comparision between the LDD and geopedological map derived from ANN

| LDD soil map | Soil based on ANN | Oder | Sub-order | Great-Group | Sub-Group |
|---|---|---|---|---|---|
| Typic Paleudalfs | Lithic Hapludults | 0 | 1 | 0 | 0 |
| Aeric Hapludalfs | Rhodic Paleudalfs | 1 | 1 | 0 | 0 |
| Oxyaquic Hapludalfs | Rhodic Paleudalfs | 1 | 1 | 0 | 0 |
| Typic Argiudolls | Rhodic Paleudalfs | 0 | 0 | 0 | 0 |
| Typic Paleudalfs | Rhodic Paleudalfs | 1 | 1 | 1 | 0 |
| Aeric Endoaqualfs | Typic Hapludalfs | 1 | 0 | 0 | 0 |
| Aeric Hapludalfs | Typic Hapludalfs | 1 | 1 | 1 | 0 |
| Lithic Hapludalfs | Typic Hapludalfs | 1 | 1 | 0 | 0 |
| Oxyaquic Hapludalfs | Typic Hapludalfs | 1 | 1 | 1 | 0 |
| Oxyaquic Paleudalfs | Typic Hapludalfs | 1 | 1 | 0 | 0 |
| Typic Argiudolls | Typic Hapludalfs | 0 | 0 | 0 | 1 |
| Typic Endoaquepts | Typic Hapludalfs | 0 | 0 | 0 | 1 |
| Typic Hapludalfs | Typic Hapludalfs | 1 | 1 | 1 | 1 |
| Typic Paleudalfs | Typic Hapludalfs | 1 | 1 | 0 | 1 |
| Typic Paleudalfs | Typic Hapludalfs/Typic Paleudalfs | 1 | 1 | 1 | 0 |
| Aeric Hapludalfs | Typic Hapludults | 1 | 1 | 1 | 0 |
| Oxyaquic Hapludalfs | Typic Hapludults | 1 | 1 | 1 | 0 |
| Typic Hapludalfs | Typic Hapludults | 1 | 1 | 1 | 1 |
| Typic Paleudalfs | Typic Hapludults | 1 | 1 | 0 | 1 |
| Aeric Endoaqualfs | Typic Paleudalfs | 1 | 0 | 0 | 0 |
| Aeric Hapludalfs | Typic Paleudalfs | 1 | 1 | 0 | 0 |
| Lithic Hapludalfs | Typic Paleudalfs | 1 | 1 | 0 | 0 |
| Mollic Epiaquepts | Typic Paleudalfs | 0 | 0 | 0 | 0 |
| Oxyaquic Hapludalfs | Typic Paleudalfs | 1 | 0 | 0 | 0 |
| Oxyaquic Paleudalfs | Typic Paleudalfs | 1 | 1 | 1 | 0 |
| Typic Argiudolls | Typic Paleudalfs | 0 | 0 | 0 | 1 |
| Typic Endoaquepts | Typic Paleudalfs | 0 | 0 | 0 | 1 |
| Typic Hapludalfs | Typic Paleudalfs | 1 | 1 | 0 | 1 |
| Typic Paleudalfs | Typic Paleudalfs | 1 | 1 | 1 | 1 |
| Typic Hapludalfs | Typic Paleudalfs/Typic Hapludalfs | 1 | 1 | 1 | 1 |
| Typic Paleudalfs | Typic Paleudalfs/Typic Hapludalfs | 1 | 1 | 1 | 1 |
| Aeric Endoaqualfs | Typic Paleudults | 0 | 0 | 0 | 0 |
| Aeric Hapludalfs | Typic Paleudults | 0 | 1 | 0 | 0 |
| Mollic Epiaquepts | Typic Paleudults | 0 | 0 | 0 | 0 |
| Oxyaquic Hapludalfs | Typic Paleudults | 0 | 1 | 0 | 0 |
| Typic Argiudolls | Typic Paleudults | 0 | 1 | 0 | 1 |
| Typic Hapludalfs | Typic Paleudults | 0 | 1 | 0 | 1 |
| Typic Paleudalfs | Typic Paleudults | 0 | 1 | 1 | 1 |
| Aeric Endoaqualfs | Typic Udifluvents | 0 | 0 | 0 | 0 |
| Aeric Hapludalfs | Typic Udifluvents | 0 | 0 | 0 | 0 |
| Lithic Hapludalfs | Typic Udifluvents | 0 | 0 | 0 | 0 |
| Mollic Epiaquepts | Typic Udifluvents | 0 | 0 | 0 | 0 |
| Oxyaquic Hapludalfs | Typic Udifluvents | 0 | 0 | 0 | 0 |
| Oxyaquic Paleudalfs | Typic Udifluvents | 0 | 0 | 0 | 0 |
| Typic Argiudolls | Typic Udifluvents | 0 | 0 | 0 | 1 |
| Typic Endoaquepts | Typic Udifluvents | 0 | 0 | 0 | 1 |
| Typic Hapludalfs | Typic Udifluvents | 0 | 0 | 0 | 1 |
| Typic Paleudalfs | Typic Udifluvents | 0 | 0 | 0 | 1 |
| Aeric Endoaqualfs | Typic Udifluvents/Typic Argiudolls | 0 | 0 | 0 | 0 |
| Oxyaquic Hapludalfs | Typic Udifluvents/Typic Argiudolls | 0 | 0 | 0 | 0 |

| LDD soil map | Soil based on ANN | Oder | Sub-order | Great-Group | Sub-Group |
|---|---|---|---|---|---|
| Typic Argiudolls | Typic Udifluvents/Typic Argiudolls | 1 | 1 | 1 | 1 |
| Typic Hapludalfs | Typic Udifluvents/Typic Argiudolls | 0 | 0 | 0 | 1 |
| Typic Paleudalfs | Typic Udifluvents/Typic Argiudolls | 0 | 0 | 0 | 1 |
| Total | | 25 | 28 | 14 | 22 |
| % area matching | | 47.17 | 53 | 26 | 42 |
| Remake: 1= Matching, 0 = Unmatching | | | | | |

## Appendix 5: Soil profile description

Soil Profile description

Profile code No.: 19 Mapping Unit: $MOC_1$111
Classification(2006): lsk, Lithic Hapludults
Location: Hoi Num Rin Royal project station, Wieng Pa Poa ,Chiang Rai
Sheet Name: Map sheet No.:
Coordinate; 47Q0547551E, 2107836N Elevation: 1244,1392
Relief: very gently sloping Slope: 2-5
Physiography: Summit and Shoulder complex
Parent material: Shale
Drainage: well drain Permeability: Rapid
Ground water depth:-m
Annual rain fall: Climate type: Aw
Natural vegetation: forest and fruits
Descript by: Ruamporn Moonjun Date:27/7/2007

| Horizon | Depth (cm) | Description |
|---|---|---|
| A | 0-10 | Red (2.5YR 4/3) slightly gravelly clay loam; moderate fine and medium sub-angular blocky structure; slightly sticky and moderately plastic; friable (moist); common very fine and fine root; strongly acid (field pH 5.5); clear and wavy boundary to Bt. |
| Bt | 10-20 | Yellowish red (5YR 5/6) gravelly clay loam; moderate fine and medium sub-angular blocky structure; slightly sticky and slightly plastic; very firm (moist); few very fine root; very strongly acid (field pH 5.0); clear and smooth boundary to Cr. |
| BC | 20-50 | Res (2.5YR 5/8) very gravelly clay; moderate fine and medium sub-angular blocky structure; slightly sticky and slightly plastic; very firm (moist); very strongly acid (field pH 5.0); clear and smooth boundary to Cr. |
| Cr | 50< | Layer of weathered shale |
| Remark | Auger hole No. | 34 |
| | Coordinate | 47Q0547327E, 2105552N |

Soil Profile description

Profile code No.: 21 Mapping Unit: $MOC_1$112
Classification(2006): f, Typic Hapludults
Location: Hoi Num Rin Royal project station, Wieng Pa Poa, Chiang Rai
Sheet Name: Pong Num Ron Map sheet No.: 4748-II
Coordinate; 47Q 547884N, 2107956E Elevation: 1172 m
Relief: moderately steep Slope:
Physiography: Steep/very steep of slope complex
Parent material: Shale Hoi Num Rin Royal project station, Wieng Pa Poa
Drainage: well drain Permeability: Rapid
Ground water depth:-m
Annual rain fall: Climate type: Aw
Natural vegetation: forest and fruits
Descript by: Ruamporn Moonjun Date: 29/7/2007

| Horizon | Depth (cm) | Description |
|---|---|---|
| A | 0-10 | Brown (7.5YR 4/3); clay loam; moderate fine subangular blocky structure; friable (moist), slightly sticky and plastic; many very fine and few coarse roots; moderately acid (field pH 5.5); clear and smooth boundary to Bt1 |
| Bt1 | 10-35 | Reddish brown (5YR 4/4); slightly gravelly clay; moderate fine and medium subangular blocky structure; friable (moist), sticky and plastic; some clay skin on ped faces and in pores; gravelly composed of soft weathered shale about 5 % by volume and diameter 3-5 mm.; few very fine roots; slightlyacid (field pH 5.0); clear and smooth boundary to Bt2 |
| BCr | 35-70 | Yellowish red (5YR 4/6); clay; moderate medium subangular blocky structure; friable (moist), sticky and plastic; some clay skin on ped faces and in pores; gravelly composed of soft weathered shale about 5 % by volume and diameter 1-2 cm; slightly acid (field pH 5.0); clear and smooth boundary toBt2 |
| C | 70+ | Layer of soft weathered shale |
| Remark | Auger hole No. | 35 |
| | Coordinate | 47Q 547384N, 2105278E Elevation:1374 |

Soil Profile description

Profile code No.: 20 Mapping Unit: $MOC_1$113
Classification(2006): f, Typic Paleudults
Location: Hoi Num Rin Royal project station, Wieng Pa Poa, Chiang Rai
Sheet Name: Pong Num Ron Map sheet No.: 4748-II
Coordinate; 47Q 547769N, 2107891E Elevation:1120, 1128, 1373
Relief:strongly sloping Slope:
Physiography: Gentle/moderately of slope complex
Parent material: Shale
Drainage: well drain Permeability: Rapid
Ground water depth:-m
Annual rain fall: Climate type: Aw
Natural vegetation: forest and fruits
Descript by: Ruamporn Moonjun Date: 29/7/2007

| Horizon | Depth (cm) | Description |
|---|---|---|
| A | 0-5 | Mixed dark reddish brown and dark brown (5YR 3/4, 80%) and (7.5YR 3/3, 20%); clay loam; moderate fine subangular blocky structure; friable (moist), slightly sticky and slightly plastic; common very fine roots; neutral, strongly acid (field pH 5.5); clear and smooth boundary to Bt1 |
| Bt1 | 5-20 | Yellowish red (5YR 4/6) clay loam to clay; moderate medium subangular blocky structure; friable (moist), sticky and plastic; patchy thin cutan on ped faces; few very fine roots; some soft shale fragments about 5-10% of volume ; very strongly acid (field pH 5.0); clear and smooth boundary to Bt2 |
| Bt2 | 20-50 | Red (2.5YR 4/6) clay; moderate medium subangular blocky structure; friable (moist), sticky and plastic; moderately thick cutan on ped faces; few very fine roots; some soft shale fragments about 5 % of volume ; very strongly acid (field pH 5.0); clear and smooth boundary to Bt3 |
| Bt3 | 50-90 | Red (2.5YR 4/6-8) clay; sticky and plastic; some soft shale fragments about 10-15 % of volume; very strongly acid (field pH 5.0) |
| Bt4 | 90-150 | Strong brown (7.5YR 4/6) clay; sticky and plastic; some soft shale fragments about 5 % of volume; very strongly acid (field pH 5.0 ) |
| Remark | Auger hole No.<br>Coordinate | 72, 78 Elevation:1128, 1373<br>47Q 547519N, 2107649E, 47Q 547481N, 2105781E |

