Oh! Champa Flower, when I admire you
I could envision thousands in my mind.

I could see your heart; I could enjoy your sweet fragrance.

I could see the flower garden that my father had planted long ago.

Whenever I feel melancholy, I think of thee
and I no longer feel lonely or sad.

Oh! Champa Flower, you have stood by my side
since I was young.

Your fragrance is significant; in my heart it stands
with love and affection.

I treasure your sweet scent, for when I feel lonely,
I can breathe in your sweet fragrance, My Dear Sweet Champa.

Sniffing your delicate fragrance is like my long lost friend.
You have been a beautiful flower since the beginning of time,
My Dear Champa Flower, My Beloved Flower.

Oh! Champa Flower, the flower of our beloved country,
Muang Laos, you are as beautiful as glittering stars.

All Lao people adore you in their hearts;
You are born in Lan Xaang, the Land of a Million Elephants

If we depart from our homeland and flee far away from her,

we will always have you as our true friend
as long as we live.

Oh! Champa Flower ,the exquisitely beautiful flower,
and the auspicious flower of Muang Laos.

Translated by Dr. Wajuppa Tossa and Prasong Saihong
(www.1)

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Abstract

When developing policies for agricultural land and land use planning, it is essential to have access to a land resource database. In Lao PDR, no such database previously existed, so we therefore attempted to make one and to implement its use by describing Phonxay District, Louang Phrabang Province, Lao PDR.

All input data in the form of digital maps were transformed to Lao National Datum 1997. The potential evapotranspiration was calculated using the FAO Penman-Monteith Combination Method and was then, together with temperature and precipitation data, interpolated to cover northern Lao PDR. By using the database, growing period zones, agro-ecological zoning, zones of soil and terrain constraints and two examples of land suitability assessment were performed for Phonxay District. The socio-economic and demographic characteristics of the district were also described.

Two growing period zones and 16 agro-ecological zones were mapped, in which seven of the zones had great potential for agricultural production. The constraint zones confirmed that 31.7 % of land in Phonxay was suitable for agriculture, being classified to zone of slight or no constrains. Bananas and pineapples suitability classification in the area corresponded well with the zones of no or slight constraint, and the agro-ecological zones suitable for agricultural production. The socio-economic comparisons of the district showed that villages with a mixed population are generally better of than other villages.

Keywords: Lao PDR, Phonxay, GIS database, Transformations of geographical coordinate systems, Calculation of evapotranspiration, Penman Monteith Combination Method, Interpolation of climate variables, Agro-Ecological Zones, Growing period zones, Zones of soil and terrain constraints, Land suitability assessment.

Summary

When developing policies for agricultural land and land use planning, it is essential to have access to a land resource database. This database should include biophysical information, socio-economic, demographic and administrative data to simplify description of an area. In Lao PDR, no such database previously existed. Our objective therefore became to make a land resource database and to use this database to describe northern Lao PDR, with focus on Phonxay District, Louang Phrabang Province, in regards to both its biophysical components and socio-economic aspects.

The database building includes transformation of geographic coordinate systems, calculation of potential evapotranspiration and interpolation of the climate variables, temperature, potential evapotranspiration and precipitation data. All input data in the form of digital maps were transformed to Lao National Datum 1997 by using a three-parameter method or by georeferencing. The parameters for the three-parameter transformations were provided by the National Geographical Department of Lao PDR.

The potential evapotranspiration was calculated by using the FAO Penman-Monteith Combination Method. Missing climatic data was estimated with alternative methods and evaluated. The potential evapotranspiration was then, together with the temperature and precipitation, interpolated, using the best interpolation technique for each individual variable, to cover northern Lao PDR. The interpolations were evaluated using a jackknife routine.

To describe northern Lao PDR and Phonxay District we used methodologies including division of the area into growing period zones, agro-ecological zones, zones of soil and terrain constraints, two examples of land suitability assessments and socio-economic and demographic analysis. The growing period zones were calculated from the precipitation and potential evapotranspiration data. Growth was considered possible if the mean monthly precipitation was larger then the mean monthly potential evapotranspiration divided by two. agro-ecological zones were mapped and each zone has a unique combination of biophysical characteristics. The zoning takes into consideration the temperature, the growing period zones, the annual mean precipitation, soil and topography. The zones of soil and terrain constraints were based on the characteristics of the soil and the slope, such as soil depth, soil fertility, soil drainage, soil texture and terrain slope. Land suitability assessment was performed for banana and pineapple. The crop requirements, temperature, growing period, precipitation and soil conditions were taken into consideration for both crops. The socio-economic data was used to describe Phonxay District and to perform a comparison between different socio-economic and demographic information to evaluate the relationships.

The transformations and interpolations of temperature, precipitation and potential evapotranspiration, together with the growing period zones, agro-ecological zones and zones of terrain and soil constraints, resulted in a land resource database.

Two growing period zones were found in Phonxay District, with 244 days and 214 days respectively. The district contains 16 different agro-ecological zones in regards to temperature, precipitation, soil and terrain. Of these 16 zones, 7 had great potential for agricultural production. The constraint zones confirmed that 31.7 % of land in Phonxay was suitable for agriculture, being classified to zone of slight or no constraints. Bananas and pineapples suitability classification in the area corresponds well with the zones of no or slight constraint and the agro-ecological zones with potential for agricultural production. Very small areas are considered well suitable for the growth of these two crops.

When comparing the agro-ecological zones with the present land use map, the result showed that, even though quite large areas have great agricultural potentials, only small areas are used as such today. The comparison also indicated that an increase of forest is needed to accomplish the goals of the conservation and the protection areas. One of the reasons for that potential land is not used for agriculture could be the absence of roads in these areas. The relationship between zones of constraints and road access showed that 70.6 % of the villages situated in zones of no constraint or slight constraints (potential for agriculture) have no roads. This makes transport to the market impossible.

The socio-economic and demographic analysis showed that the literacy rate in Phonxay District is 34 %, the population growth is 5 % per annum, the immortality rate (IMR) is 118.9, and the main religion in the district is animist. The analysis also showed that villages with a mixed ethnic population generally are better of than villages with homogeneous ethnicity.

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1 Introduction

The ability of the world's natural resources to provide the needs of its growing population is a fundamental issue for the international community. The increasing population is threatening natural recourses as people strive to get the most out of land already in production or push into virgin territory for new agricultural land. The damage is increasingly evident; arable land lost to erosion, salinity, desertification, urban spread, disappearing forest, water shortage and threats to biodiversity (FAO 2002).

These problems have highlighted the need for more effective land use planning and policies all over the world. Phonxay District, which is the study area for this thesis, is situated in Luang Phrabang Province Northern Lao People's Democratic Republic (Lao PDR) (see figure 2.1). In this area, the competition for land is evident, caused mainly by the fact that suitable land for agriculture is very limiting due to the extremely mountainous terrain. Future rational and sustainable land use planning is therefore an issue of great concern to preserve the land resources left in Northern Lao PDR and to sustain it's growing population with food. One of the most fundamental tasks for land use planning and preservation of land, required to reach both efficiency and sustainability, is collation of data into land resource databases. Data often exist but are spread across different organizations and governmental institutions within a country. Limitations of data sharing between institutions and organisations often further restrict the production and usefulness of databases.

A land resource database includes digital information on temperature, precipitation, evapotranspiration, soil, landform, land use, protected areas etc. These components are the basic for the supply of water, energy, nutrients and physical support to plants. Land resource databases can be used for many different purposes. The division of an area into agro-ecological zones (AEZ), which is a combination of the above resources to characterize an area in regards to its relevance to agricultural production, is one example (FAO 2002). The concept of AEZ involves the representation of the above resources in layers of spatial information and combination of layers using a Geographical Information System (GIS) (Food and Agricultural Organization (FAO) 1996). The land resource database could further provide a frame for various applications. It could be used in land use assessment plans with the goal to match specific crop requirements with the biophysical components of an area, quantification of land productivity, estimation of the land's population supporting capacity and multi-criteria optimisation of land resources use and development (FAO 2002).

This project was done in collaboration with the Lao-Swedish Upland Agricultural and Forestry Research Program (LSUAFPR). While in Lao PDR during spring/summer 2004 we collaborated with LSUAFRP to carry out an agro-ecosystem analysis (AEA). This analysis is a procedure of manual comparison and multidisciplinary discussions about an area's agricultural systems, and differs to the above mentioned method of AEZ since it does not use a GIS to perform the analysis.

The AEA was done as the pilot project over the Phonxay District, Luang Phrabang Province, Lao PDR. In the future, LSUAFPR are planning to perform this work on a national level.

1.1 Research Objective

The main goal with this master thesis is to build a land resource database and to use this database to describe Northern Lao PDR, with focus on Phonxay District Luang Phrabang Province, in regards to both its biophysical components and socio-economic aspects. To simplify we divided the study in two parts and two main objectives:

Part 1: Building of the land resource database, which includes transformation of geographic coordinate system, calculation of potential evapotranspiration and interpolation of the climate variables temperature, potential evapotranspiration and precipitation (see conceptual framework 3.1). The database will also consist of soil, terrain and socio-economic data.

Part 2: Analysis of the database including mapping of growing period zones, agro-ecological zones (AEZ), zones of soil and terrain constraints, as well as two examples of land suitability assessment (see conceptual framework 3.1). To further describe Phonxay socio-economic and demographic information will be spatially analysed. Everything will be done in a GIS (Geographical Information System) environment.

1.2 Data and Software

The following data and software was used in the study:

- Daily measurements of climate data including maximum and minimum temperature, maximum and minimum humidity, precipitation, wind speed and sunshine hours from 12 climate stations in Lao PDR. The data was provided by the Lao Swedish Agriculture and Forestry Research Programme.Coordinate system WGS 84.

- Climate data including monthly mean, maximum and minimum temperature and monthly mean precipitation from 22 climate stations covering the northern parts of Thailand, Vietnam and China. Provided by the Global Historical Climatology Network (GHCN). Coordinate system WGS 84.

- Soil data provided by the Soil Survey and Land Use Classification Centre, part of National Agriculture and Forestry Research Institute, Lao PDR. The soil data was in raster format with a resolution of 100 meters and belonged to the geographic coordinate system Indian Datum 1954.

- Land use data provided by the Forestry Inventory Programme Division, Lao PDR. The Land Use data was in raster format with a resolution 100 meters and belonged to the geographic coordinate system Vientiane Datum 1982.

- Terrain data in form of a digital elevation model (DEM) provided by the Watershed Classification Project, Mekong River Commission. The DEM was in raster format with a resolution 50 meters and belonged to the geographic coordinate system Indian Datum 1954.

- Hydrological data, including rivers and lakes, provided by the Watershed Classification Project, Mekong River Commission. The rivers and lakes were in vector format and belonged to the geographic coordinate system Indian Datum1954.

- Data containing administrative boundaries, villages and roads provided by the Database Management Division of the National Agriculture and Forestry Research Institute, Lao PDR.Geographic coordinate system WGS 84, Vientiane Datum 1982 and Indian Datum 1960.

- FAO’s crop environmental requirement database (Sys et al 1993).

- Statistical information on population in Phonxay district, on a village level, provided by National Statistic Centre of Lao PDR (Population Census 1995).

- Software used: ESRI: ArcGIS 8 and 9, ESRI: ArcView GIS 3.3, Clark Labs: Idrisi 32, MapInfo: MapInfo Professional version 7.0, and Microsoft office 2000.

2 Background

The study area for this thesis is Northern Lao People's Democratic Republic (Lao PDR) (18° N, 105° E) with focus on Phonxay District, Luang Phrabang Province (see figure 2.1).