Soil Profile description

Profile code No.: 24, Mapping Unit: $MOC_1$211
Classification(2006): f, Typic Hapludults
Location: Hoi Num Rin Royal project station, Wieng Pa Poa, Chiang Rai
Sheet Name: Pong Num Ron Map sheet No.: 4748-II
Coordinate; 47Q 548701E, 2108110N Elevation: 1120, 1128, 1373
Relief: Slope:
Physiography: Gentle/moderately of slope complex
Parent material: Shale
Drainage: well drain Permeability: Rapid
Ground water depth:-m
Annual rain fall: Climate type: Aw
Natural vegetation: forest and fruits
Descript by: Ruamporn Moonjun Date: 29/7/2007

| Horizon | Depth (cm) | Description |
|---|---|---|
| A | 0-10 | Brown (7.5YR 4/3); clay loam; moderate medium subangular blocky structure; friable (moist), slightly sticky and slightly plastic; common fine and medium roots; strongly acid (field pH 5.5); clear and smooth boundary to AB |
| AB | 10-20 | Brown (7.5YR 4/4); clay loam; moderate fine and medium subangular blocky structure; friable (moist), slightly sticky and slightly plastic; common fine roots; very strongly acid (field pH 5.0); clear and smooth boundary to Bt1 |
| Bt1 | 20-55 | Yellowish red (5YR 5/6); slightly gravelly clay loam to lightly gravelly clay; moderate medium subangular blocky structure; friable (moist), sticky and plastic; patchy thin cutans on ped faces and in pores; gravelly composed of weathered shale fragments about 10-15 % by volume and diameter 2-3 cm; very strongly acid (field pH 5.0); clear and smooth boundary to Bt2 |
| Bt2 | 55-80 | Yellowish red (5YR 5/6); clay; moderate medium subangular blocky structure; friable(moist), sticky and plastic; patchy thin cutans on ped faces and in pores; some soft weathered shale ragments about5-10 % by volume and diameter 2-3 cm; very strongly acid (field pH 5.0) |
| Cr | 80+ | Layer of soft weathered shale fragments |
| Remark | Auger hole No.<br>Coordinate | 37, 63 Elevation: 1128, 1373<br>47Q 547620E, 2105073N, 47Q 547659E, 2108399N |

Soil Profile description

Profile code No.: 22, Mapping Unit: $MOC_1212$

Classification(2006): f, Typic Paleudults
Location: Hoi Num Rin Royal project station, Wieng Pa Poa, Chiang Rai
Sheet Name: Map sheet No.:
Coordinate; 47Q 548342N, 2107974E Elevation: 996

Relief: Slope:
Physiography: Gentle/moderately of slope complex
Parent material: Shale
Drainage: well drain Permeability: Rapid
Ground water depth:-m
Annual rain fall: Climate type: Aw
Natural vegetation: forest and fruits
Descript by: Ruamporn Moonjun Date: 1/8/2007

| Horizon | Depth (cm) | Description |
|---|---|---|
| Ap | 0-12 | Brown (7.5YR 4/3); slightly gravelly clay loam; moderate fine and medium subangular blocky structure; friable, slightly sticky and slightly plastic; common very fine roots; gravelly composed of soft weathered shale fragments about 10-15 % of volume, diameter 2-5 cm; strongly acid (field pH 5.5); clear and smooth boundary to Bt1 |
| BA | 12-28 | Brown (7.5YR 4/4); slightly gravelly clay loam to slightly gravelly clay; moderate fine and medium subangular blocky structure; friable, sticky and plastic; few very fine roots; gravelly composed of soft weathered shale fragments about 10% of volume, diameter 2-5 cm; very strongly acid (field pH 5.0); clear and smooth boundary to Bt1 |
| Bt1 | 28-55 | Yellowish red (5YR 4/6); slightly gravelly clay; moderate fine and medium subangular blocky structure; friable, sticky and plastic; sticky and plastic; patchy thin cutan on ped faces; gravelly composed of soft weathered shale ragments about 5% of volume, diameter 5 cm; very strongly acid (field pH 5.0); clear and smooth boundary to Bt2 |
| Bt2 | 5-105 | 5 Yellowish red (5YR 4/6); clay; sticky and plastic; some weathered shale fragment about 5-10% of volume, diameter 2-5 cm; very strongly acid (field pH 5.0) |
| Bt3 | 105-160+ | Strong brown (7.5YR 5/6); clay; sticky and plastic; some weathered shale fragment about 10-20% of volume, diameter 2-5 cm; very strongly acid (field pH 5.0) |
| Remark | Auger hole No. | 38, 64 Elevation: 1062, 1164 |
| | Coordinate | 47Q 548045N, 2105498E, 47Q 547983N, 2108306E |

Soil Profile description

Profile code No.:33, Mapping Unit: MoPTRv111
Classification(2006): f, Rhodic Paleudalfs
Location: Hoi Num Rin Royal project station, Wieng Pa Poa, Chiang Rai
Sheet Name: Pong Num Ron Map sheet No.: 4748-II
Coordinate; 47Q 550358E, 2107401N Elevation: 1108
Relief: High Ridge Slope:
Physiography: Summit and Shoulder complex
Parent material: RS and CV from Andisite
Drainage: well drain Permeability: Rapid
Ground water depth:-m
Annual rain fall: Climate type: Aw
Natural vegetation: forest and fruits
Descript by: Ruamporn Moonjun Date: 3/8/2007

| Horizon | Depth (cm) | Description |
|---|---|---|
| A | 0-20 | Dark reddish brown (2.5YR 2/4), loam; weak fine crumb; very friable; slightly sticky and slightly plastic; many very fine interstitial pores; common fine roots; common fine manganese shots; few fine pieces of charcoals; clear and smooth boundary; pH 6.5 |
| Bt1 | 15-40 | Dark reddish brown (2.5YR 2.5/3); clay loam to clay; moderate fine and medium subangular blocky structure; very friable, sticky and plastic; some clay skins; few very fine roots; neutral (field pH 7.0); gradual and smooth boundary to Bt2 |
| Bt2 | 20-79 | Dark reddish brown (2.5YR 3/4), clay loam; moderate medium subangular blocky; very friable; sticky and plastic; broken moderately thick clay coating on ped faces; few fine manganese shots;very fine tubular pores; common fine roots; diffuse and smooth boundary; natural (pH 7.0) |
| Bt3 | 79-161 | Dark reddish brown (2.5YR 3/4), clay; moderate medium subangular blocky; very friable; sticky and plastic; continuous thick clay coating; few fine manganese shots; common fine tubular pores;few fine roots; natural (pH 7.0) |
| Remark | Auger hole No. | 45, 46, 47 Elevation: 1268, 1320, 1316 |
| | Coordinate | 47Q 548883E, 2104963N, 47Q 548727E, 2105054N, 47Q 549392E, 2105629N |

Soil Profile description

Profile code No.:33 Mapping Unit: MoPTRv112
Classification(2006): csk, Typic Hapludalfs
Location: Hoi Num Rin Royal project station, Wieng Pa Poa, Chiang Rai
Sheet Name: Pong Num Ron Map sheet No.: 4748-II
Coordinate; 47Q 548574N, 2105276E Elevation: 1212
Relief: High Ridge Slope:
Physiography: Steep/very steep of slope complex
Parent material: RS and CV from Andisite
Drainage: well drain Permeability: Rapid
Ground water depth:-m
Annual rain fall: Climate type: Aw
Natural vegetation: forest and fruits
Descript by: Ruamporn Moonjun Date: 6/8/2007

| Horizon | Depth (cm) | Description |
|---|---|---|
| A | 0-10 | Red (2.5YR 4/3) slightly gravelly clay loam; moderate fine and medium sub-angular blocky structure; slightly sticky and moderately plastic; friable (moist); common very fine and fine root; strongly acid (field pH 5.5); clear and wavy boundary to Bt. |
| Bt | 10-20 | Yellowish red (5YR 5/6) gravelly clay loam; moderate fine and medium sub-angular blocky structure; slightly sticky and slightly plastic; very firm (moist); few very fine root; moderately acid (field pH 6.0); clear and smooth boundary to Cr. |
| BC | 20-50 | Res (2.5YR 5/8) very gravelly clay; moderate fine and medium sub-angular blocky structure; slightly sticky and slightly plastic; very firm (moist); moderately acid (field pH 6.0); clear and smooth boundary to Cr. |
| Cr | 50< | Layer of weathered andisite |
| Remark | Auger hole No. | - |
| | Coordinate | - |

Soil Profile description

Profile code No.: 43 Mapping Unit: MoPTRv113
Classification(2006): f, Rhodic Paleudalfs
Location: Hoi Num Rin Royal project station, Wieng Pa Poa, Chiang Rai
Sheet Name: Pong Num Ron Map sheet No.: 4748-II
Coordinate; 47Q 548765E, 2105136N Elevation: 1000
4

Relief: High Ridge Slope:
Physiography: Gentle/moderately of slope complex
Parent material: RS and CV from Andisite
Drainage: well drain Permeability: Rapid
Ground water depth:-m
Annual rain fall: Climate type: Aw
Natural vegetation: forest and fruits
Descript by: Ruamporn Moonjun Date: 6/8/2007

| Horizon | Depth (cm) | Description |
|---|---|---|
| A | 0-15 | Very dusky red (2.5YR 2.5/2); clay loam; moderate fine and medium subangular blocky structure; very friable, sticky and plastic; common very fine roots; neutral (field pH 7.0); clear and smooth boundary to Bt1 |
| Bt1 | 15-40 | Dark reddish brown (2.5YR 2.5/3); clay loam to clay; moderate fine and medium subangular blocky structure; very friable, sticky and plastic; some clay skins; few very fine roots; neutral (field pH 7.0); gradual and smooth boundary to Bt2 |
| Bt2 | 40-85 | Dusky red (10R 3/4); clay; moderate medium subangular blocky structure; very friable, sticky and plastic; patchy thin cutans on ped faces and in pores; neutral (field pH 7.0); gradual and smoothboundary to Bt3 |
| Bt3 | 85-120 | Dusky red to dark red (10R 3/ 4-6); clay; sticky and plastic; neutral (field pH 7.0) |
| Bt4 | 120-150 | Dusky red to dark red (10R 3/ 4-6); clay; sticky and plastic; neutral (field pH 7.0) |
| Remark | Auger hole No. | 68,70 Elevation: 1220, 1274 |
| | Coordinate | 7Q 550229E, 2107477N, 47Q 549048E, 2105548N |

Soil Profile description

Profile code No.:32 Mapping Unit: MoPTRv211
Classification(2006):f, Typic Hapludalfs