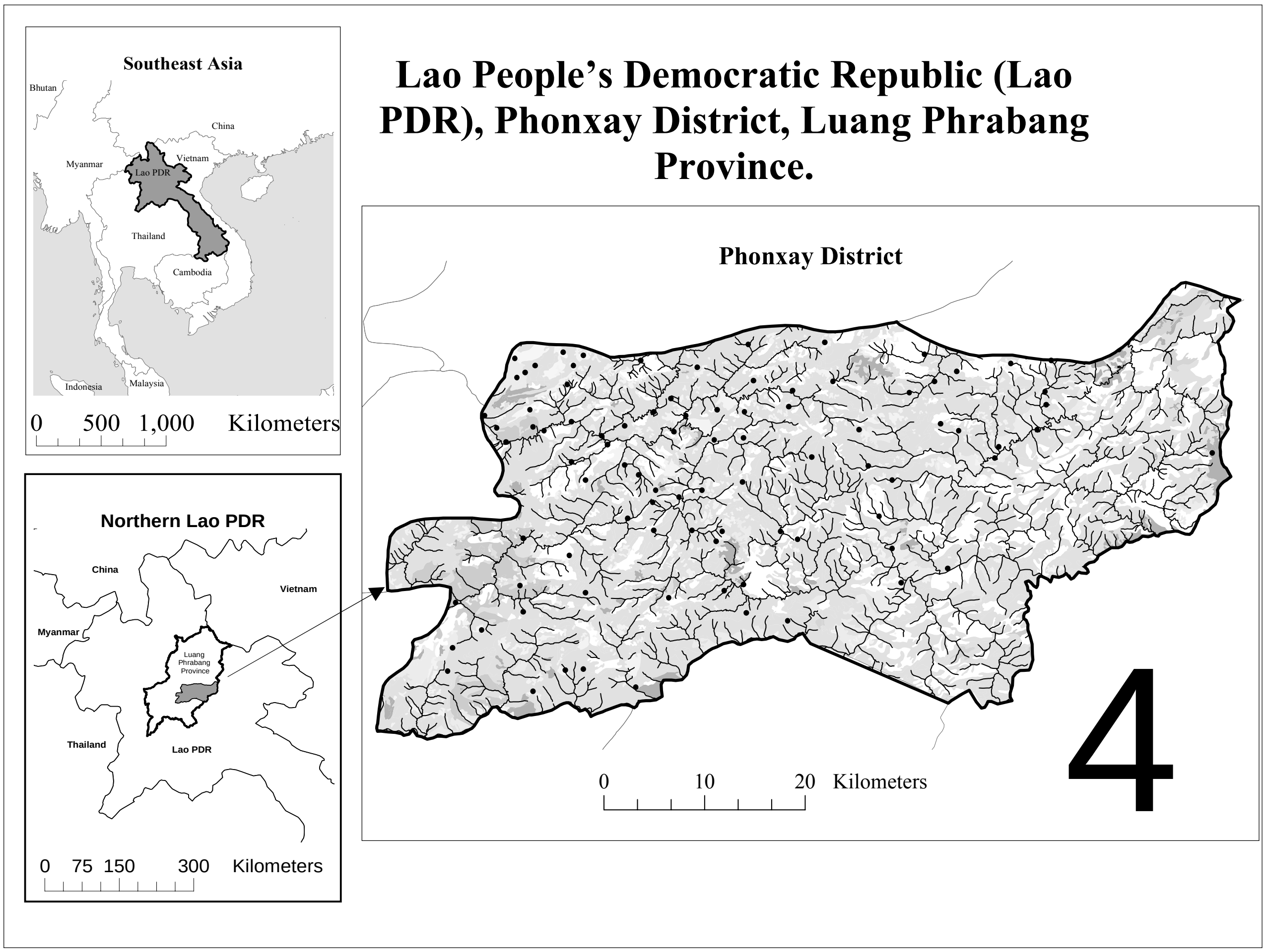


Figure 2.1: The study area for this thesis is Northern Lao People's Democratic Republic (Lao PDR) with focus on Phonxay District, Luang Phrabang Province.

2.1 Lao PDR: An Overview

Lao PDR is situated on the Indochinese peninsula at the center of the Great Mekong sub-region. The country is land locked and borders China, Vietnam, Cambodia, Thailand and Myanmar (see figure 2.1) (United Nation Development Programme (UNDP) & State Planning Committee and National Statistics Center 1998). Lao PDR is a communist state with Vientiane as the capital. It is divided into 16 provinces, one municipality and one special zone. Lao PDR has 6 million inhabitants. There are three main ethnic groups, which are Lao Loum 66 % (who traditionally live in the low lands), Lao Theung 24 % (who traditionally live in the uplands) and Lao Soung 10 % (who traditionally live in the highlands) including the Hmong and the Yao (www.2).

Counting all different ethnic groups more then 200 distinct groups can be found. These indigenous groups speak more then 28 different languages belonging to five different language groups (Chape 1996). 65% of the Lao population are Buddhist (see figure 2.2) and 33 % are animist (State Planning Committee National Statistical Centre 1997).

Figure 2.2: Buddhist Monks at a ceremony. 65% percent of the Lao population are Buddhist.

In 1975, the Lao People's Revolutionary Party (LPRP) took control of the country after 62 years of French ruling and 20 years of armed struggle and political turbulence. Since then, the Lao Government has initiated the New Economic Mechanism, which has led to considerable economic progress (UNDP & State Planning Committee and National Statistics Center 1998). During the Indochina War, Lao PDR received millions of tonnes of bombs and other undeclared interventions. This has affected the possibilities to use the land for agriculture and forestry since many of the ordinances are still unexploded (UXO) (see figure 2.3) (Chape 1996).

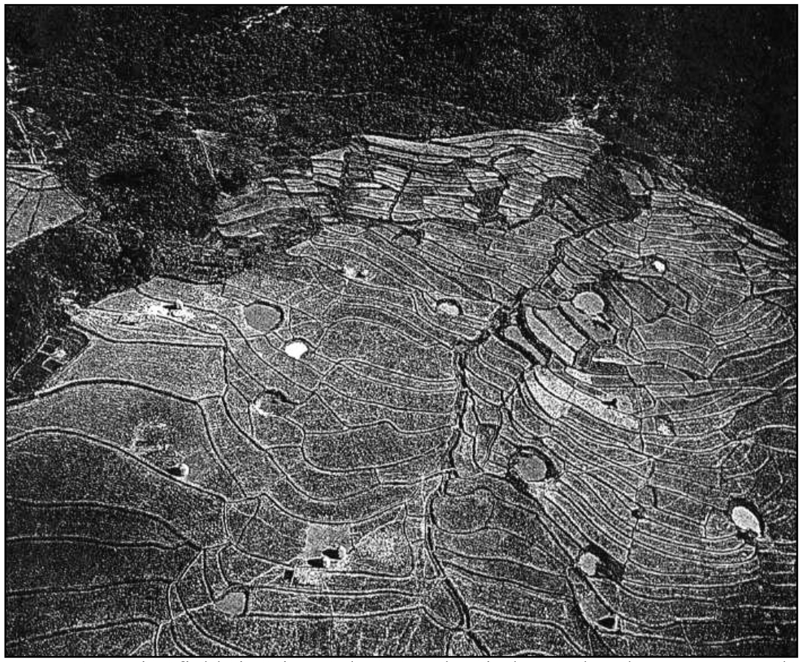


Figure 2.3: Rice fields in Xieng Khwang. The circles are bomb craters caused by the Indochina War. There are still many unexploded ordinances in Lao PDR (Chape 1996).

2.1.1 Upland Agriculture

Three hundreds thousand families in Lao PDR get their living from the forests. On an annual basis, rainy seasonal rice in shifting cultivation accounts for 20 % of the production and 34 % of the national rice area. Other crops grown in Lao PDR are maize, cassava, vegetables, fruit-trees, oil crops, cotton, cucurbits, indigo, aromatic plants. Yet another 100 000 families use forested areas for crops that grow better in this agro-ecosystem such as pineapple, bananas, sesame, cotton and opium. Some communities have sufficient lowland rice and are able to diversify their high value crops, while other communities add upland planting to their rice production to secure that they will have enough to eat (see figure 2.4 and 2.5). The annual clearance of vegetation has been estimated to 310 000 Ha. Of this 235 000 Ha is for upland rice, 30 000 Ha for maize and 45 000 Ha for other crops. The average fallow period is 4.5 years, meaning that 1.4 million ha in Lao PDR is in shifting cultivation, which is equivalent to 6 % of the national territory (Pehu 1999).

In 1985, the number of shifting cultivators was 253 000 families (about 1.5 million people). In 1990, it had increased to 277 000 families and in 1999 it was about 350 000 families. Shifting cultivation can be divided into three general groups (Pehu 1999):

- **Shifting cultivation in the plains practiced by the Lao Loum**.
- **Shifting cultivation at the foot of the mountains by the Lao Theung**.
- **Shifting cultivation on steep slopes by the Lao Soung**.

Figure 2.4: Shifting cultivation on steep slopes in Phonxay District, Lao PDR.
The annual clearance for shifting cultivation is estimated to 310 000 Ha.

Upland agriculture is very labour demanding especially when the fallow period is shortened, which increases the need of weeding. Weeding represents 39 % of the total labour requirements (Pehu 1999).The impact of the population growth on the fallow period is dramatic. The fallow period has been halved in the past 20 years and is expected to be halved again by 2013, leaving it at 1-2 years. This has resulted in that the rice yield has fallen from 2.5-3 tonnes/Ha to 1.2-2.4 tonnes/Ha (Pehu 1999).

Figure 2.5: Upland rice in Phonxay District Lao PDR.

The agricultural trends in northern Lao PDR show an increased use of irrigated land as well as crop intensification, especially around towns. Animal production has also increased to give supplementary family income for purchasing of rice (Pehu 1999).

The carrying capacity of forests, with average soil conditions, in Lao PDR has been estimated to 12 persons/km^2. Under these conditions the fallow period is long enough to restore the soil fertility and no degradation proceeds (Pehu 1999). If population density exceeds 15 persons/km^2 the fallow cycle decreases. If the population density increases to 20 persons/km^2 the communities starts to look for other alternatives. In Louang Phrabang the population density has increased to 25 persons/km^2, causing quick changes in production pattern such as off-farm employment, migration to low land areas, shift to irrigated agriculture and interest for adding value to primary production (jam, weaving etc.) (Pehu 1999).

Depending on the land use type, erosion rates vary: paddy rice 10 tonne/Ha/year, upland crops 500 tonnes/Ha/year, open swidden areas 800 tonnes/Ha/year, orchards 100 tonnes/Ha/year and forested areas 3 tonnes/Ha/year. These erosion rates can according to Pehu (1999) be decreased significantly with conservation measures.

A new policy "Management of the upland environment" was published in 1995 by the government of Lao PDR. Both the short and medium term objectives were to stop the shifting cultivation in the country by year 2000. The program used to achieve this includes a number of elements, namely: using technology to improve the productivity of crops and livestock, improving land use planning at the local level, formalizing land tenure through a process of land allocation, and developing alternatives to agricultural income for shifting cultivators. These program elements, can according to Chape (1996) lead to a number of issues. An illustrative example is from the Louang Phrabang Province where an area of 8 000 Ha supports 600 families (13 Ha per family). According to Chape (1996) the new regulations means that each family would instead receive 5 Ha. This means that this reallocation has to be accompanied by effective changes in agricultural and provision of alternative income sources. There will also be problems such as declining soil productivity. Sedentary cultivation without adequate fallow periods will not produce enough Non-Timber Forest Products (NTFPs), which are currently very important for the household economy and for nutrition. If there is not a large enough increase in rice yield it is likely that families will intensify and broaden the harvest of forest and wetland products to raise income to supplement their rice production and loss of NTFPs, or for direct alternative subsistence purposes (Chape 1996).

2.1.2 Biodiversity and Natural Resources

Water and forest are the two main natural resources in Lao PDR (Chape 1996). The natural forest in Lao PDR covers an area of 10 million Ha, of which 3 million is National Biological Conservation Areas (NBCAs) (Sisouphanthong et al 2001). According to Sisouphanthong et al (2001), the current forest cover range from 41 % to 47 % of the country. This has declined from about 70 % in the 1970s.

The decrease in forest cover is due to the clearing of lowland forests for permanent agriculture, logging, construction of roads and reservoirs, shifting cultivation, fires and the use of chemical defoliation during the Indochina War (Chape 1996).

The large forests, woodlands and other habitats in Lao PDR are home to at least 10 000 animal species, with a high diversity of mammals, birds, vertebrates and invertebrates (Sisouphanthong et al 2001). Using new weapons and hunting techniques villagers catch as many animals as possible to trade for customer goods. This has also caused a decrease in numbers and species of wildlife and fish in the country (Chape 1996).

Wood products account for more than 30 % of the total export revenue and 80 % of the domestic energy consumption is wood based, mostly in the form of fuelwood. Most of the Laotian population, especially those who live in remote areas, are also heavily dependent on forests for their subsistence and for generating income.

Forests further provide important environmental services including water and soil conservation, which are vital not only to domestic power generation and irrigation but also to the development of the Mekong River Basin (European Commission Directorate-General Development & FAO 2002).

The main rivers of Lao PDR consist of the primary and secondary tributaries of the Mekong. The Mekong River basin covers 90 % of the total area of the country. About 25 % of the Mekong River basin is located in Lao PDR, which contributes 35 % of the Mekong's total flow (Land and Water Development Division of FAO 2005). Wetlands play a very important role in the lives of the people of Lao PDR. The majority of the population live in the wetland rich Mekong basin and are dependent on wetlands for subsistence and income generation. In addition to freshwater fish - the principal source of animal protein in the country - a wide range of other wetland products are utilised. The waters of the Mekong and its tributaries are also significant for hydropower generation and irrigation capacity (The World Conservation Union 1996).

The largest hydropower plant in Lao PDR, Nam Ngun located north of Vientiane, has a total capacity of 150 MW. Two other dams in the south can generate 50 MW. Hydropower accounts for 95 % of electricity generation in Lao PDR. Government has also launched possibility studies for 21 other hydropower projects throughout the country. All these projects are located on tributaries of the Mekong River (Land and Water Development Division of FAO 2005).

According to the Land and Water Development Division of FAO (2005), the water resources in Lao PDR could further be used in irrigation of 600 000 Ha agricultural land.

Dams in the northern part of Mekong have already, according to South East Asia Rivers Network (2004), caused adverse impact on hydrology of the river, including decreased discharge and unusual rapid water fluctuations. These impacts affect the riverine ecosystems and local livelihoods of fishing communities in downstream areas as well as farmers dependent on irrigation agriculture. On Thai-Lao border, it is found that the fish catch has declined by 50 % as a result of the water fluctuations (South East Asia Rivers Network 2004).