Location: Hoi Num Rin Royal project station, Wieng Pa Poa, Chiang Rai
Sheet Name: Pong Num Ron Map sheet No.: 4748-II
Coordinate; 47Q 550603E, 2108089N Elevation: 1018
Relief: Low Ridge Slope:
Physiography: Summit and Shoulder complex
Parent material: RS and CV from Andisite
Drainage: well drain Permeability: Rapid
Ground water depth:-m
Annual rain fall: Climate type: Aw
Natural vegetation: forest and fruits
Descript by: Ruamporn Moonjun Date: 7/8/2007

| Horizon | Depth (cm) | Description |
|---|---|---|
| A | 0-10 | Brown (7.5YR 4/3); clay loam; moderate medium subangular blocky structure; friable, slightly sticky and slightly plastic; common fine and medium roots; strongly acid (field pH 5.5); clear and smooth boundary to AB |
| AB | 10-20 | Brown (7.5YR 4/4); clay loam; moderate fine and medium subangular blocky structure; friable, slightly sticky and slightly plastic; common fine roots; strongly acid (field pH 5.5); clear and smooth boundary to Bt1 |
| Bt1 | 20-55 | Yellowish red (5YR 5/6); slightly gravelly clay loam to slightly gravelly clay; moderate medium subangular blocky structure; friable, sticky and plastic; patchy thin cutans on ped faces and in pores; gravelly composed of weathered shale fragments about 10-15 % by volume and diameter 2- 3 cm; moderately acid (field pH 6.0); clear and smooth boundary to Bt2 |
| Bt2 | 55-80 | Yellowish red (5YR 5/6); clay; moderate medium subangular blocky structure; friable, sticky and plastic; patchy thin cutans on ped faces and in pores; some soft weathered shale fragments about 5-10 % by volume and diameter 2-3 cm; slightly acid (field pH 6.5) |
| Cr | 80+ | Layer of soft weathered shale fragments |
| Remark | Auger hole No. | - |
| | Coordinate | - |

Soil Profile description

Profile code No.:31 Mapping Unit: MOPTRv212
Classification(2006):f, Typic Paleudalfs
Location: Hoi Num Rin Royal project station, Wieng Pa Poa, Chiang Rai
Sheet Name: Pong Num Ron Map sheet No.: 4748-II
Coordinate; 47Q 550505E, 2108013N Elevation: 1000
Relief: Low Ridge Slope:
Physiography: Slope complex
Parent material: RS and CV from Andisite
Drainage: well drain Permeability: Rapid
Ground water depth:-m
Annual rain fall: Climate type: Aw
Natural vegetation: forest and fruits
Descript by: Ruamporn Moonjun Date: 7/8/2007

| Horizon | Depth (cm) | Description |
|---|---|---|
| A | 0-12 | Brown (7.5YR 4/3); clay loam; moderate fine and medium sub-angular blocky structure; slightly sticky and slightly plastic; firm (moist); common very fine and fine root; strongly acid (field pH 5.5); clear and wavy boundary to Bt1. |
| Bt1 | 12-20 | Yellowish red (5YR 5/6); clay; moderate fine and medium sub-angular blocky structure; moderately sticky and very plastic; very firm; few very fine; moderately acid (field pH 6.0); clear and smooth boundary to Bt2. |
| Bt2 | 20-27 | Red (2.5YR 5/6); clay; moderate fine sub-angular blocky structure; moderately sticky and very plastic; few very fine; very firm; moderately acid (field pH 6.0); clear and smooth boundary to Bt3. |
| Bt3 | 27-70 | Red (2.5YR 4/6); clay; moderate fine sub-angular blocky structure; moderately sticky and very plastic; few very fine; very firm; moderately acid (field pH 6.0); clear and smooth boundary to Bt4. |
| Bt4 | 70-150+ | Red (2.5YR 4/6); clay; moderate fine sub-angular blocky structure; moderately sticky and very plastic; very firm; moderately acid (field pH 6.0) |
| Remark | Auger hole No. | - |
| | Coordinate | - |

Soil Profile description

Profile code No.:6 Mapping Unit: MOPTRv221
Classification(2006): f, Typic Hapludalfs
Location: Hoi Num Rin Royal project station, Wieng Pa Poa, Chiang Rai
Sheet Name: Pong Num Ron Map sheet No.: 4748-II
Coordinate; 47Q 550253N, 2109683E Elevation: 1115

Relief: Low Ridge Slope:
Physiography: Summit and Shoulder complex
Parent material: RS and CV from Shale/Phyllite
Drainage: well drain Permeability: Rapid
Ground water depth:-m
Annual rain fall: Climate type: Aw
Natural vegetation: forest and fruits
Descript by: Ruamporn Moonjun Date: 8/8/2007

| Horizon | Depth (cm) | Description |
|---|---|---|
| A | 0-10 | Brown (7.5YR 4/3); clay loam; moderate fine subangular blocky structure; friable, slightly sticky and plastic; many very fine and few coarse roots; moderately acid (field pH 6.0); clear and smooth boundary to Bt1 |
| Bt1 | 10-40 | Reddish brown (5YR 4/4); slightly gravelly clay; moderate fine and medium subangular blocky structure; friable, sticky and plastic; some clay skin on ped faces and in pores; gravelly composed of soft weathered shale about 5 % by volume and diameter 3-5 mm.; few very fine roots; slightly acid (field pH 6.5); clear and smooth boundary to Bt2 |
| Bt2 | 40-70 | Yellowish red (5YR 4/6); clay; moderate medium subangular blocky structure; friable, sticky and plastic; some clay skin on ped faces and in pores; gravelly composed of soft weathered shale about 5 % by volume and diameter 1-2 cm; slightly acid (field pH 6.5); clear and smooth boundary toBt2 |
| Cr | 70+ | Layer of soft weathered shale |

Remark Auger hole No. 50 Elevation: 1160
Coordinate 47Q 549994N, 2109370E

Soil Profile description

Profile code No.:5 Mapping Unit: MOPTRv222
Classification(2006): f, Typic Paleudalfs
Location: Hoi Num Rin Royal project station, Wieng Pa Poa, Chiang Rai
Sheet Name: Pong Num Ron Map sheet No.: 4748-II
Coordinate; 47Q 549888E, 2109738N Elevation: 1078

Relief:Low Ridge Slope:
Physiography: Slope complex
Parent material: RS and CV from Shale/Phyllite
Drainage: well drain Permeability: Rapid
Ground water depth:-m
Annual rain fall: Climate type: Aw
Natural vegetation: forest and fruits
Descript by: Ruamporn Moonjun Date: 8/8/2007

| Horizon | Depth (cm) | Description |
|---|---|---|
| A | 0-10 | Brown (7.5YR 4/3); clay loam; moderate fine and medium subangular blocky structure; friable, slightly sticky and slightly plastic; common very fine and fine roots; strongly acid (field pH 6.5);clear and smooth boundary to Bt1 |
| Bt1 | 10-30 | Brown (7.5YR 4/4); clay loam to clay; moderate medium subangular blocky structure; very friable, slightly sticky and slightly plastic; some clay skin on ped faces and in pores; some soft weatheredshale fragments about 5% by volume and diameter 3-5 cm; common very fine and fine roots; verystrongly acid (field pH 6.0); clear and smooth boundary to Bt1 |
| Bt2 | 30-50 | Brown (7.5YR 4/4); clay; moderate fine and medium subangular blocky structure; friable, sticky and plastic; patchy thin clay skin on ped faces and in pores; some soft weathered shale fragments about 5-10% by volume and diameter 3-5 cm; common very fine and few coarse roots; verystrongly acid (field pH 6.0); clear and smooth boundary to Bt1 |
| Bt3 | 50-70 | Brown (7.5YR 4/4); clay; moderate fine and medium subangular blocky structure; friable, sticky and plastic; patchy thin clay skin on ped faces and in pores; some soft weathered shale fragments about 5-10% by volume and diameter 3-5 cm; few charcoal fragments; common very fine and few coarse roots; very strongly acid (field pH 6.0); clear and smooth boundary to Bt1 |
| Bt4 | 70-110 | Brownish yellow (10YR 6/6); slightly gravelly clay; moderate medium and coarse angular blocky structure; friable, sticky and plastic; some clay skin on ped faces and in pores; some soft weathered shale fragments about 10% by volume and diameter 3-5 cm; very strongly acid (fieldpH 6.0) |
| Bt5 | 110-160+ | Mixed brownish yellow and reddish brown (10YR 6/6 & 5YR 5/4); slightly gravelly clay; moderate medium and coarse angular blocky structure; friable, sticky and plastic; some clay skin on ped faces and in pores; some soft weathered shale fragments about 15% by volume anddiameter 5-10 cm; very strongly acid (field pH 6.0) |

Remark Auger hole No. 51 Elevation: 1070
Coordinate 47Q 549744E, 2109339N

Soil Profile description

Profile code No.: 7 Mapping Unit: MOPTRv222
Classification(2006): csk, Typic Hapludalfs
Location: Hoi Num Rin Royal project station, Wieng Pa Poa, Chiang Rai
Sheet Name: Pong Num Ron Map sheet No.: 4748-II
Coordinate; 47Q 550390, 2109609 Elevation: 1080

Relief:Low Ridge Slope:
Physiography: Slope complex
Parent material: RS and CV from Shale/Phyllite
Drainage: well drain Permeability: Rapid
Ground water depth:-m
Annual rain fall: Climate type: Aw
Natural vegetation: forest and fruits
Descript by: Ruamporn Moonjun Date: 11/8/2007

| Horizon | Depth (cm) | Description |
|---|---|---|
| A | 0-10 | Brown (7.5YR 4/3); clay loam; moderate medium subangular blocky structure; friable, slightly sticky and slightly plastic; common fine and medium roots; strongly acid (field pH 5.5); clear andbsmooth boundary to AB |
| AB | 10-20 | Brown (7.5YR 4/4); clay loam; moderate fine and medium subangular blocky structure; friable, slightly sticky and slightly plastic; common fine roots; strongly acid (field pH 5.5); clear and smooth boundary to Bt1 |
| Bt1 | 20-55 | Yellowish red (5YR 5/6); slightly gravelly clay loam to slightly gravelly clay; moderate medium subangular blocky structure; friable, sticky and plastic; patchy thin cutans on ped faces and in pores; gravelly composed of weathered shale fragments about 10-15 % by volume and diameter 2-3 cm; moderately acid (field pH 6.0); clear and smooth boundary to Bt2 |
| Bt2 | 55-80 | Yellowish red (5YR 5/6); clay; moderate medium subangular blocky structure; friable, sticky and plastic; patchy thin cutans on ped faces and in pores; some soft weathered shale fragments about 5-10 % by volume and diameter 2-3 cm; slightly acid (field pH 6.5) |
| Cr | 80+ | Layer of soft weathered shale fragments |

Remark Auger hole No. 52 Elevation: 1135
Coordinate 47Q 550522, 2109918

Soil Profile description

Profile code No.:29 Mapping Unit: MOPTRv311

Classification(2006):f, Typic Hapludalfs
Location: Hoi Num Rin Royal project station, Wieng Pa Poa, Chiang Rai
Sheet Name: Pong Num Ron Map sheet No.: 4748-II
Coordinate; 47Q 550367E, 2107861N Elevation: 1004

Relief: Spur Slope:
Physiography: Summit and Shoulder complex
Parent material: RS and CV from Andisite
Drainage: well drain Permeability: Rapid
Ground water depth:-m
Annual rain fall: Climate type: Aw
Natural vegetation: forest and fruits
Descript by: Ruamporn Moonjun Date: 12/8/2007

| Horizon | Depth (cm) | Description |
|---|---|---|
| A | 0-10 | Brown (7.5YR 4/3); clay loam; moderate medium subangular blocky structure; friable, slightly sticky and slightly plastic; common fine and medium roots; strongly acid (field pH 5.5); clear and smooth boundary to AB |
| AB | 10-20 | Brown (7.5YR 4/4); clay loam; moderate fine and medium subangular blocky structure; friable, slightly sticky and slightly plastic; common fine roots; strongly acid (field pH 5.5); clear and smooth boundary to Bt1 |
| Bt1 | 20-55 | Yellowish red (5YR 5/6); slightly gravelly clay loam to slightly gravelly clay; moderate medium subangular blocky structure; friable, sticky and plastic; patchy thin cutans on ped faces and in pores; gravelly composed of weathered shale fragments about 10-15 % by volume and diameter 23 cm; moderately acid (field pH 6.0); clear and smooth boundary to Bt2 |
| Bt2 | 55-80 | Yellowish red (5YR 5/6); clay; moderate medium subangular blocky structure; friable, sticky and plastic; patchy thin cutans on ped faces and in pores; some soft weathered shale fragments about 5-10 % by volume and diameter 2-3 cm; slightly acid (field pH 6.5) |
| Cr | 80+ | Layer of soft weathered shale fragments |

Remark Auger hole No. 79 Elevation: 1150
Coordinate 47Q 548734E,2105682N

Soil Profile description

Profile code No.:44 Mapping Unit: MOPTRv312
Classification(2006):f, Typic Paleudalfs
Location: Hoi Num Rin Royal project station, Wieng Pa Poa, Chiang Rai
Sheet Name: Pong Num Ron Map sheet No.: 4748-II
Coordinate; 47Q 548942E, 2105316N Elevation: 932

Relief: Spur Slope:
Physiography: Slope complex
Parent material: RS and CV from Andisite
Drainage: well drain Permeability: Rapid
Ground water depth:-m
Annual rain fall: Climate type: Aw
Natural vegetation: forest and fruits
Descript by: Ruamporn Moonjun Date: 13/8/2007

| Horizon | Depth (cm) | Description |
|---|---|---|
| A | 0-15 | Dark brown (7.5YR 3/3); clay loam; moderate fine subangular blocky structure; friable, slightly sticky and slightly plastic; many very fine roots; strongly acid (field pH 5.5); clear and smooth boundary to BA |
| BA | 15-30 | Dark reddish brown (5YR 3/3); slightly gravelly clay loam to slightly gravelly clay; moderate fine and medium subangular blocky structure; friable, slightly sticky and slightly plastic; few very fine roots; gravelly composed of soft weathered shale fragments about 10 % by volume and diameter 1 cm; moderately acid (field pH 6.0); clear and smooth boundary to Bt1 |
| Bt1 | 30-70 | Dark reddish brown (5YR 3/4); slightly gravelly clay; moderate fine subangular blocky structure; friable, slightly sticky and slightly plastic; some clay skins on ped faces and in pores; gravelly composed of soft weathered shale fragments about 10 % by volume and diameter 1-2 cm; moderately acid (field pH 6.0); clear and smooth boundary to Bt1 |
| Bt2 | 70-130 | Dark reddish brown (5YR 3/4); slightly gravelly clay; sticky and slightly plastic; gravelly composed of soft weathered shale fragments about 5 % by volume and diameter 1-2 cm; moderately acid (field pH 6.0) |
| Bt3 | 130-180+ | Red (2.5YR 4/6); slightly gravelly clay;, sticky and plastic; gravelly composed of soft weathered shale fragments about 5-10 % by volume and diameter 0.5-1 cm; slightly acid (field pH 6.5) |

Remark Auger hole No. 76, 77 Elevation: 1200, 1172
Coordinate 47Q 548933E, 2105668N, 47Q 549833E, 2107436N

Soil Profile description

Profile code No.:3 Mapping Unit: MOPTRv321
Classification(2006): f, Typic Hapludalfs
Location: Hoi Num Rin Royal project station, Wieng Pa Poa, Chiang Rai
Sheet Name: Pong Num Ron Map sheet No.: 4748-II
Coordinate; 47Q 548765E, 2109948N Elevation: 830

Relief: Spur Slope:
Physiography: Summit and Shoulder complex
Parent material: RS and CV from Shale/Phyllite
Drainage: well drain Permeability: Rapid
Ground water depth:-m
Annual rain fall: Climate type: Aw
Natural vegetation: forest and fruits
Descript by: Ruamporn Moonjun Date: 14/8/2007

| Horizon | Depth (cm) | Description |
|---|---|---|
| Ap | 0-10 | Brown (7.5YR 4/3-4); clay loam; moderate fine and medium subangular blocky structure; friable, slightly sticky and slightly plastic; common very fine roots; strongly acid (field pH 5.5); clear and smooth boundary to Bt1 |
| Bt1 | 0-30 | 1 Reddish brown (5YR 4/4); clay loam; moderate fine subangular blocky structure; friable, slightly sticky and slightly plastic; patchy thin cutan on ped faces; few very fine roots; moderately acid (field pH 6.0); clear and smooth boundary to Bt2 |
| Bt2 | 30-60 | Yellowish red (5YR 4/6); clay; moderate fine subangular blocky structure; friable, slightly sticky and slightly plastic; patchy thin cutan on ped faces; strongly acid (field pH 5.5); clear and smooth boundary to Bt3 |
| Bt3 | 60-105 | Yellowish red (5YR 4/6); clay; slightly sticky and slightly plastic; moderately acid (field pH 6.0) Bt4 105-135 Mixed strong brown and yellowish red (7.5YR 4/6 & 5YR 4/6;20%); clay; sticky and plastic; common fine soft black $MnO_2$ 5-10 %; moderately acid (field pH 6.0) |
| Bt5 | 135-180 | Strong brown (7.5YR 4/6); clay; sticky and plastic; some soft weathered shale about 5%; slightly acid (field pH 6.5) |

Remark Auger hole No. 49 Elevation: 874
Coordinate 47Q 548276E, 2110131N

Soil Profile description

Profile code No.: 75 Mapping Unit: MOPTRv322
Classification(2006): f, Typic Paleudalfs
Location: Hoi Num Rin Royal project station, Wieng Pa Poa, Chiang Rai
Sheet Name: Pong Num Ron Map sheet No.: 4748-II
Coordinate; 47Q 549569E, 2110023N Elevation: 932
Relief: Spur Slope:
Physiography: Slope complex
Parent material: RS and CV from Shale/Phyllite
Drainage: well drain Permeability: Rapid
Ground water depth:-m
Annual rain fall: Climate type: Aw
Natural vegetation: forest and fruits
Descript by: Ruamporn Moonjun Date: 15/8/2007

| Horizon | Depth (cm) | Description |
|---|---|---|
| Ap | 0-10 | Dark brown (7.5YR 3/3); clay loam; moderate fine and medium subangular blocky structure; friable, sticky and plastic; common fine and few coarse roots; slightly acid (field pH 6.5); clear and smooth boundary to BA |
| BA | 10-24 | Brown (7.5YR 4/4); clay; moderate fine and medium subangular blocky structure; friable, sticky and plastic; common very fine and few coarse roots; slightly acid (field pH 6.5); clear and smooth boundary to Bt1 |
| Bt1 | 24-45 | Reddish brown (5YR 4/4); clay; moderate fine and medium subangular blocky structure; friable, sticky and plastic; patchy thin cutan on ped faces; some fragment of weathered shale diameter 5 cm; neutral (field pH 7.0); clear and smooth boundary to Bt2 |
| Bt2 | 45-70 | Reddish brown to yellowish red (5YR 4/4-6); clay; moderate fine and medium subangular blocky structure; friable, sticky and plastic; patchy thin cutan on ped faces; neutral (field pH 7.0); clear and smooth boundary to Bt3 |
| Bt3 | 70-120 | Red (2.5YR 4/4); clay; sticky and plastic; neutral (field pH 7.0) |
| Bt4 | 120-160+ | Red (2.5YR 4/8); clay; sticky and plastic; neutral (field pH 7.0) |

Remark Auger hole No. -
Coordinate -

Soil Profile description

Profile code No.: 9 Mapping Unit: MOPTRv331
Classification(2006):f, Typic Hapludalfs
Location: Hoi Num Rin Royal project station, Wieng Pa Poa, Chiang Rai
Sheet Name: Pong Num Ron Map sheet No.: 4748-II
Coordinate; 47Q 550847E, 2109598N Elevation: 950
Relief: Spur Slope:
Physiography: Summit and Shoulder complex
Parent material: RS and CV from Granite
Drainage: well drain Permeability: Rapid
Ground water depth:-m
Annual rain fall: Climate type: Aw
Natural vegetation: forest and fruits
Descript by: Ruamporn Moonjun Date: 15/8/2007

| Horizon | Depth (cm) | Description |
|---|---|---|
| A | 0-13 | A 0-10 Brown (7.5YR 4/3); clay loam; moderate medium subangular blocky structure; friable, slightly sticky and slightly plastic; common fine and medium roots; strongly acid (field pH 5.5); clear and smooth boundary to AB |
| Bt1 | 13-27 | AB 10-20 Brown (7.5YR 4/4); clay loam; moderate fine and medium subangular blocky structure; friable, slightly sticky and slightly plastic; common fine roots; strongly acid (field pH 5.5); clear and smooth boundary to Bt1 |
| Bt2 | 27-60 | Bt1 20-55 Yellowish red (5YR 5/6); slightly gravelly clay loam to slightly gravelly clay; moderate medium subangular blocky structure; friable, sticky and plastic; patchy thin cutans on ped faces and in pores; gravelly composed of weathered shale fragments about 10-15 % by volume and diameter 2-3 cm; moderately acid (field pH 6.0); clear and smooth boundary to Bt2 |
| Btc3 | 60-70 | Bt2 55-80 Yellowish red (5YR 5/6); clay; moderate medium subangular blocky structure; friable, sticky and plastic; patchy thin cutans on ped faces and in pores; some soft weathered shale fragments about 5-10 % by volume and diameter 2-3 cm; slightly acid (field pH 6.5) |
| Cr | 70-110 | Cr 80+ Layer of soft weathered shale fragments |

Remark Auger hole No. -
Coordinate -

Soil Profile description

Profile code No.:8 Mapping Unit: MOPTRv332
Classification(2006):f, Typic Paleudalfs
Location: Hoi Num Rin Royal project station, Wieng Pa Poa, Chiang Rai
Sheet Name: Pong Num Ron Map sheet No.: 4748-II
Coordinate; 47Q 550542E, 2109611N Elevation: 1085
Relief: Spur Slope:
Physiography: Slope complex
Parent material: RS and CV from Granite
Drainage: well drain Permeability: Rapid
Ground water depth:-m
Annual rain fall: Climate type: Aw
Natural vegetation: forest and fruits
Descript by: Ruamporn Moonjun Date: 16/8/2007

| Horizon | Depth (cm) | Description |
|---|---|---|
| A | 0-10 | Dark brown (7.5YR 3/2); clay loam; moderate fine subangular blocky structure; very friable, slightly sticky and slightly plastic; common medium and coarse roots; moderately acid (field pH 6.0); clear and smooth boundary to Bt1 |
| Bt1 | 10-42 | Brown (7.5YR 4/3); clay; moderate fine and medium subangular blocky structure; very friable, sticky and plastic; some clay skins; common medium and coarse roots; strongly moderately acid (field pH 6.0); clear and smooth boundary to Bt2 |
| Bt2 | 42-70 | Reddish brown (5YR 4/4); clay; moderate fine and medium subangular blocky structure; friable, sticky and plastic; common medium and coarse roots; patchy thin cutans on ped faces and in pores; moderately acid (field pH 6.0); clear and smooth boundary to Bt3 |
| Bt3 | 70-110 | Yellowish red (5YR 4/6); clay; moderate medium subangular blocky structure; friable, sticky and plastic; common medium and coarse roots; patchy thin cutans on ped faces and in pores; moderately acid (field pH 6.0) |
| Bt4 | 110-150 | Yellowish red (5YR 5/6); clay; moderate medium subangular blocky structure; friable, sticky and plastic; patchy thin cutans on ped faces and in pores; some weathered shale fragments about 5-10% by volume diameter 5 cm; moderately acid (field pH 6.0) |