2.1.3 Socio-Economy and Demography

Lao PDR is one of the poorest countries in the world; it ranks 135 out of all countries on the UNDP Human Development Index in 2001. Despite more than a decade of high economic growth, following the introduction of market-oriented reforms, annual GDP per capita in Lao PDR is US$ 350 (United Nations Development Assistance Framework 2002). These low-income levels reflect the minimal living conditions of the majority of the people in the country. The rural areas, where 83 % of the population lives are particularly underdeveloped. 87 % of those living in poverty are households headed by farmers and 99 % of the rural poor are people in farming households (see figure 2.6).

Figure 2.6: Rural Lao woman at work (United Nation Development programme, State Planning Committee & National Statistics Center, 1998).

According to the UNDP, the State Planning Committee and the National Statistics Center (1998), the life expectancy at birth in Lao PDR is 51.7 years. This is 14 years less then the average for Southeast Asia, and the lowest in ASEAN (Association of Southeast Asian Nations) and 20 years less then in the neighboring country Thailand (UNDP, the State Planning Committee & the National Statistics Center 1998).

The infant mortality rate (IMR) in Lao PDR is 93 deaths per 1 000 live births. This is significantly higher then in Thailand, which has an IMR of 29.
58 % of the infant deaths occur during the first year. The maternal mortality rate in Lao PDR is 650 deaths per 100 000 live births in comparison to Thailand's 200 (UNDP, the State Planning Committee & the National Statistics Center, 1998). The level of the mother's education is also a factor influencing child mortality in Lao PDR (see figure 2.7).

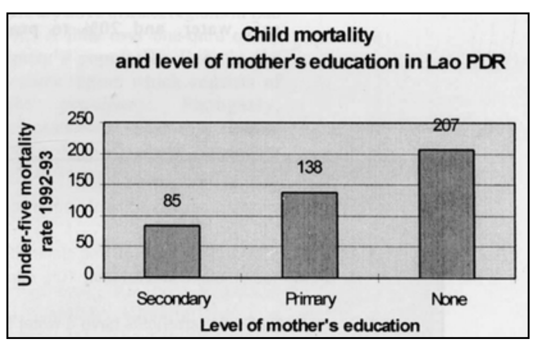


Figure 2.7. Child mortality and level of mother's education. As can be seen, child mortality rate decreases with an increase of the mother's educational level (UNDP, State Planning Committee & National Statistics Center 1998).

In 1994, Lao PDR achieved an adult literacy of 60 % in comparison to Thailand's 93.5 %. Between 1990 and 1995, the number of pupils completing primary school doubled. The likelihood for a school aged child to enroll in school went up from 64 % to 72 % and the proportion of unqualified teachers dropped from 38 % to 10 %. However, more then 4 000 remote villages continue to be without access to primary school. In 1994, one in four children at the age six to ten did not attend school. Less than half the children entering school finished primary education. Half of the ethnic minority girls never attended school and most of the other half completed only two grades (UNDP, the State Planning Committee & the National Statistics Center 1998).

The health state in Lao PDR is very poor. Malaria ranks as the number one health problem with 1.4 million cases a year and 14 000 deaths. The health problems are particularly severe for women because of the high fertility rate of 6.7, which is the highest in South East Asia. This leads to an annual population growth of 2.5 %. In 1993, almost 40 % of the women reported that they delivered their babies at home with no help, 30 % reported that a friend or relative assisted them and 23 % had assistance from traditional healers or midwives at home. Only 7 % went to a hospital or a clinic (UNDP, State Planning Committee and National Statistics Center 1998). 41 % of the Lao children are malnourished and 12 % are severely malnourished.

2.1.4 The Tropical Climate of South East-Asia

The South East-Asian region at large have many differences such as lowlands and mountain ranges but the climates in the region have one thing in common, they are all controlled by the Asian monsoon system (Landsberg 1981). The monsoon system can be divided into the northeast monsoon season and the southwest monsoon season. The dry season always comes during the northeast monsoon lasting from November to March (see figure 2.8). The wet season comes during the southwest monsoon and the mean annual precipitation varies between 1 000 – 3 000 mm (see figure 2.8). The mean monthly temperature in the region varies between 20 to 30°C (see figure 2.8).

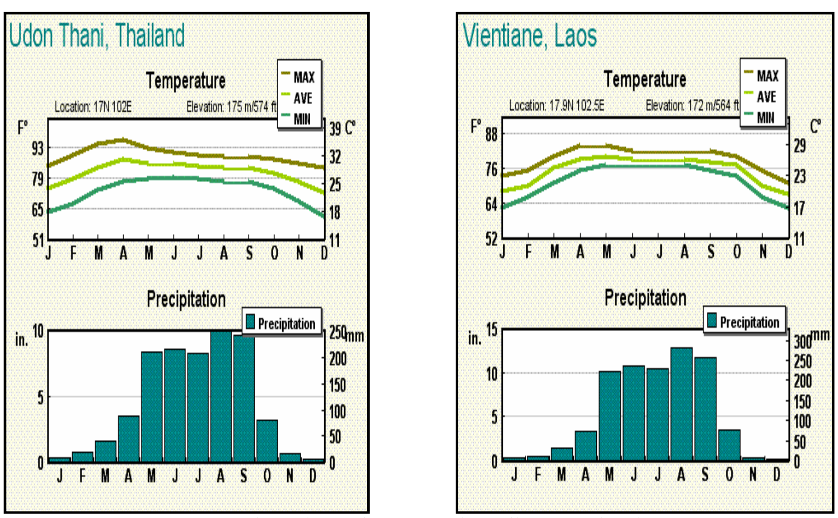


Figure 2.8: Two examples of South East-Asian climate. The dry season comes during the northeast monsoon lasting from November to March. The wet season comes during the southwest monsoon and the mean annual precipitation varies between 1 000 – 3 000 mm. The temperature in the region varies between 20 to 30°C (www.3).

The Northeast Monsoon Season
The northeast monsoon season lasts from November to March. During this season the atmospheric conditions are quite stable. The season brings two air masses to the region. The first air mass comes from Siberia and Mongolia. It is originally cold, dry and stable but when it reaches the region it becomes modified and warmed. The second air mass originates over the Pacific Ocean. It is tropical maritime air that is warm and stable. However the first air mass usually dominates the region (Landsberg 1981).

During February and March, the wind direction changes to a more easterly direction and the temperature increases with five to seven degrees between January and March (see figure 2.8). The high daytime temperature causes thunderstorms that bring the mango-rains to the area. These rains indicate the end of the dry season (Landsberg 1981).

The First Inter-Monsoon Period
During April and May, the northeast monsoon retreats further north and the southwest monsoon advances over continental Southeast Asia. This means that clouds and precipitation comes to the region. For most parts in the north of the region, April is the hottest month (see figure 2.8). During the hottest hours of the day thunderstorms are frequent, but they do not bring much rain, although over the mountains local convection causes larger rain amounts (Landsberg 1981).

The Southwest Monsoon Season
The southwest monsoon season lasts from June to September and the whole region is dominated by southwesterly winds. Since only one air mass is controlling the region the temperature is more or less constant. This is the main rainfall season for the area (Landsberg 1981).

The Second Inter-Monsoon Season
The southwest monsoon weakens in September due to the beginning of the cooling of the continent. The monsoon retreats southward at the same time as the northeast monsoon advances south. However, the velocity of both air masses is very low and the general circulation almost stops. In spite of this the intensity of convergence is relatively high and a broad zone of heavy precipitation accompanies the border zone. Typhoons can also influence the region during this season (Landsberg 1981).

Elevations Influence on Climate
According to Landsberg (1981) & Nieuwolt (1982) the elevation in the area has two main effects on the climate. The first is the temperature and the second is the air currents where the result mainly can be seen in winds and precipitation.

The temperature decreases with elevation at a normal rate of 0.6ºC per 100 m for the region. This is also what Chapman & Danh suggest in their report in 1997. The intensity of both solar and terrestrial radiation increases with elevation. Therefore, climate stations at the top of mountains usually have larger temperature ranges than lowland stations nearby. Clouds form earlier over mountains than over valleys, because valley and upslope winds start early in the day.

The wind velocity is normally higher in high altitudes than in low. This is caused by the lower friction at high altitudes Landsberg (1981) & Nieuwolt (1982). The relief in the region forces the air masses to rise, which often causes orographic precipitation on the windward side and rain-shadow on the leeward side.

If the rain carrying winds comes mainly from one direction, the mountain ranges can become sharp climatic dividers. According to Landsberg (1981) & Nieuwolt (1982) precipitation in the region generally increases with elevation, up to a certain level, and thereafter decreases. According to Landsberg (1981) & Nieuwolt (1982) the climatologists have not been able to agree on which level the decree starts.

2.2 The Study Area

2.2.1 Louang Phrabang Province

Louang Phrabang province is located in the mountainous northern part of Lao PDR. The total area of the province is 20 226 km^2 and of that 85 % is upland, the province capital is Louang Phrabang (Luang Phrabang Province 2000). The province includes 11 districts, 1 176 villages and 63 582 households. The annual revenue is 17 billion Kip (1.7 million USD).

The population in the province is 385 480 (194 540 women). There are 12 ethnic groups, 39 % Lao Loum, 45 % Lao Theung and 16 % Lao Soung. The population density is 22 pers/km^2 and the population growth rate is 2.4 % per year. Over 80 % of the population are involved in agricultural production, mainly rice cultivation, 17 % are engaged in commerce and 3 % are government officials or others (Luang Phrabang Province 2000).

There are 12 hospitals in the province and 39 health centres and 945 schools (see figure 2.9). The majority of people in the province live in poverty, especially in the remote areas, with little or no access to public services. The living conditions are low and the mortality is high especially in upland areas (Luang Phrabang Province 2000).

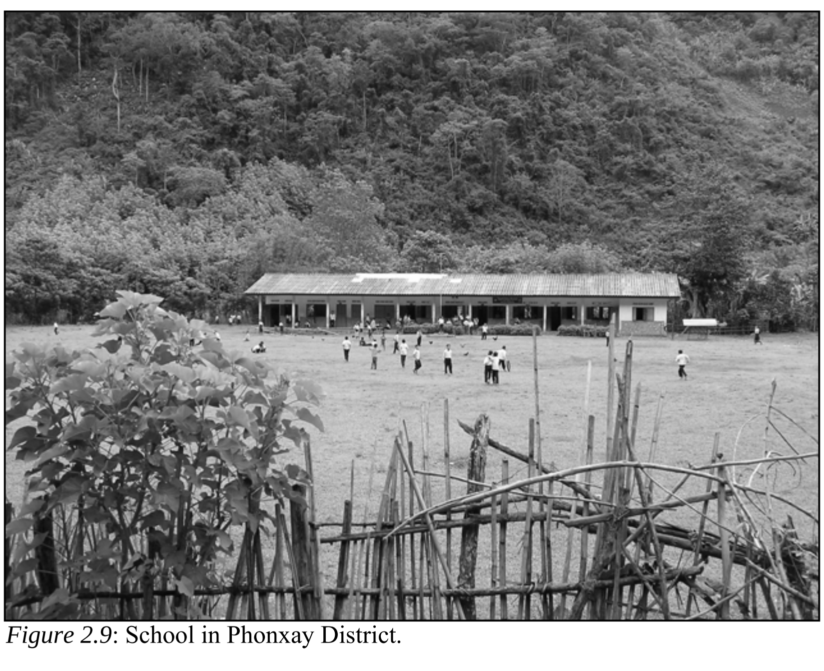


Figure 2.9: School in Phonxay District.

On average, in the province, the yield of irrigated rice is 4.2 tonne/Ha/year, rain fed rice is 3.5 tonne/Ha/year and upland rice 1.7 tonne/Ha/year. A few years ago, the province started emphasising food production. This was done by increasing the land area under cultivation, promoting the integration of farming systems to boost the yield, constructions of irrigation schemes for dry season rice cultivation as well as expansion and commercialisation of fruit and vegetable production. The province also started promoting livestock (see figure 2.10) where it was feasible and an upland allocation programme to reduce and eventually eliminate sifting cultivation (Luang Phrabang Province 2000).

Figure 2.10: Luang Phrabang province have started promoting livestock to reduce and eventually eliminate sifting cultivation. Water buffaloes are common livestock in Phonxay District.

In the 1998-1999 provincial budget, agriculture and forestry represented 36.3 %, rural development 8.2 %, industry 0.3 %, education 4.0 %, health 1.9 %, information and culture 6.5 %, infrastructure, communication and transport 29.3 %, labour and social welfare 0.3 % and other sectors 13.1 %.

Louang Phrabang province have stated a number of developmental goals which includes (Luang Phrabang Province 2000):

- Provincial food self sufficiency.
- Commercialised agriculture production and animal husbandry (including food processing for export and to reduce food imports).
- Poverty alleviation.
- Improved rural access to infrastructure, basic public health services and quality education.
- Forest conservation.
- Tourism development and cultural preservation.
- Better incorporation of gender issues in the development process.