Remark Auger hole No. -
Coordinate -

Soil Profile description

Profile code No.: 28 Mapping Unit: MOPTRv411
Classification(2006): vf, Rhodic Paleudalfs
Location: Hoi Num Rin Royal project station, Wieng Pa Poa, Chiang Rai
Sheet Name: Pong Num Ron Map sheet No.: 4748-II
Coordinate; 47Q 550148E, 2107629N Elevation: 932
Relief: Glacies surface Slope:
Physiography: Erosional surface
Parent material: RS and CV from Andisite RS and CV from Andisite
Drainage: well drain Permeability: Rapid
Ground water depth:-m
Annual rain fall: Climate type: Aw
Natural vegetation: forest and fruits
Descript by: Ruamporn Moonjun Date: 17/8/2007

| Horizon | Depth (cm) | Description |
|---|---|---|
| BA | 12-30 | Yellowish red (5YR 4/6); clay loam to clay; moderate fine subangular blocky structure; friable, slightly sticky and slightly plastic; common very fine roots; moderately acid (field pH 6.0); clear and smooth boundary to Bt1 |
| Bt1 | 30-80 | Red (2.5YR 4/6); clay loam to clay; moderate fine and medium subangular blocky structure; friable, sticky and plastic; some clay skin on ped faces and in pores; few very fine roots; moderately acid (field pH 6.0); clear and smooth boundary to Bt2 |
| Bt2 | 80-120 | Red (2.5YR 4/6-8); clay loam to clay; moderate fine subangular blocky structure; very friable, sticky and plastic; some clay skin on ped faces and in pores; moderately acid (field pH 6.0); clear and smooth boundary to Bt3 |
| Bt3 | 120-180 | Red (2.5YR 4/8); clay; moderate fine subangular blocky structure; very friable, sticky and plastic, moderately acid (field pH 6.0) |

Remark Auger hole No. -
Coordinate -

Soil Profile description

Profile code No.: 26 Mapping Unit: MOPTRv412
Classification(2006): vf, Typic Paleudalfs
Location: Hoi Num Rin Royal project station, Wieng Pa Poa, Chiang Rai
Sheet Name: Pong Num Ron Map sheet No.: 4748-II
Coordinate; 47Q 549367E, 2107571N Elevation: 876

Relief: Glacies surface Slope:
Physiography: Accumulation surface
Parent material: CV from Andisite
Drainage: well drain Permeability: Rapid
Ground water depth:-m
Annual rain fall: Climate type: Aw
Natural vegetation: forest and fruits
Descript by: Ruamporn Moonjun Date: 17/8/2007

| Horizon | Depth (cm) | Description |
|---|---|---|
| A | 0-15 | Dark brown (7.5YR 3/4); clay loam; moderately fine and medium subangular blocky structure; friable, slightly sticky and slightly plastic; common very fine roots; neutral (field pH 7.0) |
| Bt1 | 15-40 | Reddish brown (5YR 4/4); clay loam to clay; moderately fine and medium subangular blocky structure; friable, slightly sticky and plastic; patchy clay cutan on ped faces; few very fine roots; neutral (field pH 7.0)neutral (field pH 7.0) |
| Bt2 | 40-70 | Reddish brown to yellowish red (5YR 4/4-6); clay; moderately fine and medium subangular blocky structure; friable, sticky and plastic; patchy clay cutan on ped faces; few very fine roots; neutral (field pH 7.0)neutral (field pH 7.0) |
| Bt2 | 70-110 | Yellowish red (5YR 4/6); clay; sticky and plastic; neutral (field pH 7.0)neutral (field pH 7.0) |
| Bt3 | 110-150 | Red (2.5YR 4/6); clay; moderately alkaline (field pH 8.0) |
| Remark | Auger hole No. | 69 Elevation: 928 |
| | Coordinate | 47Q 549790E, 2107576N |

Soil Profile description

Profile code No.: 10, Mapping Unit: MOTRg111
Classification(2006): f, Typic Hapludalfs
Location: Hoi Num Rin Royal project station, Wieng Pa Poa, Chiang Rai
Sheet Name: Pong Num Ron Map sheet No.: 4748-II
Coordinate; 47Q 550974E, 2110462N Elevation: 1080
Relief: High Ridge Slope:
Physiography: Summit and Shoulder complex
Parent material: RS and CV from Shale/Phyllite
Drainage: well drain Permeability: Rapid
Ground water depth:-m
Annual rain fall: Climate type: Aw
Natural vegetation: forest and fruits
Descript by: Ruamporn Moonjun Date: 18/8/2007

| Horizon | Depth (cm) | Description |
|---|---|---|
| A | 0-15 | Dark brown (7.5YR 3/3); clay loam; moderate fine subangular blocky structure; friable, slightly sticky and slightly plastic; many very fine roots; strongly acid (field pH 5.5); clear and smoothboundary to BA |
| BA | 5-30 | 1 Dark reddish brown (5YR 3/3); slightly gravelly clay loam to slightly gravelly clay; moderate fine and medium subangular blocky structure; friable, slightly sticky and slightly plastic; few very fine roots; gravelly composed of soft weathered shale fragments about 10 % by volume and diameter 1 cm; moderately acid (field pH 6.0); clear and smooth boundary to Bt1 |
| Bt1 | 30-70 | Dark reddish brown (5YR 3/4); slightly gravelly clay; moderate fine subangular blocky structure; friable, slightly sticky and slightly plastic; some clay skins on ped faces and in pores; gravelly composed of soft weathered shale fragments about 10 % by volume and diameter 1-2 cm;moderately acid (field pH 6.0); clear and smooth boundary to Bt1 |
| Bt2 | 70-130 | Dark reddish brown (5YR 3/4); slightly gravelly clay; sticky and slightly plastic; gravelly composed of soft weathered shale fragments about 5 % by volume and diameter 1-2 cm; moderately acid (field pH 6.0) |
| Bt3 | 130-180 | Red (2.5YR 4/6); slightly gravelly clay;, sticky and plastic; gravelly composed of soft weathered shale fragments about 5-10 % by volume and diameter 0.5-1 cm; neutral (field pH 7.0) |
| Remark | Auger hole No. | 61 Elevation: 1018 |
| | Coordinate | 47Q 550846E, 2110298N |

Soil Profile description

Profile code No.: 11 Mapping Unit: MOTRg112
Classification(2006): f, Typic Paleudalfs
Location: Hoi Num Rin Royal project station, Wieng Pa Poa, Chiang Rai
Sheet Name: Pong Num Ron Map sheet No.: 4748-II
Coordinate; 47Q 551142E, 2110535N Elevation: 1018
Relief: High Ridge Slope:
Physiography: Slope complex
Parent material: RS and CV from Shale/Phyllite
Drainage: well drain Permeability: Rapid
Ground water depth:-m
Annual rain fall: Climate type: Aw
Natural vegetation: forest and fruits
Descript by: Ruamporn Moonjun Date: 19/8/2007

| Horizon | Depth (cm) | Description |
|---|---|---|
| A | 0-25 | Brown (10YR 5/3); clay loam; moderate fine subangular blocky structure; very friable, sticky and plastic; common fine roots; moderately acid (field pH 6.0); clear and smooth boundary to Bt1 |
| Bt1 | 5-50 | 2 Brown (7.5YR 5/4); clay loam to clay; moderate fine subangular blocky structure; friable, sticky and plastic; patchy thin cutan on ped faces and in pores; few fine roots; slightly acid (field pH 6.5); clear and smooth boundary to Bt2 |
| Bt2 | 50-70 | Strong brown (7.5YR 5/6); clay; moderate medium subangular blocky structure; friable, sticky and plastic; patchy thin cutan on ped faces and in pores; neutral (field pH 7.0) |
| Bt3 | 70-90 | Strong brown (7.5YR 5/6-8); clay; sticky and plastic; neutral (field pH 7.0) |
| Bt4 | 90-150+ | Mixed strong brown and yellowish red (7.5YR 5/6 & 5YR 5/6); clay with gritty sand; neutral (field pH 7.0) |

Remark Auger hole No. -
Coordinate -

Soil Profile description

Profile code No.: 14 Mapping Unit: MOTRg211

Classification(2006): f, Typic Hapludalfs
Location: Hoi Num Rin Royal project station, Wieng Pa Poa, Chiang Rai
Sheet Name: Pong Num Ron Map sheet No.: 4748-II
Coordinate; 47Q 552204E, 2110583N Elevation: 864

Relief: Low Ridge Slope:
Physiography: Summit and Shoulder complex
Parent material: RS and CV from Granite
Drainage: well drain Permeability: Rapid
Ground water depth:-m
Annual rain fall: Climate type: Aw
Natural vegetation: forest and fruits
Descript by: Ruamporn Moonjun Date: 19/8/2007

| Horizon | Depth (cm) | Description |
|---|---|---|
| A | 0-13 | Brown (7.5YR 4/3); clay loam; moderate medium subangular blocky structure; friable, slightly sticky and slightly plastic; common fine and medium roots; strongly acid (field pH 5.5); clear and smooth boundary to AB |
| AB | 13-27 | 10-20 Brown (7.5YR 4/4); clay loam; moderate fine and medium subangular blocky structure; friable, slightly sticky and slightly plastic; common fine roots; strongly acid (field pH 5.5); clear and smooth boundary to Bt1 |
| Bt1 | 27-60 | Bt1 20-55 Yellowish red (5YR 5/6); slightly gravelly clay loam to slightly gravelly clay; moderate medium subangular blocky structure; friable, sticky and plastic; patchy thin cutans on ped faces and in pores; gravelly composed of weathered shale fragments about 10-15 % by volume and diameter 2- 3 cm; moderately acid (field pH 6.0); clear and smooth boundary to Bt2 |
| Btc2 | 60-70 | Bt2 55-80 Yellowish red (5YR 5/6); clay; moderate medium subangular blocky structure; friable, sticky and plastic; patchy thin cutans on ped faces and in pores; some soft weathered shale fragments about5-10 % by volume and diameter 2-3 cm; slightly acid (field pH 6.5) |
| C | 70-110 | Cr 80+ Layer of soft weathered shale fragments |

Remark Auger hole No. 15, 53, 54 Elevation: 854, 780, 786
Coordinate 47Q 552289E, 2110664N,47Q 552700E, 2111059N,47Q 552807E, 2110994N