2.2.2 Phonxay District

Phonxay District is located in Louang Phrabang Province in the northern part of Lao PDR. It is characterised by its rugged terrain and narrow valleys along rivers and streams. 90 % of the total area of the district is mountainous, which is a limiting factor for paddy rice cultivation (see figure 2.11). The mountainous terrain restricts the agricultural practises to mainly upland rain fed farming systems. The total area of paddy land is approximately 190 Ha.

Figure 2.11: Small areas of paddy rice cultivation can be found in the narrow valleys in Phonxai District. On the slopes on the opposite side of the valley there is shifting cultivation and teak plantations.

Pockets of elevated rolling plateaus can be found at higher altitudes. These are usually isolated but can support both natural forests and grasslands and are therefore used by highland villages for cattle raising (LSUAFRP 2004).

The district has rather small areas of natural forests left. The most important and least disturbed is located in the northeast, this area is included in the National Biodiversity Conservation Area. For the villagers near by, these areas are important non-timber forest products areas (LSUAFRP 2004).

Phonxay District has a total population of 24 586 people, and there are 92 villages (Luang Phrabang Province 2000). The District is populated by all three main ethnic groups. The Lao Loum occupie the riverside valleys, the Lao Toung the valleys and hill slopes and the lao Soung the higher elevations. Recently however there have been large changes in this distribution both due to voluntary migration, but also planned re-location from the more mountainous areas to low-lying areas. At present, there are many villages of mixed ethnicity in Phonxay (LSUAFRP 2004).

Phonxay is one of the ten poorest districts in Lao PDR. The district administration has determined that of 56 surveyed villages only five are in the low poverty brackets, 10 are less poor and 41 (73 %) are in the severe poverty brackets.

Opium addiction is common and only 17 villages in the District have permanently clean water (LSUAFRP 2004).

The district is not connected to the national electricity grid and the access to the district and within it, is by road, which is difficult in the wet season. The development priorities, as decided by the province, are to reduce shifting cultivation through resettlement of upland villages and expansion of cash crop (Luang Phrabang Province 2000).

2.2.2.1 Soils

In tropical climates, like in Phonxay District, soil temperature and the soil moisture is usually high. This favours a fast chemical disintegration of the parent rock. The climatic factors further favours bacterial activity causing little humus to form. Large amount of precipitation in tropical areas causes an increase in nutrient removal due to leaching and erosion. Accoring to Nieuwolt (1982) this is particularly noticeable when rain comes in intense rainstorms. The alternating wet and dry climate in Phonxay can lead to that the evaporation of the groundwater near the surface during the dry period counterbalances the leaching of the salts during the wet season. This process can create a hard crust in the topsoil layer, which has serious effects for agriculture (Nieuwolt 1982). Furthermore, tropical soils are very susceptible to removal of vegetation. If removed, severe effects including increased nutrient loss, loss of organic matter, temperature and moisture changes as well as increased soil erosion (Nieuwolt 1982).

The soil map over Phonxay District was provided and done by the Soil Survey and Land Use Classification Centre, part of National Agriculture and Forestry Research Institute, Lao PDR and the soil classification system used was the FAO/UNESCO's system: Soil map of the world from 1989. This system divides the soils in the world into 30 soil reference groups (FAO 2001). These groups are based on the formation of the soils due to evolutionary or geographical conditions.

According to Olsson (2003), the method used by the Soil Servey and Land Use Classification Centre of Lao PDR to produce the soil map over the Phonxay District was as follows. A physiographic map was compiled by combining the results from surveys and aerial photograph interpretations. This map was then used as a starting point for the field survey. The delineation of soil units in the field was based on morphological characteristics, such as texture and soil depth. Soil samples were taken from pits at different genetic horizons. In addition to the pits, auger sampling to 15 cm depth was done at the same density as the pit samples (one pit per 60 ha). The samples were taken to the NAFRI (National Agriculture and Research Institute) lab for preparation and chemical analysis. Based on these results the soil subgroups were determined and the soil map was digitised. Each soil map unit was given a value for soil type, soil depth, steepness and assessed topsoil fertility. An example of a full combination is given below (table 2.1-2.5) (Olsson 2003):

A full combination can be as follows:

CMe – D – L – a (M)

Which means:

CM	Cambisols
CMe	Eutric Cambisols
D	Deep (> 100 cm depth)
L	Loam texture
a	Flat or almost flat physiography with 0 – 2 % slope
M	Medium topsoil fertility

Table 2.1: Explanation of soil depth classes in the soil map (Land Management 2002).

Acronym	Description	Depth
R	Rock Out Crop	0-30 cm
S	Shallow Soil	30-50 cm
T	Thin Soil	50-75 cm
M	Moderate Deep Soil	75-100 cm
D	Deep Soil	> 100 cm

Table 2.2: Explanation of topsoil texture classes in the soil map (Land Management 2002).

Acronym	Discription
Sa	Sand
Ls	Loamy Sand
Sl	Sandy Loam
Scl	Sandy Clay Loam
L	Loam
Sil	Silty Loam
Si	Silt
Sicl	Silty Clay Loam
Cl	Clay Loam
Sc	Sandy Clay
Sic	Silty Clay
C	Clay

Table 2.3: Explanation of slope classes in the soil map (Land Management 2002).

Acronym	Description	Slope
a	Flat or almost flat	0 – 2 %
b	Undulating	2 – 8 %
c	Rolling	8 – 16 %
d	Hilly	16 – 30 %
e	Steeply dissected	30 – 55 %
f	Mountainous	> 55 %

Table 2.4: Explanation of indices of soil fertility in the soil map. For each criterion the soil can receive between one and three points. The points are added together which gives an indication of the fertility level. OM represent the percentage of organic matter, BS is the base saturation, CEC –T is the total cation exchange capacity, P_{PPM} is the Available Phosphorus (BRAYII method) and the K_2O is the Potassium of the soil sample (Land Management, 2002).

Fertility rate	% OM	% BS	CEC-T me/ 100g soil	P_{PPM}	K_2Omg/100g of soil
Low (L)	< 2.0 (1)	< 50 (1)	< 10 (1)	< 10 (1)	< 4.0 (1)
Medium (M)	2.0 – 4.0 (2)	50 – 75 (2)	10 – 20 (2)	10 – 25 (2)	4.0 – 12.0 (2)
High (H)	> 4.0 (3)	> 75 (3)	> 20 (3)	> 25 (3)	> 12.0 (3)

Table 2.5: Soil fertility rate after the points from the above table has been added together (Land Management 2002).

Acronym	Description	Fertility rate
L	Low fertility	≤ 7
M	Medium fertility	8 – 12
H	High fertility	≥ 13

The Land Management Component (2002) gives a description of the three main soil groups found in Phonxay.

The first group are *leptosols* that are limited in depth by bedrock, very calcareous materials, continuous cemented layer less then 30 cm from the surface or have less then 20 % fine particles over a depth of 75 cm of the surface. These soils are shallow, less than 30 cm deep. *Eutric Leptosols* are a subgroup to *leptosols*. In the Phonxay they have a pH value of 7.1, a medium organic matter content of 3 %, high available phosphorous content of 31 ppm and a high available potassium level of 32 mg/100 g soil. The soil is classified as low fertile.

The second group are *cambisols*, which are mineral soils where soil formation is limited by age. These soils are in the transition between immature and mature soils. They are developed on undulating terraces and floodplains with slopes ranging from 0 to 8 %. These soils are deep, depending on the topography. The mechanical composition of these soils is loam. The soils are well drained with a soil fertility classification of medium. The subgroup *Eutric Cambisols* in the study area has a slight acid reaction of pH 6.4, a medium organic matter content of 2.5 %, medium available phosphorous content of 16 ppm and medium available potassium of 10 mg/100g soil.

The third group are *acrisols*, which are mineral soils. They are typicly red and yellow acuaring in wet tropical and subtropical regions (FAO 2001). The soil formation is determined by climate conditions and climate induced vegetation in wet or moist tropical areas. They are formed on undulating terraces and steeply dissected slopes ranging from 8 to 55 %. These soils are shallow to deep and their mechanical composition is sandy loam to clay loam. They are well to excessively drained soils and have a nutrient content that is classified medium. The subgroup *Haplic Acrisols* have low to high organic matter contents of 1 – 4.5 %, medium levels in phosphorous availability of 1.5 – 24 ppm and medium to high potassium content of 14.4 – 71.2 mg/100g soil.

2.3 Agro-Ecological Zoning Assessment

Heavy population pressure and the related increased competition from different types of land users have emphasised the need for more effective land use planning and management. Rational and sustainable land use is an issue of great concern to the Lao government and the land users interested in decreasing the poverty and preserving the land resources. Policy-makers and land users in Phonxay face a number of basic challenges:

- The need of new agricultural land for the growing population and for the migrating population, who are moving into larger villages causing a higher population pressure.

- The need of more roads and roads of better quality. This is particularly important since roads are a necessity to reach local markets.

- The need to reverse land degradation in agricultural areas by improving conditions and re-establishing their fertility.

- The need to prevent degradation in new areas exploited for agriculture.

- The need to protect wildlife and aquatic life as well as to protect the water resource themselves.

In all these challenges, planning and management of land resources is a key factor to ensure that land is allocated to the use providing the greatest sustainable benefit.

The (Agro-Ecological Zoning) AEZ methodology was developed by the FAO in collaboration with the International Institute for Applied Systems Analysis (IIASA). The main purpose of the methodology was to analyse solutions to various problems concerning land resources both at regional, national and sub-national levels (FAO, Land and Water Development Division 1996). Over the past 20 years, the term has become widely used and has been associated with a wide range of different activities, which are all related yet quiet different in scope and objectives (FAO 2002).

The AEZ methodology uses databases, linked to a GIS and sometimes computer models to characterise an area in regards to its relevance to agricultural production (FAO, Land and Water Development Division 1996). The essential databases needed to perform an AEZ comprises of biophysical information of climate, soil, and landform, which are the basic for the supply of water, energy, nutrients and physical support to plants. Sustainable management of land resources therefore requires sound policies and planning based on knowledge of these resources.

AEZ can be used in various assessment applications, including (FAO 2002).

- A general inventory and database construction of the biophysical resources within an area.
- A land resource inventory, which is a zoning to characterise an area in regards to its relevance to agricultural. These zones are called agro-ecological zones.
- Estimation of arable land.
- Zoning in regards to an area's soil/terrain, climatic or socio-economic constraints.
- Zoning of growing periods over an area.
- Land use assessment plans with the goal to match specific crop requirements with the biophysical components of an area.
- Quantification of land productivity.
- Estimation of the land's population supporting capacity.
- Potential yield calculations.
- Land suitability and land productivity evaluations, including forestry and livestock production.

Ecological-Economic Zoning (EEZ) is an alternative, or an advanced approach to AEZ, in which an expanded multi-layered AEZ database, including socio-economic data, is used (FAO, Land and Water Development Division 1996). This is, as we see it, a more holistic approach since an areas agricultural potential, for example, depends on both biophysical and socio-economic components. If both factors are not included in the analysis it could easily lead to that decision makers might take wrong decisions. Depending on the aim of the study, a wide scope of socio-economic and demographic factors could be included.

The essential demands in a land resource inventory are the growing period, the precipitation, the thermal regime, the soil mapping units and the terrain (FAO, Land and Water Development Division 1996).

The thermal regime refers to the amount of heat available for plant growth and development during the growing period and the growing period is defined as the period of the year when both temperature and moisture is suitable for crop growth. According to FAO (1998) this occur when the precipitation (P) plus moisture stored in the soil exceeds half the potential evapotranspiration (PET). PET is estimated using the Penman-Monteith equation (FAO 1997).

2.3.1 Calculation of Potential Evapotranspiration, Using Climatic Data

Direct measurements of evapotranspiration are usually too expensive and the time required often exceeds the time available for a complete research project (Burman & Pochop 1994). Therefore, a large number of methods to estimate potential evapotranspiration, using climatic data, have been developed, used and evaluated over the last 50 years (FAO 1998). Examples of methods are the Penman-Monteith Combination Method, the Blaney-Criddle (FAO-24 version) and the Jensen-Haise Method (Burman & Pochop 1994). In May 1990, FAO organized a consultation of experts and researches in collaboration with the International Commission for Irrigation and Drainage and with the World Meterological Organization. At this meeting, the FAO's recommended methodologies, published by FOA in the 1977 Drainage Paper No 24, was reviewed and updated. The experts came to the recommendation to adopt the Penman-Monteith Combination Method as a new standard for reference evapotranspiration. This method requires the following data for daily, weekly, ten-day or monthly calculations (FAO 1998):

- Site location: Altitude above sea level (m) and latitude (degrees). These data are needed to adjust some weather parameters for the local average value of atmospheric pressure (a function of site elevation) and to compute extraterrestrial radiation and, in some cases daylight hours.

- Temperature: The average daily maximum and minimum air temperature in degrees Celsius (°C) are required. Average mean daily temperature could also be used but with the effects of an underestimation of potential evapotranspiration.

- Humidity: The average daily actual vapour pressure in kilopascals (kPa). Could also be derived from maximum/minimum relative humidity (%), psychrometric data (dry wet bulb temperature in °C) or dewpoint temperature (°C).