Soil Profile description

Profile code No.: 18 Mapping Unit: MOTRg212
Classification(2006): f, Typic Paleudalfs
Location: Hoi Num Rin Royal project station, Wieng Pa Poa, Chiang Rai
Sheet Name: Pong Num Ron Map sheet No.: 4748-II
Coordinate; 47Q 552050E, 2110892N Elevation: 812
Relief: Low Ridge Slope:
Physiography: Slope complex
Parent material: RS and CV from Granite
Drainage: well drain Permeability: Rapid
Ground water depth:-m
Annual rain fall: Climate type: Aw
Natural vegetation: forest and fruits
Descript by: Ruamporn Moonjun Date:

| Horizon | Depth (cm) | Description |
|---|---|---|
| A | | 0-12 Brown to dark brown (7.5YR 4/4), loam; moderate fine subangular and weak fine to medium granular; friable; slightly sticky and slightly plastic; common fine granules of ant and termite activity; common fine vesicular and few fine tubular pores; gravelss composed of shale gragments; many fine cocon roots; clear and wavy boundary; pH 5.5 |
| B1t | | 12-47 Yellowish red (5YR 4/8); clay loam; strong fine to medium subangular blocky; friable; sticky and slightly plastic; few patches of ant and termite activity; broken moderately thick clay coating on ped face; common very fine to fine tubular pores; common fine and few medium roots; gradual and smooth boundary; pH 5.5 |
| B2t | | 47-105 Yellowish red (5YR 4/8); clay; strong fine to medium subangular blocky; friable; sticky and plastic; continuous moderately thick clay coating on ped face; few patches of ant and termite activity; common fine tubular pores; few fine roots; gradual and smooth boundary; pH 5.5 |
| B3t | | 105-151 Yellowish red (5YR 5/6); light clay; moderate medium subangular blocky; slightly firm; sticky and plastic; broken moderately thick clay coating on ped faces; common very fine and few fine tubular pores; gravels composed of 5% shale fragments; few fine roots; pH 6.0 |

Remark Auger hole No. -
Coordinate -

Soil Profile description

Profile code No.: 12, Mapping Unit: MOTRg311
Classification(2006): f, Typic Hapludalfs
Location: Hoi Num Rin Royal project station, Wieng Pa Poa, Chiang Rai
Sheet Name: Pong Num Ron Map sheet No.: 4748-II
Coordinate; 47Q 551290E, 2110404N Elevation: 968

Relief: Spur Slope:
Physiography: Summit and Shoulder complex
Parent material: RS and CV from Granite
Drainage: well drain Permeability: Rapid
Ground water depth:-m
Annual rain fall: Climate type: Aw
Natural vegetation: forest and fruits
Descript by: Ruamporn Moonjun Date: 21/8/2007

| Horizon | Depth (cm) | Description |
|---|---|---|
| A | 0-13 | A 0-10 Brown (7.5YR 4/3); clay loam; moderate medium subangular blocky structure; friable, slightly sticky and slightly plastic; common fine and medium roots; strongly acid (field pH 5.5); clear and smooth boundary to AB |
| AB | 13-27 | AB 10-20 Brown (7.5YR 4/4); clay loam; moderate fine and medium subangular blocky structure; friable, slightly sticky and slightly plastic; common fine roots; strongly acid (field pH 5.5); clear andsmooth boundary to Bt1 |
| Bt1 | 27-60 | Bt1 20-55 Yellowish red (5YR 5/6); slightly gravelly clay loam to slightly gravelly clay; moderate medium subangular blocky structure; friable, sticky and plastic; patchy thin cutans on ped faces and in pores; gravelly composed of weathered shale fragments about 10-15 % by volume and diameter 2-3 cm; moderately acid (field pH 6.0); clear and smooth boundary to Bt2 |
| Bt2 | 60-70 | Bt2 55-80 Yellowish red (5YR 5/6); clay; moderate medium subangular blocky structure; friable, sticky and plastic; patchy thin cutans on ped faces and in pores; some soft weathered shale fragments about5-10 % by volume and diameter 2-3 cm; slightly acid (field pH 6.5) |
| Cr | 70-110+ | Layer of soft weathered shale fragments |

Remark Auger hole No. 57, 58 Elevation: 902, 902
Coordinate 47Q 552062E, 2110275N, 47Q 551885E, 2110009N

Soil Profile description

Profile code No.: 74 Mapping Unit: MOTRg312
Classification(2006): f, Typic Paleudalfs
Location: Hoi Num Rin Royal project station, Wieng Pa Poa, Chiang Rai
Sheet Name: Pong Num Ron Map sheet No.: 4748-II
Coordinate; 47Q 551794E, 2109843N Elevation: 856
Relief: Spur Slope:
Physiography: Slope complex
Parent material: RS and CV from Granite
Drainage: well drain Permeability: Rapid
Ground water depth:-m
Annual rain fall: Climate type: Aw
Natural vegetation: forest and fruits
Descript by: Ruamporn Moonjun Date: 21/8/2007

| Horizon | Depth (cm) | Description |
|---|---|---|
| Ap | 0-15 | Dark brown (7.5YR 3/3); loam; moderate fine and medium granular structure; very friable, nonsticky and non-plastic; common fine and very fine roots; moderately acid (field pH 6.0); clear and smooth boundary. |
| Bt1 | 15-40 | Reddish brown (5YR 4/3); clay loam; moderate medium and coarse subangular blocky structure; very friable, slightly sticky and slightly plastic; patchy thin cutan along pores and continuous on ped faces; few fine roots; slightly acid (field pH 6.5); clear and smooth boundary. |
| Bt2 | 40-70 | Reddish brown (5YR 4/4); clay loam; moderate fine and medium subangular blocky structure; friable, sticky and plastic; patchy thin cutan along pores, broken on ped faces; very few fine roots; slightly acid (field pH 6.5); clear and smooth boundary. |
| Bt3 | 0-110 | 7Yellowish red (5YR 5/6); silty clay; strong medium to coarse subangular blocky structure; firm, sticky and plastic; patchy thin cutan along pores; slightly acid (field pH 6.5); gradual and smoothboundary. |
| Bt4 | 110-150 | Reddish yellow (5YR 6/6); silty clay; strong medium to coarse subangular blocky structure; firm, sticky and plastic; patchy thin cutan on ped faces; neutral (field pH 7.0); gradual and wavy boundary. |
| Bt5 | 150-200 | Reddish yellow (5YR 6/6); silty clay; strong medium to coarse subangular blocky structure; firm, sticky and plastic; patchy thin cutan on ped faces; neutral (field pH 7.0) |

Remark Auger hole No. -
Coordinate -

Soil Profile description

Profile code No.: 56 Mapping Unit: MOTRg411
Classification(2006): f, Typic Paleudalfs
Location: Hoi Num Rin Royal project station, Wieng Pa Poa, Chiang Rai
Sheet Name: Pong Num Ron Map sheet No.: 4748-II
Coordinate; 47Q 552492E, 2110620N Elevation: 798, 820
Relief: Hill Slope:
Physiography: Slope facet complex
Parent material: and CV from Granite
Drainage: well drain Permeability: Rapid
Ground water depth:-m
Annual rain fall: Climate type: Aw
Natural vegetation: forest and fruits
Descript by: Ruamporn Moonjun Date: 21/8/2007

| Horizon | Depth (cm) | Description |
|---|---|---|
| A | 0-15 | Dark brown (7.5YR 3/4); clay loam; moderately fine and medium subangular blocky structure; friable, slightly sticky and slightly plastic; common very fine roots; neutral (field pH 7.0) |
| Bt1 | 15-40 | Reddish brown (5YR 4/4); clay loam to clay; moderately fine and medium subangular blocky structure; friable, slightly sticky and plastic; patchy clay cutan on ped faces; few very fine roots; neutral (field pH 7.0)neutral (field pH 7.0) |
| Bt2 | 40-70 | Reddish brown to yellowish red (5YR 4/4-6); clay; moderately fine and medium subangular blocky structure; friable, sticky and plastic; patchy clay cutan on ped faces; few very fine roots; neutral (field pH 7.0)neutral (field pH 7.0) |
| Bt2 | 70-110 | Yellowish red (5YR 4/6); clay; sticky and plastic; neutral (field pH 7.0) |
| Bt3 | 110-150 | Red (2.5YR 4/6); clay; moderately alkaline neutral (field pH 7.0) |

Remark Auger hole No. -
Coordinate -

Soil Profile description

Profile code No.: 73 Mapping Unit: MOTRg411
Classification(2006): csk, Typic Hapludalfs
Location: Hoi Num Rin Royal project station, Wieng Pa Poa, Chiang Rai
Sheet Name: Pong Num Ron Map sheet No.: 4748-II
Coordinate; 47Q 552556E, 2110782N Elevation: 798, 820
Relief: Hill Slope:
Physiography: Slope facet complex
Parent material: and CV from Granite
Drainage: well drain Permeability: Rapid
Ground water depth:-m
Annual rain fall: Climate type: Aw
Natural vegetation: forest and fruits
Descript by: Ruamporn Moonjun Date: 22/8/2007

| Horizon | Depth (cm) | Description |
|---|---|---|
| A | 0-13 | A 0-10 Brown (7.5YR 4/3); clay loam; moderate medium subangular blocky structure; friable, slightly sticky and slightly plastic; common fine and medium roots; strongly acid (field pH 5.5); clear and smooth boundary to AB |
| Bt1 | 13-27 | AB 10-20 Brown (7.5YR 4/4); clay loam; moderate fine and medium subangular blocky structure; friable, slightly sticky and slightly plastic; common fine roots; strongly acid (field pH 5.5); clear and smooth boundary to Bt1 |
| Bt2 | 27-60 | Bt1 20-55 Yellowish red (5YR 5/6); slightly gravelly clay loam to slightly gravelly clay; moderate medium subangular blocky structure; friable, sticky and plastic; patchy thin cutans on ped faces and in pores; gravelly composed of weathered shale fragments about 10-15 % by volume and diameter 2-3 cm; moderately acid (field pH 6.0); clear and smooth boundary to Bt2 |
| Btc3 | 60-70 | Bt2 55-80 Yellowish red (5YR 5/6); clay; moderate medium subangular blocky structure; friable, sticky and plastic; patchy thin cutans on ped faces and in pores; some soft weathered shale fragments about 5-10 % by volume and diameter 2-3 cm; slightly acid (field pH 6.5) |
| C | 70-110 | Cr 80+ Layer of soft weathered shale fragments |

Remark Auger hole No. -
Coordinate -

Soil Profile description

Profile code No.: 27, Mapping Unit: Va111, Va121, Va131, Va141, Va151
Classification(2006): fine loamy, mixed, themic Typic Udifluvents
Location: Hoi Num Rin Royal project station, Wieng Pa Poa, Chiang Rai
Sheet Name: Pong Num Ron Map sheet No.: 4748-II
Coordinate; 47Q 549643E, 2107629N Elevation: 764-1120

Relief: Vale Slope:
Physiography: Bottom side complex
Parent material: Alluvio-colluvium from shale , granite and andisite
Drainage: moderate well drain Permeability: Rapid
Ground water depth:-m
Annual rain fall: Climate type: Aw
Natural vegetation: forest and fruits
Descript by: Ruamporn Moonjun Date: 22/8/2007

| Horizon | Depth (cm) | Description |
|---|---|---|
| A | 0-20 | Dark brown (7.5YR 3/2); gravelly loam; moderate fine subangular blocky structure; slightly sticky and slightly plastic; common very fine roots; slightly acid (field pH 6.5) |
| C1 | 20-50 | Dark brown (7.5YR 3/3); very gravelly loam; moderate fine subangular blocky structure; slightly sticky and slightly plastic; few very fine roots; slightly acid field pH 6.5) |
| C2 | 50-100 | Dark brown (10YR 3/3); very gravelly loam; moderate fine subangular blocky structure; slightly sticky and slightly plastic; neutral (field pH 7.0) |
| C3 | 100-150 | Dark yellowish brown (10YR 3/4); very gravelly loam; moderate fine subangular blocky structure; slightly sticky and slightly plastic; neutral (field pH 7.0 ) |