- Radiation: The average daily net radiation in mega joules per square metre per day ($MJ\ m^{-2}\ day^{-1}$). Can also be derived from the average short-wave radiation measured with a pyranometer or from the daily actual duration of bright sunshine (hours per day) measured with a sunshine recorder.

- Wind speed: The average daily wind speed in metre per second ($m\ s^{-1}$).

3 Methodology

The methodology is divided in two parts one with the process of Land Resource Database building and one with the analyses of the database (see conceptual framework figure 3.1).

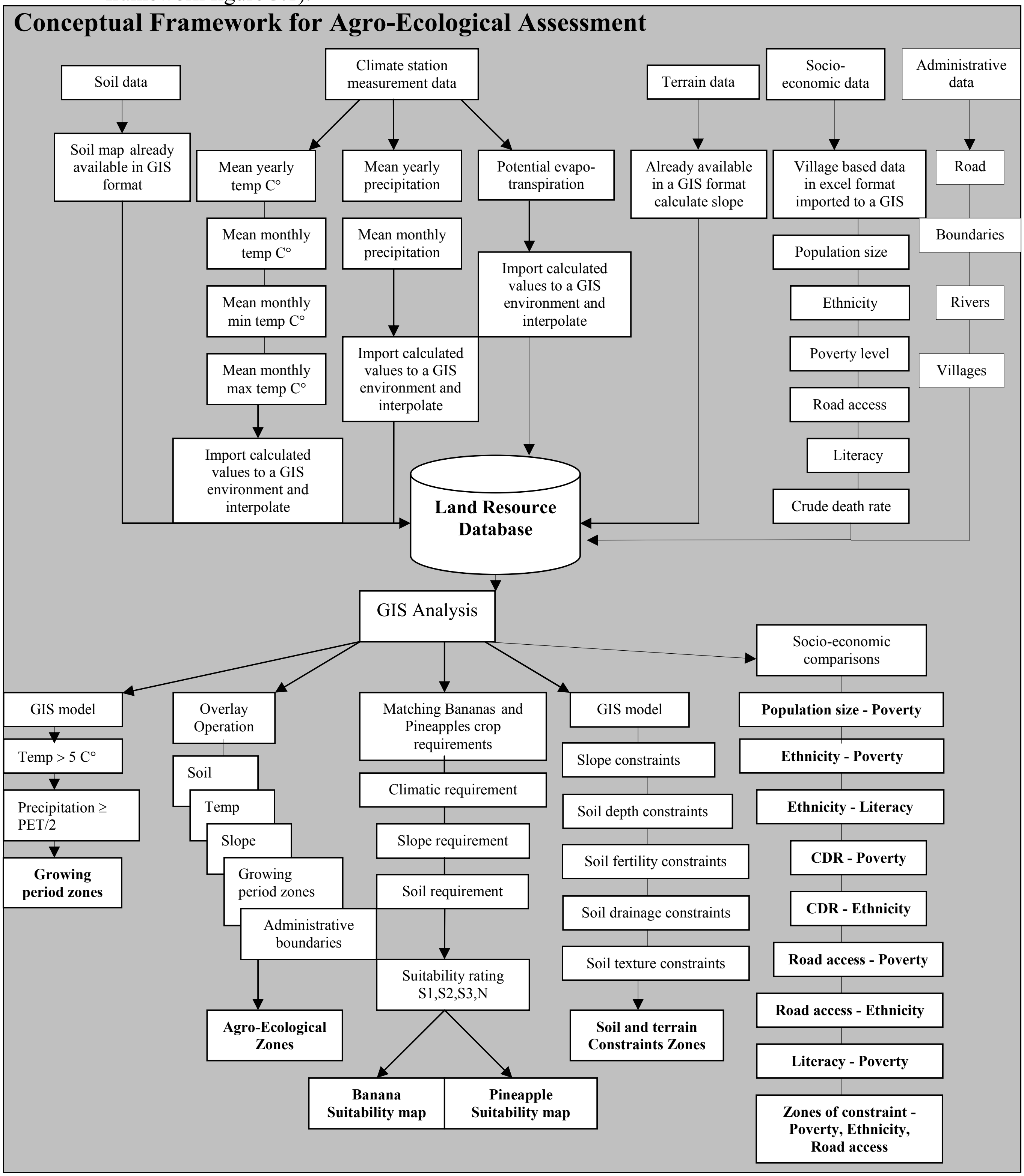


Figure 3.1: Conceptual framework for the agro-ecological assessment done in this study.

Part 1

Preparation of digital data and database building, includes transformation of geographic coordinate systems, calculations of evapotranspiration, estimation of missing climatic data, evaluation of alternative methods, interpolation of climate variables and slope calculation.

3.1 Transformations of Geographic Coordinate System

A geographic coordinate system (GCS) uses a three dimensional spherical surface to define locations on the earth. A GCS is often incorrectly called a datum, but a datum is only one part of a GCS. A GCS includes an angular unit of measure, a prime meridian, and a datum (based on a spheroid) (Environmental Systems Research Institute, Inc, 1994-2000) (for a more detailed description of a GCS see Appendix 8.1)

The geographic coordinates of a point depend on the datum to which they are related. The latitude, longitude and height of a point defined on datum "1" (for example, Lao National Datum 1997) will almost certainly be different to the latitude, longitude and height for the same point defined on datum "2" (for example, WGS84). The difference has to do with that the ellipsoids of the datums are positioned or oriented differently and/or they may differ in size. Coordinates can be transformed from one datum to another but requires that the relationship between them is known.

There are several methods of transformations, which have different characteristics, and different levels of accuracy. The two most commonly used datum transformation methods use three or seven parameters.

Before performing any transformations in this study, each individual data layers geographic coordinate system had to be identified. Only a few had an already defined system. To assume to what system the layers that were missing a system belonged to, each layer was compared with the layers that had a defined system. The geographic coordinate systems identified were: WGS 84, Indian Datum 1954, Indian Datum 1960, Vientiane Datum 1983, and Lao National Datum 1997 (see Appendix 8.2 for description of the geographic coordinate systems).

3.1.1 Three-Parameter Method

Lao National Datum 1997 is the geographic coordinate system recommended by the National Geographic Department of Lao PDR. Therefore, all the other systems found were transformed to Lao National Datum 1997. In this study, the three–parameter method was used since we were restricted to three known parameters. This simplest form of transformation involves applying shifts to three geocentric coordinates. The geocentric transformation models the differences between two datums in the X,Y and Z coordinate system (see figure 3.2). These differences (parameters) were given to us by the Geographical Department of Lao PDR and can be found in Appendix 8.2.

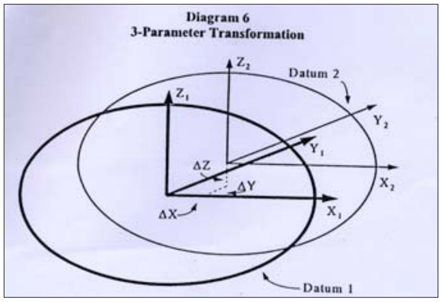


Figure 3.2: A three parameters transformation, is a method that models the differences between the two datums in the X, Y and Z coordinate system (Environmental Systems Research Institute, Inc 1994-2000).

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{new} = \begin{bmatrix} \Delta X \\ \Delta Y \\ \Delta Z \end{bmatrix} + \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{original}$$

3.1.2 Georeferencing

Georeferencing was used to transform the coordinates for the soil map and the digital elevation model, both provided as raster data layers, since we could not identify what system they belonged to. Georeferencing is a procedure where you fit points in your map to known positions, or corresponding points in an already defined data layer. The basic procedure for georeferencing is to transform the data with the unknown coordinate system into the same space as the target data with known coordinate system. This is done by identifying a series of ground control points in the two data layers. Hereby it is possible to define relationships between the two systems. Examples of places to find control points are road intersections, water bodies, rivers, edges of land cover parcels, and similar features. When you have created enough links, you can transform or warp the raster to map coordinates. Warping uses a mathematical transformation, in two dimensions, to determine the correct map coordinate location.

A first order affine transformation was used on both maps:

$$x' = Ax + By + C$$

$$y' = Dx + Ey + F$$

Where x and y are coordinates of the input layer, and x' and y' are the transformed coordinates. A, B, C, D, E and F are determined by comparing the location of source and destination control points. They scale, skew, rotate, and translate the layer coordinates.

The resampling method used for the soil map was a Nearest Neighbor Assignment, since this data is of categorical type. Nearest Neighbor Assignment takes the value from the cell closest to the transformed cell as the new value (see figure 3.3). The number of links used was 23 and the Root Mean Square Error was 0.35.

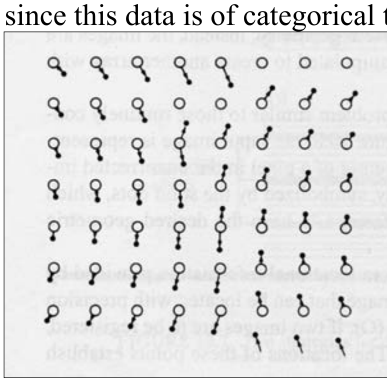


Figure 3.3: Nearest neighbor assignment takes the value from the cell closest to the transformed cell as the new value (Campbell 1996).

The resampling method used for the Digital Elevation model was a Bilinear Interpolation, since the data is of continuos type. A Bilinear Interpolation Technique combines a greater number of nearby cells (4) to compute the value for the transformed cell (see figure 3.4). The technique use's a weighted averaging method to compute the output transformed cell value. The number of links used was 15 and the Root Mean Square Error was 0.51.

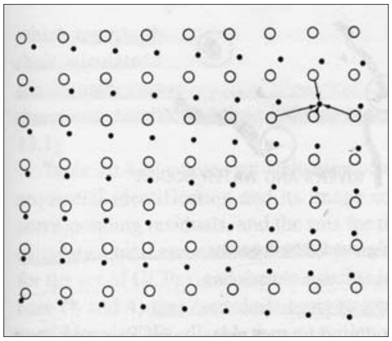


Figure 3.4: The Bilinear interpolation technique combines a greater number of nearby cells to compute the value for the transformed cell (Campbell 1996).

3.2 Calculating Potential Evapotranspiration or Reference Crop Evapotranspiration

The potential evapotranspiration rate from a reference surface that is not short in water is called the reference crop evaporation, or reference evapotranspiration ET_0 (FAO 1998). ET_0 is the evaporating power of the atmosphere at a specific location and time of the year. The calculation of ET_0 was introduced with the purpose to study the evaporative demands of the atmosphere independently of crop type, crop development and management practices (FAO 1998). To prevent the need to define evapotranspiration parameters for each crop and stage of growth the concept of a reference surface was introduced. Grass together with alfalfa is a well-studied crop, regarding its aerodynamic and surface characteristic, and is accepted world-wide as a reference surface (FAO 1998). The FAO's Expert Consultation on Revision of Methodologies for Crop Water Requirements (1992) definition for the reference surface is:

"A hypothetical reference crop with an assumed height of 0.12 meter, a fixed surface resistance of 70 s m^{-1} and an albedo of 0.23".

To calculate ET_0 the FAO Penman Monteith Combination Method, we used the following equation (see Appendix 9.3 for a derivation of this method) (FAO 1998):

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 U_2)}$$

Where

ET_0 Reference Evapotranspiration [mm day^{-1}]
R_n Net radiation at the crop surface [MJ m^{-2} day^{-1}]
G Soil heat flux density [MJ m^{-2} day^{-1}]
T Mean daily air temperature at 2 m height [°C]
U_2 Wind speed at 2 m height [m s^{-1}]
e_s Saturation vapour pressure [kPa]
e_a Actual vapour pressure [kPa]
$e_s - e_a$ Saturation vapour pressure deficit [kPa]
Δ Slope vapour pressure curve [kPa $°C^{-1}$]
γ Psychrometric constant [kPa $°C^{-1}$]

The potential evaporation is converted from MJ $m^{-2}day^{-1}$ to mm day^{-1} by multiplying by 0.408.

Daily values of evapotranspiration were calculated for 12 climate stations in northern Lao PDR. The number of years, with collected data, at each station varied between five and nineteen.

3.2.1 Net Radiation *(R_n)*

Net radiation is the difference between incoming and outgoing radiation. This includes downwelling solar radiation, reflected upwelling solar radiation, downwelling longwave radiation emitted from the atmosphere and uppwelling longwave radiation emitted from the earth (Stull 2000). It is the balance between these that defines the net radiation and is given by (FAO 1998):

$$R_n = R_{ns} - R_{nl}$$

R_n The net radiation [MJ m^{-2} day^{-1}]
R_{ns} The incoming net short-wave radiation [MJ m^{-2} day^{-1}]
R_{nl} The outgoing net long-wave radiation [MJ m^{-2} day^{-1}]

Net radiation is a positive value when there is more incoming radiation than outgoing radiation. This typically occurs during the daytime. At night, net radiation is usually negative as there is no incoming solar radiation and net long-wave radiation is dominated by the outgoing terrestrial long-wave flux (FAO 1998).