Remark Auger hole No. 30, 41, 25, 40, 48, 65, 23, 39, 2, 4,13 Elevation: 764-1120
Coordinate 47Q 549987E, 2108111N, 47Q 548435E, 2105457N,
47Q 549363E, 2107919N 47Q 548306E, 2105532N,
47Q 547740E, 2109829N 47Q 549614E, 2107850N,
47Q 548302E, 2108130N 47Q 548242E, 2105754N,
47Q 548278E, 2109867N 47Q 549024E, 2110100N

Soil Profile description

Profile code No.: 16 Mapping Unit: Va151
Classification(2006): fl,Typic Argiudolls
Location: Hoi Num Rin Royal project station, Wieng Pa Poa, Chiang Rai
Sheet Name: Pong Num Ron Map sheet No.: 4748-II
Coordinate; 47Q 552500E, 2110752N Elevation: 760

Relief: Vale Slope: 0-2
Physiography: Bottom side complex
Parent material: Alluviocolluvium from Granite
Drainage: moderate well drain Permeability: slow
Ground water depth: 2-3-m
Annual rain fall: Climate type: Aw
Natural vegetation: forest
Descript by: Ruamporn Moonjun Date: 22/8/2007

| Horizon | Depth (cm) | Description |
|---|---|---|
| Ap | 0–27 | Very dark greyish brown (10YR 3/2 f) clay, containing humus, a few small stones of mixed form, type and condition, a few small roots, 1–10 pores per dm2, strong very coarse angular structure, fast onsistency, clear smooth boundary. |
| C | 27–34 | Brown (10YR 4/3 f) clay, humus poor, a few small stones of mixed form, type and condition, some small roots, 1–10 pores per dm2, moderately coarse angular structure, brittle consistency, continuous thin coatings of clay minerals and humus in root channels + aggregate peds, gradual wavy boundary. |
| Bvt | | Yellowish brown (10YR 5/4 f) sandy clay, humus poor, a few small stones of mixed form, type and condition, a few small soft rounded Fe and Mn oxide and hydroxide nodules, some small roots, 1–10 pores per dm2, moderately coarse prismatic structure, very brittle consistency, continuous thin coatings of clay minerals and humus in root channels + aggregate peds, clear, wavy boundary. |
| Bv2 | 48–62 | Brown (10YR 4/3 f) clayey sand, humus poor, a few small stones of mixed form, type and condition, frequent small roots, moderately thin angular structure, brittle consistency,gradual smooth boundary. |
| 2Cc | 62–150 | Light yellowish brown (10YR 6/4 f) clayey, silty sand with bands of silty clay, many big clear very pale brown (10YR 8/2) horizontally striped spots, secondary spots of light grey (5Y 7/2 f), horizontally striped gley character, humus poor, a few small stones of mixed form, type and condition plus lumps of lime, a few small soft rounded Fe oxide and hydroxide concretions, structureless, loose consistency, gradual, wavyboundary. |
| 3Cc g | 150–260 | Brown (10YR 5/3 f) clay, spots of grey (5Y 6/1 f) reducing environment, humus poor, a few small stones of mixed form, type and condition plus lumps of lime, a few small soft and hard rounded Fe oxide and hydroxide concretions, strong very coarse angular structure, very brittle consistency. |

Remark Auger hole No. 17 Elevation: 766
Coordinate 47Q 552187E, 2110843N

## Appendix 6: Soil attributes data

| No. | Landform symbol | landform description | Soil name | BD | LL | PL | PI | Shear strength |
|---|---|---|---|---|---|---|---|---|
| 1 | MOC1111 | Summit and Shoulder complex | Lithic Hapludults | 1.36 | 33.11 | 26.51 | 6.60 | 3.34 |
| 2 | MOC1112 | Steep/very steep of slope com | Typic Hapludults | 1.33 | 30.96 | 25.03 | 5.93 | 5.15 |
| 3 | MOC1113 | Gentle/moderately of slope comp | Typic Paleudults | 1.49 | 29.52 | 21.50 | 8.02 | 4.78 |
| 4 | MOC1211 | Summit and Shoulder complex | Typic Hapludults | 1.33 | 30.96 | 25.03 | 5.93 | 5.15 |
| 5 | MOC1212 | Slope complex | Typic Paleudults | 1.49 | 29.52 | 21.50 | 8.02 | 4.78 |
| 6 | MOPTRv111 | Summit and Shoulder complex | Rhodic Paleudalfs | 1.34 | 39.36 | 37.52 | 1.84 | 4.00 |
| 7 | MOPTRv112 | Slope complex | Typic Hapludalfs | 1.35 | 22.35 | 28.84 | 3.50 | 4.00 |
| 8 | MOPTRv113 | Gentle/moderately of slope comp | Rhodic Paleudalfs | 1.34 | 39.36 | 37.52 | 1.84 | 4.28 |
| 9 | MOPTRv211 | Summit and Shoulder complex | Typic Hapludalfs | 1.47 | 38.59 | 31.33 | 7.26 | 4.58 |
| 10 | MOPTRv212 | Slope complex | Typic Paleudalfs | 1.51 | 33.82 | 33.00 | 0.82 | 5.60 |
| 11 | MOPTRv221 | Summit and Shoulder complex | Typic Hapludalfs | 1.47 | 38.59 | 31.33 | 7.26 | 4.58 |
| 12 | MOPTRv222 | Slope complex | Typic Paleudalfs/ Typic Hapludalfs | 1.41 | 30.90 | 30.42 | 0.48 | 4.26 |
| 13 | MOPTRv311 | Summit and Shoulder complex | Typic Hapludalfs | 1.47 | 38.59 | 31.33 | 7.26 | 4.58 |
| 14 | MOPTRv312 | Slope complex | Typic Paleudalfs | 1.51 | 33.82 | 33.00 | 0.82 | 5.60 |
| 15 | MOPTRv321 | Summit and Shoulder complex | Typic Hapludalfs | 1.47 | 38.59 | 31.33 | 7.26 | 4.58 |
| 16 | MOPTRv322 | Slope complex | Typic Paleudalfs | 1.44 | 31.45 | 28.84 | 2.61 | 3.04 |
| 17 | MOPTRv331 | Summit and Shoulder complex | Typic Hapludalfs | 1.47 | 38.59 | 31.33 | 7.26 | 4.58 |
| 18 | MOPTRv332 | Slope complex | Typic Paleudalfs | 1.56 | 31.45 | 28.84 | 2.21 | 5.08 |
| 19 | MOPTRv411 | Erosional surface | Rhodic Paleudalfs | 1.51 | 33.82 | 33.00 | 0.82 | 5.60 |
| 20 | MOPTRv412 | Accumulation surface | Typic Paleudalfs | 1.51 | 33.82 | 33.00 | 0.82 | 5.60 |
| 21 | MOTRg111 | Summit and Shoulder complex | Typic Hapludalfs | 1.47 | 38.59 | 31.33 | 7.26 | 4.58 |
| 22 | MOTRg112 | Slope complex | Typic Hapludalfs | 1.47 | 38.59 | 31.33 | 7.26 | 4.58 |
| 23 | MOTRg211 | Summit and Shoulder complex | Typic Hapludalfs | 1.47 | 38.59 | 31.33 | 7.26 | 4.58 |
| 24 | MOTRg212 | Slope complex | Typic Paleudalfs | 1.42 | 18.52 | 15.82 | 2.70 | 4.26 |
| 25 | MOTRg311 | Summit and Shoulder complex | Typic Hapludalfs | 1.47 | 38.59 | 31.33 | 7.26 | 4.58 |
| 26 | MOTRg312 | Slope complex | Typic Paleudalfs | 1.42 | 18.52 | 15.82 | 2.70 | 4.26 |
| 27 | MOTRg411 | Slope facet complex | Typic Hapludalfs/ Typic Paleudalfs | 1.35 | 38.59 | 31.33 | 7.26 | 4.58 |
| 28 | Va111 | Bottom side complex | Typic Udifluvents | 1.52 | 32.19 | 30.59 | 1.60 | 4.20 |
| 29 | Va121 | Bottom side complex | Typic Udifluvents | 1.52 | 32.19 | 30.59 | 1.60 | 4.20 |
| 30 | Va131 | Bottom side complex | Typic Udifluvents | 1.52 | 32.19 | 30.59 | 1.60 | 4.20 |
| 31 | Va141 | Bottom side complex | Typic Udifluvents | 1.52 | 32.19 | 30.59 | 1.60 | 4.20 |
| 32 | Va151 | Bottom side complex | Typic Udifluvents/ Typic Argiudolls | 1.33 | 25.23 | 22.54 | 2.69 | 2.48 |
| Remark | BD = bulk density | LL= liquid limit | PL= Plastic limit | PI= Plasticity index | | | | |

## Appendix 7: Plastic limit and Liquid limit in some clay type

| Type of clay | Plastic limit | Liquid limit |
|---|---|---|
| Silty clay | 20-30 | 25-40 |
| Kaolinite | 20-40 | 40-70 |
| Montmorillnite | 100-200 | 300-600 |

## Appendix 8: The ANN result processes from the difference iterations

A) Iteration = 500

```
Learning Performance in file E:\PredictorAndROI\New Folder (10)\soil_properties_1
number of inputnodes    : 6
number hiddenlayers     : 1
nodes hidden layer 1    : 6
nodes per hiddenlayers
parameters
Learning rate           :       0.200000
Momentum                :       0.900000
Maximum system error    : 0.0001

results
learning time           :          21.906000 seconds
number of epochs spent:         500
normalized system error    0.00559181
Size of training set :       252
Training pixels correctly classified       97%

             | Confusion Matrix:  Groundtruth\calculated
    map      |  samples points training set
 classnames|     0     1     2     3     4     5     6     7     8     9

Region #1  |    33     0     0     0     0     0     0     0     0     0
Typic Udif|     0    32     0     2     0     0     1     0     0     0
Rhodic Pal|     0     0    15     0     0     0     0     0     0     0
Lithic Hap|     0     0     0    42     0     0     0     0     0     0
Typic Hapl|     0     0     0     0     9     0     0     0     0     0
Typic Hapl|     0     0     0     0     0    14     0     0     0     0
Typic Hapl|     0     0     0     1     0     0    35     0     0     0
Typic Pale|     0     0     0     0     0     0     0    16     0     0
Typic Pale|     0     0     0     0     0     1     0     0    29     0
Typic Pale|     2     0     0     0     0     0     0     0     0    20

% class OK|    94   100   100    93   100    93    97   100   100   100
```