3.2.1.1 Net Solar or Net Short Wave Radiation *(R_{ns})*

$$R_{ns} = (1-\alpha)R_s$$

R_{ns} The incoming net short-wave radiation [MJ m^{-2} day^{-1}]
α Albedo or canopy reflection coefficient, which is 0.23 for the hypothetical grass reference crop [dimension less]
R_s The incoming net short-wave radiation [MJ m^{-2} day^{-1}]

Solar radiation (R_s)
The solar radiation is the amount of radiation reaching a horizontal plane. The solar radiation can be calculated using the Ångström's formula which relates solar radiation to extraterrestrial radiation and relative sunshine duration. Depending on the atmospheric conditions and solar declination (latitude and month), the Ångström values a_s and b_s will vary. Where no measurements have been done, FAO (1998) recommend to use a_s= 0.25 and b_s= 0.50. The solar Radiation R_s is given by (FAO 1998):

$$R_s = \left(a_s + b_s \frac{n}{N}\right) R_a$$

R_s The incoming solar radiation [MJ m^{-2} day^{-1}]
$a_s + b_s$ Fraction of extraterrestrial radiation reaching the earth on clear days (n = N)
n Actual duration of sunshine [hour]
N Maximum possible duration of sunshine or daylight hours [hour]
R_a Extraterrestrial radiation [MJ m^{-2} day^{-1}]

Note that a+b is always less than 1 because less than 100 % of the extraterrestrial solar radiation will reach the earth's surface over a daily or monthly period (Burman & Pochop 1994).

Extraterrestrial Radiation for Daily Periods (R_a)
Extraterrestrial radiation is the solar radiation received on a horizontal surface above the earth's atmosphere and is a function of latitude, date and time of the day (Burman & Pochop 1994). If the sun is directly overhead, the angle of incidence is zero and the extraterrestrial radiation is 0.0820 MJ m^{-2} min^{-1}. When seasons change, the position of the sun and the length of the day changes which in turn changes the R_a (FAO 1998).

The extraterrestrial radiation R_a, for each day of the year and for different latitudes can be estimated from the solar constant, the solar declination and the time of the year (FAO 1998):

$$R_a = \frac{24(60)}{\pi} G_{sc} d_r \left[\omega_s \sin(\varphi)\sin(\delta) + \cos(\varphi)\cos(\delta)\sin(\omega_s)\right]$$

R_a Extraterrestrial radiation [MJ m^{-2} day^{-1}]
G_{sc} Solar constant = 0.0820 [MJ m^{-2} min^{-1}]
d_r Inverse relative distance Earth-Sun
ω_s Sunset hour angle
φ Latitude [rad]
δ Solar declination [rad]

Inverse Relative Distance Earth-Sun (d_r)
The distance between the earth and the sun vary slightly during a year. For the purpose of calculating evapotranspiration this variation, according to Burman & Pochop (1994), is not significant and a simple empirical algorithm can be used:

$$d_r = 1 + 0.033 \cos\left(\frac{2\pi}{365} J\right)$$

d_r Inverse Relative Distance Earth-Sun
J Number of days in the year

Sunset Hour angle (ω_s)
The sunset hour angle is given by:

$$\omega_s = \arccos\left[-\tan(\varphi)\tan(\delta)\right]$$

w_s Sunset hour angle
φ Latitude [rad]
δ Solar declination [rad]

Latitude (φ)

The latitude, φ, expressed in radians is positive for the northern hemisphere and negative for the southern hemisphere. The conversion from decimal degree to radians is given by (FAO 1998):

$$[Radians] = \frac{\pi}{180}[decimal\,\deg rees]$$

Solar declination (δ)
The solar declination angle is defined as the angle between the ecliptic and the plane of the earth's equator (Stull 2000). Because the axis of the earth is tilted with respect to the sun, the seasons of the year is defined by the apparent angle of the earth with respect to the sun. The declination of the sun, for a given day of the year, varies from year to year because of the fact that the time required for the earth to make one revolution around the sun is about a quarter of a day longer than a year (Burman & Pochop 1994). This leads to the necessity to add an extra day in February every forth year (Burman & Pochop 1994). The solar declination angle for any day of the year is given by:

$$\delta = 0.409 \sin\left(\frac{2\pi}{365} J - 1.39\right)$$

δ Solar declination [rad]
J Number of days in the year

The tilt of the earth axis relative to the ecliptic is Φ = 23.45° = 0.409 radians.

3.2.1.2 Net Longwave Radiation *(R_{nl})*
The net longwave radiation is the difference between outgoing and incoming longwave radiation. When solar radiation strikes the earth it is converted to heat energy. This energy is then lost by emission of heat from the earth. The emitted radiation is partly absorbed by particles in the atmosphere. Part of this absorbed energy is then reamitted back to earth. Consequently the earth's surface both emits and receives longwave radiation (Ahrens 2000).

The rate of the longwave energy emission is proportional to the absolute temperature of the surface raised to the fourth power. This relationship is expressed quantitatively by the Stefan Boltzmann law (Ahrens 2000). The net energy flux leaving the earth's surface is, however, less than that emitted and given by Stefan Boltzmann law. This is due to the absorption and emittens by particles in the atmosphere (FAO 1998). The concentration of these particles should be known when assessing the net outgoing flux. As humidity and cloudiness play an important role, the Stefan Boltzmanns law is corrected by these factors when estimating the net outgoing flux of longwave radiation. It is thereby assumed that the concentrations of the other absorbers are constant:

$$R_{nl} = \sigma\left[\frac{T_{\max k^4} + T_{\min k^4}}{2}\right](0.34 - 0.14\sqrt{e_a})(1.35\frac{R_s}{R_{so} - 0.35})$$

R_{nl} Net outgoing longwave radiation [MJ m^{-2} day^{-1}]

σ Stefan-Boltzmann constant [4.903 10^{-9} MJ K^{-4} day^{-1}]
$T_{max,K}$ Maximum absolute temperature during the 24-hour period [K = °C +273.16]
$T_{min,K}$ Minimum absolute temperature during the 24-hour period [K = °C + 273.16]
e_a Actual vapour pressure [kPa]
R_s/R_{so} Relative shortwave radiation (limited to≤1.0)
R_s Measured or calculated solar radiation [MJ m^{-2} day^{-1}]
R_{so} Calculated clear-sky radiation [MJ m^{-2} day^{-1}]

An average of the maximum air temperature to the forth power and the minimum air temperature to the forth power is commonly used in the Stefan-Boltzmann equation for 24-hour steps. The term $(0.34-0.14\sqrt{e_a})$ expresses the correction for air humidity, and will be smaller if the humidity increase. The effect of cloudiness is expressed by $(1.35\ R_s/R_{so}-0.35)$.

Clear Day Solar Radiation (R_{so})
Clear day or cloudless day radiation, R_{so}, is the solar energy received on a horizontal surface when no clouds attenuate the radiation (Burman & Pochop 1994). However, atmospheric particles, such as dust and water, also diminish radiation.

When calibrated values for a_s and b_s are not available (FAO 1998):

$$R_{so} = (0.75 + 2 * 10^{-5} z) R_a$$

R_{so} Clear day solar radiation
z Station elevation above sea level [m]

3.2.2 Soil Heat Flux *(G)*

The soil heat flux is the energy that is utilised in heating the soil. G is positive when soil is warmed up and negative when soil is cooled down (FAO 1998). Soil heat flux, G, is small compared to R_s, R_n and other terms of the energy balance and therefore often neglected when estimating evapotranspiration (Burman & Pochop 1994).
The influence of G on final estimates is particularly small, when the surface is covered by vegetation and calculation time step is 24 hours or longer.

If not ignored, Kincaid & Heermann (1974) and Wright (1882) recommend the following algorithm which is based on broad assumptions of the root zone depth, the soil heat capacity, and the notion that soil temperature lags air temperature (Burman and Pochop 1994):

$$G = 0.3768\left[\overline{T}_D - \left(\overline{T}_{D-1} + \overline{T}_{D-2} + \overline{T}_{D-3}\right)/3\right]$$

G Daily soil heat flux [MJ m^{-2} day^{-1}]
D The calendar day number
$\overline{T}$ Daily average temperature [°C]
0.3768 Constant that varies with the unit of G and the air temperature T

3.2.3 Mean Saturation Vapour Pressure (e_s)

The concentration of water vapour in the air can be quantified by vapour pressure (Stull 2000). Warmer air can hold more water vapour at equalibrium than colder air. If air is cooled below the saturation temperature, some water condenses into liquid, which releases latent heat and warms the air (Stull 2000). The saturation vapour pressure is the maximum amount of water vapour necessary to keep moist air in equilibrium with a surface of pure water or ice. It represents the maximum amount of water vapour that the air can hold at any given temperature and pressure (Ahrens 2000). The saturation vapour pressure increases in a non-linear rate with increasing temperature (Burman & Pochop 1994). The relationship is expressed by the Clausius-Clapeyron equation (Stull 2000):

$$e_s = \frac{e^0(T_{max}) + e^0(T_{min})}{2}$$

e_s Mean saturation vapour pressure [kPa]
$e^0(T)$ Saturation vapour pressure at the air temperature T [kPa]

$$e^0(T) = 0.6108 \exp\left[\frac{17.27T}{T + 237.3}\right]$$

$e^0(T)$ Saturation vapour pressure at the air temperature T [kPa]
T Air temperature [°C]

3.2.4 Actual Vapour Pressure (e_a)

The actual vapour pressure indicates the air's total water vapour content (Ahrens 2000). The actual vapour pressure can be derived from measurements of relative humidity by (FAO 1998):

$$e_a = \frac{e^0(T_{min})\frac{RH_{max}}{100} + e^0(T_{max})\frac{RH_{min}}{100}}{2}$$

e_a Actual vapour pressure [kPa]
$e^0(T_{min})$ Saturation vapour pressure at daily minimum temperature [kPa]
$e^0(T_{max})$ Saturation vapour pressure at daily maximum temperature [kPa]
RH_{max} Maximum relative humidity [%]
RH_{min} Minimum relative humidity [%]

3.2.5 Slope of Saturation Vapour Pressure Curve (Δ)

The saturation vapour pressure curve describes the relationship between saturation vapour pressure and temperature. The slope of the curve at a given temperature is given by (FAO 1998):

$$\Delta = \frac{4098\left[0.6108 \exp\left(\frac{17.27T}{T + 237.3}\right)\right]}{(T + 237.3)^2}$$

Δ Slope vapour pressure curve at a given air temperature [kPa °C^{-1}]
T Air temperature [°C] (estimated with Tmax-Tmin/2)

3.2.6 Psychrometric Constant (γ)
Is given by (FAO 1998):

$$\gamma = \frac{C_p P}{\varepsilon \lambda} = 0.665 \times 10^{-3} P$$

γ Psychrometric constant [kPa °C^{-1}]
P Atmosperic pressure [kPa]
λ Latent heat of vaporization, 2.24 [MJ kg^{-1}]
C_p Specific heat at constant pressure, 1.013 10^{-3} [MJ kg^{-1} °C^{-1}]
ε Ratio molecular weight of water vapour/dry air = 0.622

Atmospheric pressure (P)

$$P = 101.3(\frac{293 - 0.0065z}{293})$$

P Atmosperic pressure [kPa]
Z Elevation above sea level [m]

3.3 Estimation of Missing Climatic Data

In some cases, climatic variables were missing. According to FAO (1998), a use of an alternative methodology should generally be avoided and instead they highly recommend using that standard FAO Penman-Monteith Combination Method. There are basically two ways of solving this problem. Either you use information from a nearby station or calculate your missing variable using a different methodology (FAO 1998).

In the northern part of Lao PDR, the climate stations are quiet spread out which means that the stations are not close enough to experience similar conditions within the same day. The differences in relief within the area, would also be a factor, strongly influencing regional climatic conditions. Therefore, we decided not to use information from a nearby station but instead calculate the missing variable by using a different methodology.

3.3.1 Estimating Actual Vapour Pressure (e_a) Derived From Daily Minimum Temperature
Where humidity data was missing, we estimated actual vapour pressure by assuming that dew point temperature (T_{dew}) was near the daily minimum temperature (T_{min}). This statement assumes that at sunrise, when the air temperature is close to T_{min}, the air is nearly saturated with water vapour and that the relative humidity is nearly 100 %. If T_{min} is used to represent T_{dew} then (FAO 1998):

$$e_a = e^0(T_{min}) = 0.611 \exp\left[\frac{17.27 * T_{min}}{T_{min} + 237.3}\right]$$

e_a Actual vapour pressure [kPa]
$e^0(T_{min})$ Saturation vapour pressure at daily minimum temperature [kPa]

This relationship $T_{dew} = T_{min}$ is valid for locations where the cover crop of the station is well watered. In humid and sub humid climates like in Lao PDR, T_{min} and T_{dew} measured in the early morning may be less than T_{dew} measured during the daytime because of dew during the night. After sunrise evaporation of the dew will once again humidify the air and will increase the value measured for T_{dew} during the daytime (see figure 3.5).

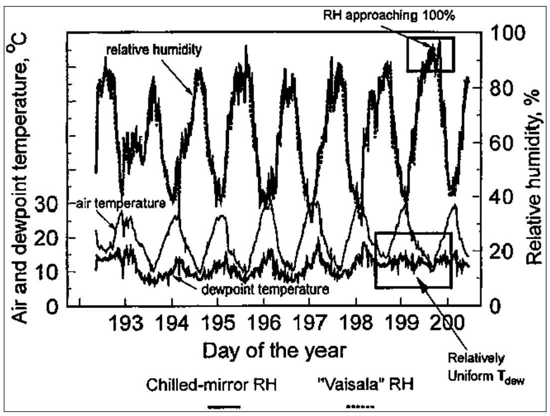


Figure 3.5: In humid and sub humid climates, T_{min} and T_{dew} measured in the early morning may be less than T_{dew} measured during the daytime because of dew during the night. After sunrise evaporation of the dew will once again humidify the air and will increase the value measured for T_{dew} during the daytime (FAO 1998).

3.3.2 Estimating Solar Radiation Derived From Air Temperature Differences

The difference between the maximum and minimum air temperature is related to the degree of cloud cover in a location. Clear sky conditions result in high temperature during the day (T_{max}) because the atmosphere is transparent to the incoming solar radiation, and in low temperatures during the night (T_{min}) because less outgoing long wave radiation is absorbed by the atmosphere. On the other hand, in overcast conditions T_{max} is relatively smaller because a significant part of the incoming solar radiation never reaches the earth's surface and is absorbed and reflected by clouds. Similarly, T_{min} will be relatively higher as the cloud cover acts as a blanket and decreases the net outgoing long wave radiation. Therefore, the difference between maximum and minimum air temperature (T_{max}-T_{min}) can be used as an indicator of the fraction of extraterrestrial radiation that reaches the earth's surface (FAO 1998).

The Hargreaves radiation formula, adjusted and validated at several weather stations in a variety of climate conditions, became:

$$R_s = k_{Rs}\sqrt{(T_{max} - T_{min})} * R_a$$

R_a Extraterrestrial radiation [MJ m^{-2} day^{-1}]
T_{max} Maximum air temperature [°C]
T_{min} Minimum air temperature [°C]
K_{Rs} Adjustment coefficient (0.16..0.19 [$°C^{-0,5}$]

The square root of the temperature difference is closely related to the existing daily solar radiation in a given location (FAO 1998). The adjustment coefficient K_{RS} is empirical and differs for interior or costal regions. For interior regions, like Lao PDR, where land mass dominates and air masses are not strongly influenced by a larger water body, $K_{RS} \cong 0.16$.

3.3.3 Estimating Missing Wind Speed

Where there was missing wind speed data, we used the long-term monthly average values.

3.4 Evaluation of Alternative Methods

The alternative methods to estimate actual vapour pressure and solar radiation was evaluated by using the years of climate data where measurements of solar hours and relative humidity existed. During these years, the solar-radiation and the actual vapour pressure was calculated by using both the "real" method and the alternative method. Afterwards the mean difference between the methods was calculated.

3.5 Interpolation of Climate Variables

Interpolation is a technique where measurements, in this study point measures of precipitation, evapotranspiration and temperature are used to generate a continuous surface. When interpolating a surface measures close to each other are assumed to be more alike than measures further apart. This is a fundamental geographical principle called spatial autocorrelation. There are two main groups of interpolation techniques the deterministic and the geostatistical or stochastic.

Deterministic interpolation can be divided into global and local which both use mathematical functions to generate a continuous surface (Johnston et al 2001). Global techniques use all the samples in the dataset and local techniques use sample points within neighbourhoods to calculate predictions (Johnston et al 2001). Examples of deterministic interpolation methods are Inverse Distance Weighting, Polynomial Interpolation, Thiessen-polygons and Spline Interpolation (Eklundh et al 1999).

The geostatistical interpolation techniques rely on both statistical and mathematical functions to generate a continuous surface. The geostatistical techniques quantify the spatial autocorrelation among measured points as well as account for the spatial configuration of the sample points around the prediction location (Johnston et al 2001). Furthermore, geostatistical methods quantify the estimation uncertainty. For these reasons, geostatistical techniques have become more commonly used (Journel and Huijbregts (1978) and Goovaerts (2000). Examples of geostatistical interpolation techniques are Ordinary Kriging, Cokriging, Detrended Kriging (Johnston et al 2001).

When data is abundant, most interpolation techniques give similar results. When data are sparse and measurements differ significantly even at a relatively reduced spatial scale, like in Lao PDR, the choice of interpolation method become critical (Hartkamp et al 1999).

Cokriging use an additional co-variable to interpolate a continuous surface. An example of a co-variable to precipitation, evapotranspiration and temperature is elevation because topography is assumed to influence these variables.

Studies like the one by Martínez-Cob (1996) propose that in areas with large topographic variations, the influence of elevation on climate variables should be taken into account and the use of methods using a co-variable should be preferable. On the contrary other studies like the one by Dalezios et al (2002) suggest that not all variations in, for example evapotranspiration, can be described by topographic effects. According to Goovaerts (2000) as well as Martínez-Cob (1996) methods, that account for elevation for example cokriging should perform better if there is a good statistical correlation between the climate variables and elevation. Goovaerts (2000) suggest a correlation coefficient larger then 0.75. Finally, Isaaks and Srivastava (1989) states that an interpolation method may be the best only for some specific situation.

To investigate what interpolation technique to use, for each climate variable, different methods were tested and evaluated. This was done in a number of ways.

- To explore if kriging was a good technique we studied the semivariogram and the variance after detrending the data (if there was a trend present).

- To explore if co-kriging was a good interpolation technique we investigated if there was a relationship between the altitude and the climate variables. If a significant correlation was found, a co-kriging could be used to interpolate the data. If not, another method would be preferable.

- To further explore what interpolation technique that gave the best result, for a given variable, we used cross validation (jacknife routine).

3.5.1 Evaluation to Define Temporal Resolution

Before interpolating, an evaluation using a mean monthly value to estimate growing period, instead of daily values was performed. The evaluation was performed during a 10-year period (1994-2003) for 5 stations situated close to Phonxay District. This evaluation was done to decide if the growing period could be interpreted using mean monthly values instead of daily values. The evaluation was done by plotting daily values as well as monthly mean values of precipitation and potential evapotranspiration divided by two. Thereafter, the number of days per year when the precipitation exceeded the potential evapotranspiration was estimated. If the estimated growing period per year was approximately the same for daily values as for monthly mean values, interpolation of mean monthly climate values would be preferable since the number of interpolations and time would be considerably reduced.

3.5.2 Temperature

A global polynomial interpolation technique was used to interpolate mean monthly temperature, mean monthly minimum temperature and mean monthly maximum temperature. Daily minimum and maximum temperature data was recorded at 34 climate stations spread across northern Lao PDR, Thailand, and Vietnam (see figure 4.1).

A global polynomial interpolation fits a smooth surface that is defined by a mathematical function (a polynomial) to the sample points (Johnston et al 2001). The polynomial order was chosen, depending on how well it fitted the sample points. Cross validation (jacknife routine) and visual interpretation of the trend was used as tools to explore which polynomial order fitted the best.

The models tested were a first order polynomial (linear), a second order polynomial (quadratic) or a third order polynomial (cubic).

First order (Johnston et al 2001)**:**

$$Z(x_i,y_i)=\beta_0+\beta_1 x_i+\beta_2 y_i+\varepsilon(x_i,y_i)$$

$Z(x_i,y_i)$ is the datum at location $(x_i,y_i)\beta_j$ are parameters, and $\varepsilon(x_i,y_i)$ is a random error.

Second order (Johnston et al 2001)**:**

$$Z(x_i,y_i)=\beta_0+\beta_1 x_i+\beta_2 y_i+\beta_3 x_i^2+\beta_4 y_i^2+\beta_5 x_i y_i+\varepsilon(x_i,y_i)$$

Third order (Johnston et al 2001)**:**

$$Z(x_i,y_i)=\beta_0+\beta_1 x_i+\beta_2 y_i+\beta_3 x_i^2+\beta_4 y_i^2+\beta_5 x_i y_i+\beta_6 x_i^2+\beta_7 y_i^2+\beta_8 x_i^2 y_i+\beta_9 x_i y_i^2+\varepsilon(x_i,y_i)$$

A digital elevation model over Phonxay District was used to adjust the interpolated sea level temperatures to the landscape topography. This was done by using an adiabatic lapse rate of 0.6 degrees per 100 meter (Chapman & Danh 1997).

3.5.3 Potential Evapotranspiration

A global polynomial interpolation technique was also used to interpolate mean monthly values of potential evapotranspiration across northern Lao PDR. 12 climate stations across northern Lao PDR were used to interpolate this variable (see figure 4.5). The largest distance between the climate stations was about 3 700 km.

3.5.4 Precipitation

A radial basis function, also known as spline, is a local deterministic interpolation technique that was used to interpolate mean monthly values of precipitation. The 34 climate stations used were spread across northern Lao PDR, Thailand, and Vietnam (see figure 4.1). Radial basis functions methods are a series of exact interpolation techniques, which means that the surface goes through each sample value (Johnston et al 2001).

Radial basis function interpolation techniques are like fitting a rubber membrane through the sample values while minimising the total curvature of the surface (Johnston et al 2001). The chosen basis function determines how the rubber membrane will fit between the values (Johnston et al 2001).

Four different basis functions were used, completely regularized spline, spline with tension, inverse multiquadric spline and thin plate spline.

Completely regularized spline (Johnston et al 2001*):*

$$\phi(r) = -\sum_{n=1}^{\infty} \frac{(-1)^n (\sigma * r)^{2n}}{n} = \ln\left(\frac{\sigma * r}{2}\right)^2 + E_1\left(\frac{\sigma * r}{2}\right)^2 + C_E$$

ϕ (r) Is a radial basis function
r Is $||s_i - s_o||$, Euclidian distance between the prediction s_0 and eash data location s_i
$E_1(x)$ Is the exponential integral function and
C_E Is the Euler constant.

Spline with tension function (Johnston et al 2001):

$$\phi(r) = \ln\left(\frac{\sigma * r}{2}\right) + K_0(\sigma * r) + C_E$$

K_0 is the modified Bessel function.

Inverse multiquadric function (Johnston et al 2001):

$$\phi(r) = \left(r^2 + \sigma^2\right)^{-\frac{1}{2}}$$

Thin-plate spline function (Johnston et al 2001):

$$\phi(r) = (\sigma * r)^2 \ln(\sigma * r)$$

3.5.5 Cross Validation

To choose the best polynomial degree to interpolate temperature and potential evapotranspiration, as well as to select the best radial basis function to interpolate, precipitation cross validation was used. The calculated statistics serve as indicator whether the model and/or its associated parameter values are reasonable (Johnston et al 2001). Cross validation withhold one data sample at the time and then make as many prediction surfaces as sample points. This way, it is possible to compare the predicted values to the observed values and get information about the model. For models that provide the most accurate prediction, the mean error should be close to 0, and the root-mean-square error should be as small as possible (Johnston et al 2001).

Mean Predicted error:

$$\frac{\sum_{i=1}^{n}\left(\hat{Z}(s_i) - z(s_i)\right)}{n}$$

Root-mean-square prediction error:

$$\sqrt{\frac{\sum_{i=1}^{n}\left(\hat{Z}(s_i) - z(s_i)\right)^2}{n}}$$

$\hat{Z}(s_i)$ Is the predicted value from cross validation for location s_i
$z(s_i)$ Is the observed valuefor location s_i
n The number of locations

3.6 Slope

The algorithm used to calculation slope was:

$$rise\_run = \sqrt{(dz/dx)^2 + (dz/dy)^2}$$

rise_run	The slope
(dz/dx)	The difference in altitude in the x direction [m]
(dz/dy)	The difference in altitude in the y direction [m]

dz/dx and dz/dy was calculated using the third order finite differentiation method based on a 3*3 window (Burrough 1986) "a" through "i" represent the z-value in the window.

a	b	c
d	e	f
g	h	i

$$(dz/dx) = \frac{((a + 2d + g) - (c + 2f + i))}{(8 * x\_mesh\_spacing)}$$

$$(dz/dy) = \frac{((a + 2b + c) - (g + 2h + i))}{(8 * y\_mesh\_spacing)}$$

(dz/dx)	The difference in altitude in the x direction [m]
(dz/dy)	Difference in altitude in the y direction [m]
"a" through "i"	Represents the z-value in the window
x_mesh_spacing	Cell length in the x direction [m]
y_mesh_spacing	Cell length in the y direction [m]

To calculate the slope from percent to degrees the following formula can be used:

$$slope(\deg rees) = \arctan(slope(\%))$$

An application of the slope calculation algorithm can be found in Appendix 8.4 (Eklundh et al 1999).

The slope map was used to create two layers; one to use in the agro-ecological zoning and one to show the constraints in Phonxay District caused by the steepness of the slope (see Zones of soil and terrain constraint).