B) Iteration = 1000

```
Learning Performance in file E:\PredictorAndROI\New Folder (10)\soil_propert:
number of inputnodes    : 6
number hiddenlayers     : 1
nodes hidden layer 1    : 6
nodes per hiddenlayers
parameters
Learning rate           :       0.200000
Momentum                :       0.900000
Maximum system error    : 0.0001

results
learning time           :          38.922000 seconds
number of epochs spent:         1000
normalized system error    0.00380537
Size of training set :       252
Training pixels correctly classified       98%

             | Confusion Matrix:  Groundtruth\calculated
    map      |  samples points training set
 classnames|     0     1     2     3     4     5     6     7     8     9

Region #1  |    33     0     0     0     0     0     0     0     0     0
Typic Udif|     0    32     0     0     0     0     1     0     0     0
Rhodic Pal|     0     0    15     0     0     0     0     0     0     0
Lithic Hap|     0     0     0    44     0     0     0     0     0     0
Typic Hapl|     0     0     0     0     9     0     0     0     0     0
Typic Hapl|     0     0     0     0     0    14     0     0     0     0
Typic Hapl|     0     0     0     1     0     0    35     0     0     0
Typic Pale|     0     0     0     0     0     0     0    16     0     0
Typic Pale|     0     0     0     0     0     1     0     0    29     0
Typic Pale|     2     0     0     0     0     0     0     0     0    20

% class OK|    94   100   100    97   100    93    97   100   100   100
```

C) Iteration = 5000

```
Learning Performance in file E:\PredictorAndROI\New Folder (10)\soil_properties_1
number of inputnodes    : 6
number hiddenlayers     : 1
nodes hidden layer 1    : 6
nodes per hiddenlayers
parameters
Learning rate           :       0.200000
Momentum                :       0.900000
Maximum system error    : 0.0001

results
learning time           :          231.23400 seconds
number of epochs spent:         5000
normalized system error    0.00374104
Size of training set :       252
Training pixels correctly classified       98%

             | Confusion Matrix:  Groundtruth\calculated
    map      |  samples points training set
 classnames|     0     1     2     3     4     5     6     7     8     9

Region #1  |    33     0     0     0     0     0     0     0     0     0
Typic Udif|     0    32     0     0     0     0     1     0     0     0
Rhodic Pal|     0     0    15     0     0     0     0     0     0     0
Lithic Hap|     0     0     0    44     0     0     0     0     0     0
Typic Hapl|     0     0     0     0     9     0     0     0     0     0
Typic Hapl|     0     0     0     0     0    14     0     0     0     0
Typic Hapl|     0     0     0     1     0     0    35     0     0     0
Typic Pale|     0     0     0     0     0     0     0    16     0     0
Typic Pale|     0     0     0     0     0     1     0     0    29     0
Typic Pale|     2     0     0     0     0     0     0     0     0    20

% class OK|    94   100   100    97   100    93    97   100   100   100
```

## Appendix 9:The ANN process to select the number of nodes (neurons)

A) Node of hidden layer is 3 (50% of input layer)

```
Learning Performance in file E:\PredictorAndROI\New Folder (10)\soil_prope
number of inputnodes     : 6
number hiddenlayers      : 1
nodes hidden layer 1     : 3
nodes per hiddenlayers
parameters
Learning rate            :      0.900000
Momentum                 :      0.700000
Maximum system error     : 0.0001

results
learning time               :      453.93800 seconds
number of epochs spent:      10000
normalized system error     0.0232590
Size of training set :      252
Training pixels correctly classified       88%
```

| map classnames | Confusion Matrix: Groundtruth\calculated samples points training set 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| Region #1 | 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Typic Udif | 0 | 29 | 0 | 0 | 0 | 0 | 7 | 0 | 0 | 0 |
| Rhodic Pal | 0 | 0 | 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Lithic Hap | 0 | 3 | 0 | 42 | 0 | 0 | 1 | 0 | 0 | 0 |
| Typic Hapl | 0 | 0 | 0 | 2 | 9 | 0 | 0 | 0 | 0 | 0 |
| Typic Hapl | 0 | 0 | 0 | 0 | 0 | 14 | 0 | 0 | 0 | 0 |
| Typic Hapl | 0 | 0 | 0 | 1 | 0 | 0 | 28 | 0 | 0 | 0 |
| Typic Pale | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 16 | 0 | 0 |
| Typic Pale | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 29 | 0 |
| Typic Pale | 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 20 |
| % class OK | 57 | 90 | 100 | 93 | 100 | 93 | 77 | 100 | 100 | 100 |

B) Node of hidden layer is 6 (100% of input layer)

```
Learning Performance in file E:\PredictorAndROI\New Folder (10)\soi
number of inputnodes     : 6
number hiddenlayers      : 1
nodes hidden layer 1     : 6
nodes per hiddenlayers
parameters
Learning rate            :      0.900000
Momentum                 :      0.700000
Maximum system error     : 0.0001

results
learning time               :      579.56300 seconds
number of epochs spent:      10000
normalized system error     0.00451781
Size of training set :      252
Training pixels correctly classified       97%
```

| map classnames | Confusion Matrix: Groundtruth\calculated samples points training set 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| Region #1 | 33 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Typic Udif | 0 | 32 | 0 | 2 | 0 | 0 | 1 | 0 | 0 | 0 |
| Rhodic Pal | 0 | 0 | 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Lithic Hap | 0 | 0 | 0 | 42 | 0 | 0 | 0 | 0 | 0 | 0 |
| Typic Hapl | 0 | 0 | 0 | 0 | 9 | 0 | 0 | 0 | 0 | 0 |
| Typic Hapl | 0 | 0 | 0 | 0 | 0 | 14 | 0 | 0 | 0 | 0 |
| Typic Hapl | 0 | 0 | 0 | 1 | 0 | 0 | 35 | 0 | 0 | 0 |
| Typic Pale | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 16 | 0 | 0 |
| Typic Pale | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 29 | 0 |
| Typic Pale | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 20 |
| % class OK | 94 | 100 | 100 | 93 | 100 | 93 | 97 | 100 | 100 | 100 |

C) Number of hidden node is 9 (150% of input node)

```
Learning Performance in file E:\PredictorAndROI\New Folder (10)\sc
number of inputnodes     : 6
number hiddenlayers      : 1
nodes hidden layer 1     : 9
nodes per hiddenlayers
parameters
Learning rate            :      0.900000
Momentum                 :      0.700000
Maximum system error     : 0.0001

results
learning time               :      493.15700 seconds
number of epochs spent:      10000
normalized system error     0.00372956
Size of training set :      252
Training pixels correctly classified       98%
```

| map classnames | Confusion Matrix: Groundtruth\calculated samples points training set 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| Region #1 | 33 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Typic Udif | 0 | 32 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| Rhodic Pal | 0 | 0 | 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Lithic Hap | 0 | 0 | 0 | 44 | 0 | 0 | 0 | 0 | 0 | 0 |
| Typic Hapl | 0 | 0 | 0 | 0 | 9 | 0 | 0 | 0 | 0 | 0 |
| Typic Hapl | 0 | 0 | 0 | 0 | 0 | 14 | 0 | 0 | 0 | 0 |
| Typic Hapl | 0 | 0 | 0 | 1 | 0 | 0 | 35 | 0 | 0 | 0 |
| Typic Pale | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 16 | 0 | 0 |
| Typic Pale | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 29 | 0 |
| Typic Pale | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 20 |
| % class OK | 94 | 100 | 100 | 97 | 100 | 93 | 97 | 100 | 100 | 100 |

## Appendix 10: Tentative decision tree for the ocuurence of soil

| Time | Organism | Relief | lithology | landscape | landform | Time | Soil |
|---|---|---|---|---|---|---|---|
| | Hill Evergreen forest | Glacis surface | CV from Andesite | Mt in HTRv | Erosional surface | Mature | hodic Paleudalfs |
| | | | CV from Andesite | Mt in HTRv | Accumulation surface | Mature | Typic Paleudalfs |
| | | High Ridge | RS and CV from Andesite | Mt in HTRv | Summit and Shoulder complex | Mature | Rhodic Paleudalfs |
| | | | RS and CV from Andesite | Mt in HTRv | Gentle/moderately of slope complex | Mature | Rhodic Paleudalfs |
| | | Low Ridge | RS and CV from Andesite | Mt in HTRv | Steep/very steep of slope complex | Mature | ypic Hapludalfs |
| | | | RS and CV from Andesite | Mt in HTRv | Summit and Shoulder complex | Mature | Typic Hapludalfs |
| | | | RS and CV from Andesite | Mt in HTRv | Slope complex | Mature | Typic Paleudalfs |
| | | Spur | RS and CV from Andesite | Mt in HTRv | Summit and Shoulder complex | Mature | Typic Hapludalfs |
| | | | RS and CV from Andesite | Mt in HTRv | Slope complex | Mature | Typic Paleudalfs |
| | | Vale | Alluvio-colluvium from Andesite | Valley | Bottom side complex | Young | Typic Udifluvents |
| Udic | | | | | | | |
| | Hill Evergreen forest/Pine Forest | Ridge | RS and CV from Shale | Mt in CI | Summit and Shoulder complex | Old | Paralithic Hapludults |
| | | | RS and CV from Shale | Mt in CI | Steep/very steep of slope com | Old | Typic Hapludults |
| | | | RS and CV from Shale | Mt in CI | Gentle/moderately of slope complex | Old | Typic Paleudults |
| | | Spur | RS and CV from Shale | Mt in CI | Summit and Shoulder complex | Old | Typic Hapludults |
| | | | RS and CV from Shale | Mt in CI | Slope complex | Old | Typic Paleudults |
| | | Vale | Alluvio-colluvium from Shale | Valley | Bottom side complex | Young | Typic Udifluvents |
| | Mixed Deciduous Forest/Hill Evergreen forest | Low Ridge | RS and CV from Shale/Phyllite | Mt in HTRv | Summit and Shoulder complex | Mature | Typic Hapludalfs |
| | | | RS and CV from Shale/Phyllite | Mt in HTRv | Slope complex | Mature | Typic Paleudalfs/ Typic apludalfs |
| | | Spur | RS and CV from Andesite | Mt in HTRv | Summit and Shoulder complex | Mature | Typic Hapludalfs |
| | | Vale | RS and CV from Shale/Phyllite | Mt in HTRv | Slope complex | Mature | Typic Paleudalfs |
| | | | RS and CV from Shale/Phyllite | Mt in HTRv | Slope complex | Mature | Typic Paleudalfs |
| | | | Alluvio-colluvium from Shale and Phyllite | Valley | Bottom side complex | Young | Typic Udifluvents |
| | Mixed Deciduous Forest-high moisture | High Ridge | RS and CV from Shale/Phyllite | Mt in TRg | Summit and Shoulder complex | Mature | Typic Hapludalfs |
| | | | RS and CV from Shale/Phyllite | Mt in TRg | Slope complex | Mature | Typic Hapludalfs |
| | | hill | RS and CV from Granite | Mt in TRg | Slope facet complex | Mature | Typic Hapludalfs/ Typic Paleudalfs |
| | | Low Ridge | RS and CV from Granite | Mt in TRg | Summit and Shoulder complex | Mature | Typic Hapludalfs |
| | | | RS and CV from Granite | Mt in TRg | Slope complex | Mature | Typic Paleudalfs |
| | | Spur | RS and CV from Granite | Mt in HTRv | Slope complex | Mature | Typic Paleudalfs |
| | | | RS and CV from Granite | Mt in HTRv | Summit and Shoulder complex | Mature | Typic Hapludalfs |
| | | | RS and CV from Granite | Mt in TRg | Summit and Shoulder complex | Mature | Typic Hapludalfs |
| | | | RS and CV from Granite | Mt in TRg | Slope complex | Mature | Typic Paleudalfs |
| | | Vale | Alluvio-colluvium from Granite | Valley | Bottom side complex | Young | Typic Udifluvents /Typic Argiudolls |