Slope classes used in the agro-ecological zoning:

0-8 %	Level to underlating.
8-30 %	Rolling to hilly.
>30 %	Steeply dissected to mountainous

Terrain-slope constraints was divided into:

0-8 %	No constraints
8-16 %	Slight constraints
16-30 %	Constraints
>30 %	Severe constraints

Part 2

This part of the methodology exemplifies how the land resource database could be used. The analyses were done over northern Lao PDR with a focus on Phonxay District, and includes division of areas into growing period zones, agro-ecological zones, zones of soil and terrain constraints, land suitability assessment for bananas and pineapples and socio-economic analysis to describe the district and its different zones (see Conceptual Framework 3.1).

3.7 Growing Period Zones

Length of thermal growing period is defined as the period during the year when prevailing temperature is conductive to crop growth (Tmean ≥ 5° C) and precipitation plus moisture stored in the soil profile exceed half the potential evapotranspiration (PET) (FAO 1985).

There are four main types of growing periods; normal, intermediate, all year around humid, and all year around dry (see figure 3.6 & 3.7).

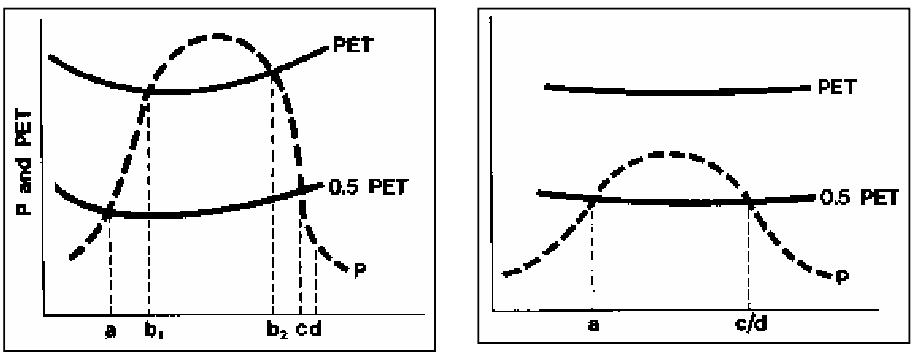


Figure 3.6: The left graph illustrates a normal growing period where precipitation (P) exceed potential evapotranspiration (PET) for part of the year. a is the beginning of rain and the growing period. b_1 and b_2 is the start and end of humid period respectively. c is the end of rainy season. d is the end of growing period. The right graph illustrates an intermediate growing period where P does not normally exceed PET, but does exceed PET/0.5 for part of the year (FAO 1985).

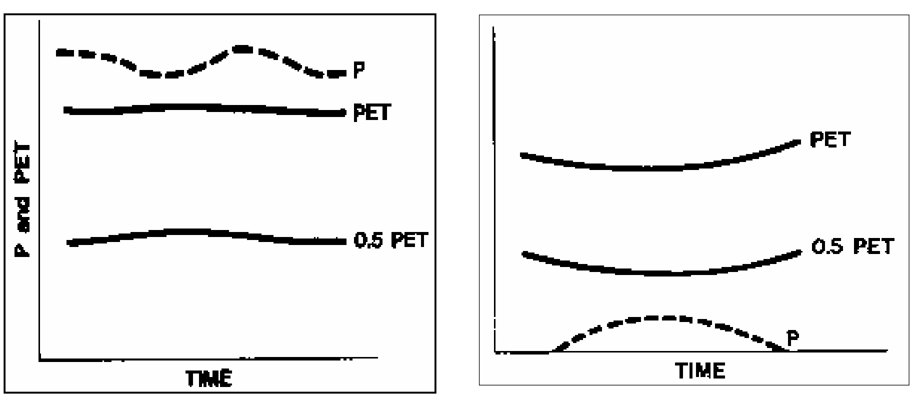


Figure 3.7: The left graph illustrates an all year humid growing period where precipitation (P) exceed potential evapotranspiration (PET) the whole year. The right graph illustrates an all year round dry growing period where PET and PET/0.5 exceeds P the whole year (FAO 1985).

The procedure to calculate the growing period was done by creating the following conditional statement where each pixel value in the raster of mean monthly precipitation and mean monthly potential evapotranspiration was compared (see figure 3.8):

If mean monthly precipitation (P) ≥ mean monthly potential evapotranspiration (PET)/2, then give the number of days in that particular month, if not give a value of zero (see figure 3.8).

Afterwards the days per month were summarized and the number of days when precipitation was larger or equal to the potential evapotranspiration divided by two was defined and zones of growing period were created (see figure 3.8).

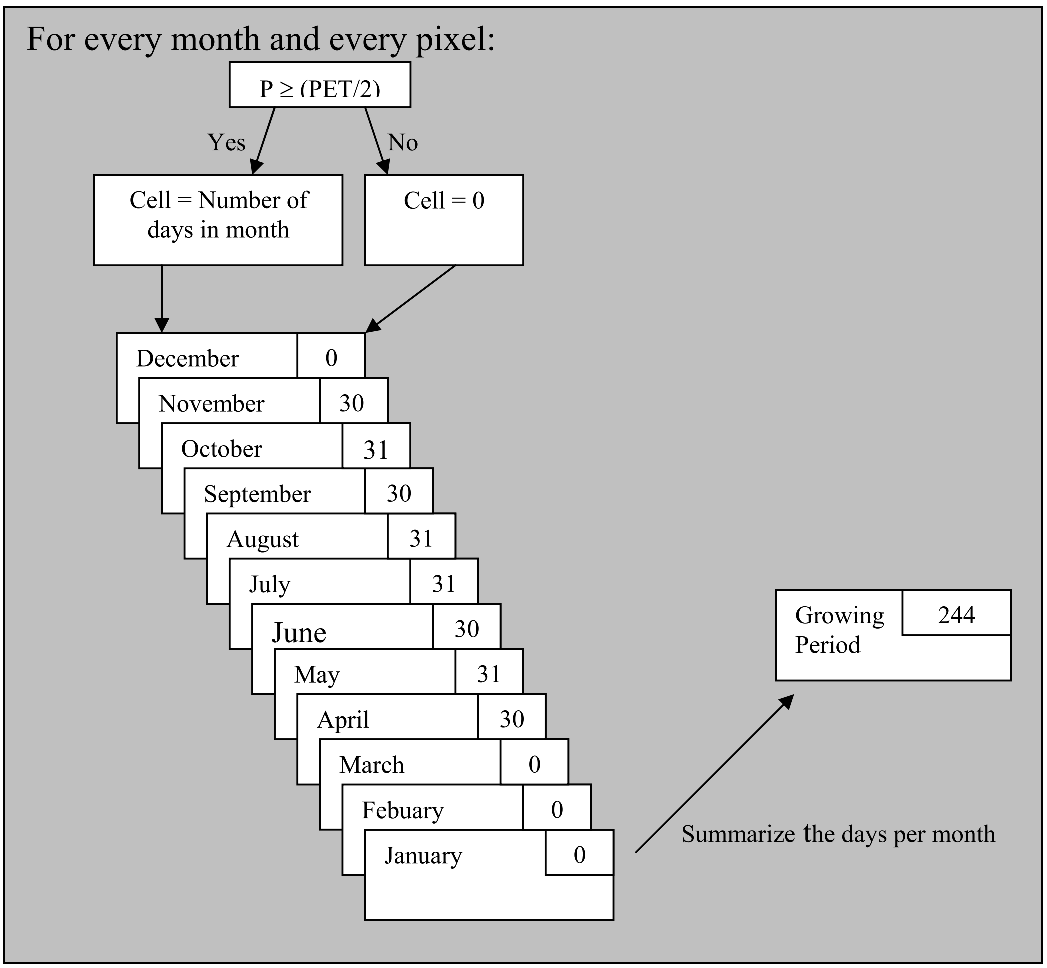


Figure 3.8: To calculate the growing period a conditional statement was established where each pixel value in the raster, of mean monthly precipitation and mean monthly potential evapotranspiration, was compared. If P ≥ PET/2, then give the number of days in that particular month, if not give a value of zero. Summarize the days per month and each pixel in the raster is given the number of growing period days. In this particular pixel the result became 244 days of growing period.

Mean temperature during the growing period was established by summing the temperature during the months when potential evapotranspiration divided by two exceeds precipitation. Thereafter the summed temperature was divided by the number of days of the same period. Monthly minimum and monthly maximum temperature during the growing period was calculated the same way.

3.8 Agro-Ecological Zones in Phonxay District

Agro ecological zones is a subdivision of land into smaller units determined by combining mean temperature during the growing period, zones of growing period, soil and slope (see figure 3.1). Administrative boundaries and conservation areas were also used in the combination.

Defining these zones can be important to assess similarities between different locations in Phonxay District, and thus be useful for land use planning but also for better targeting of existing or new crops and species. It also offers a framework for assessment of land degradation and land suitability.

We divided the mean temperature during the growing period into three equally large groups:

1. 15-19°C
2. 19-23°C
3. 23-27°C

The soilmap was divided into the three main soil groups present in the area:

1. Acrisols
2. Cambisols
3. Leptosols.

The Slope map was divided into three groups according to FAO (2002):

1. 0-8 %, level to underlating.
2. 8-30 %, rolling to hilly.
3. >30 %, steeply dissected to mountainous.

A geographical Information System (GIS) was used to perform an overlay operation of the above variables.

3.9 Zones of Soil and Terrain Constraints in Phonxay District

This is a kind of zoning that allows characterization of a region according to the prevailing soil and terrain constraints (FAO 2002). The zones could be used as identifiers of the landscapes potential agricultural capability. In areas with severe constraints, agriculture is very demanding and perhaps impossible. In areas with no constraints, the potential for agricultural activity is good, without major land improvements needed (FAO 2002).

The constraints considered and defined by FAO (2002) include:

- Terrain-slope constraints was divided into:

  No constraints: 0-8 %
  Slight constraints: 8-16 %
  Constraints: 16-30 %
  Severe constraints: >30 %

- Soil depth constraints:

  Severe constraints: All soils with depth limitations within 50 cm of the surface caused by the presence of coherent hard rock or hard pans (shallow soils): Lithosols (l), Renzinas (E), Rankers (U), all soils with Litic phase.

  Constraints: All soils with depth limitations within 100 cm of the surface by the presence of Petrocalcic, Petrogypsic, Petroferric and Duripan phases.

  No constraints: deep soils: all other soils.

- Soil fertility constraints

  Severe constraints: all soils with low natural fertility and soils were a major land improvement is required before cultivation is possible: all other soils.

  Constraints: Soils with moderate natural fertility: Jd, Gh, Gd, Rd, Q, Qc, Ql, T, To, Th, Xy, M, Mo, Mg, Bc, Bd, Bh, Bg, Bf, Lf, Lp, Lc, Lg, D, De, Dg, Pl, W, We, Wh, A, Ao, Ah, Nd, Nh, Fr and Fh (FAO & United Nations Educational, Scientific and Cultural Organization (UNESCO) 1974).

No constraints: Soils with high natural fertility. J, Je; G, Ge, Gc, Gm, R, Re, Rc, E, Tm, V, VP, Vc, S, Y, Yh, Yk, Yl, X, Xh, Xk, Xl, K, Kh, Kk, Kl, C, Ch, Ck, Cl, Cg, H, Hh, Hc, Hl, Hg, B, Be, Bk, Bv, L, Lo, Lk, Lv, Wm, N and Ne (FAO & UNESCO 1974)

- Soil Drainage constraints

Severe constraints: Poorly and imperfectly draind soils: All Gleysols (G, Ge, Gc, Gd, Gm, Gh, Gp and Gx), all Planosols (W, We, Wd, Wm, Wh, Ws, Wx) and all gleyic sub-groups (Zg, Sg, Mg, Hg, Lg, Dg, Pg and Ag), except Bg (FAO &UNESCO 1974).

No constraints: Excesseivily and well draind soils: all other soils.

- Soil texture constraints

Severe constraints: Coarse textured soils. Soils with less then 18 % clay, more than 65 % sand, or which have stones, boulders or rock outcrops in the surface layer or at the surface: All Arenosols (Q, Qc, Ql, Qf, Qa), all Regosols (R, Re, Rc, Rd, Rx) and Vitric Andosols (Tv) with coarse texture, and all soils with petric and stony phase.

Constraints: Soils with heavy cracking clays: soils with 30 % or more clay to at least 50 cm deep, with cracks at least 1 cm wide and 50 cm deep at some period in most years, and high bulk density between the cracks: All vertisols (V, Vp, Vc) and vertic sub-groups (Bv and Lv).

No constraints: Soils with medium and fine textures: all other soil.

A GIS model was created to map the zones of constraints (see figure 3.9). Three constraint maps (soil depth, soil fertility and soil texture) were reclassified into the following classes:

3 000 = Severe Constraints
2 = Constraints
4 = No Constraints

The slope map had one more additional class (Constraints) and the soil drainage map had only two classes (Severe Constraints and No Constraints) (se figure 3.9). For Severe Constraint an odd value of 3 000 was given with the purpose to easier distinguish this class from the other classes. After the reclassification, the five constraint maps were summarized and divided by 20 (the maximum possible value (4*5))with the intention to produce a percentage map. The next step was to reclassify the percentage map to a soil and terrain constraint zone map. This was done by reclassifying the percentage map into the following classes (see figure 3.9):

≥ 100 % = Severe Constraints
≥ 80 % < 100% = No Constraints
< 80 % = Constraints

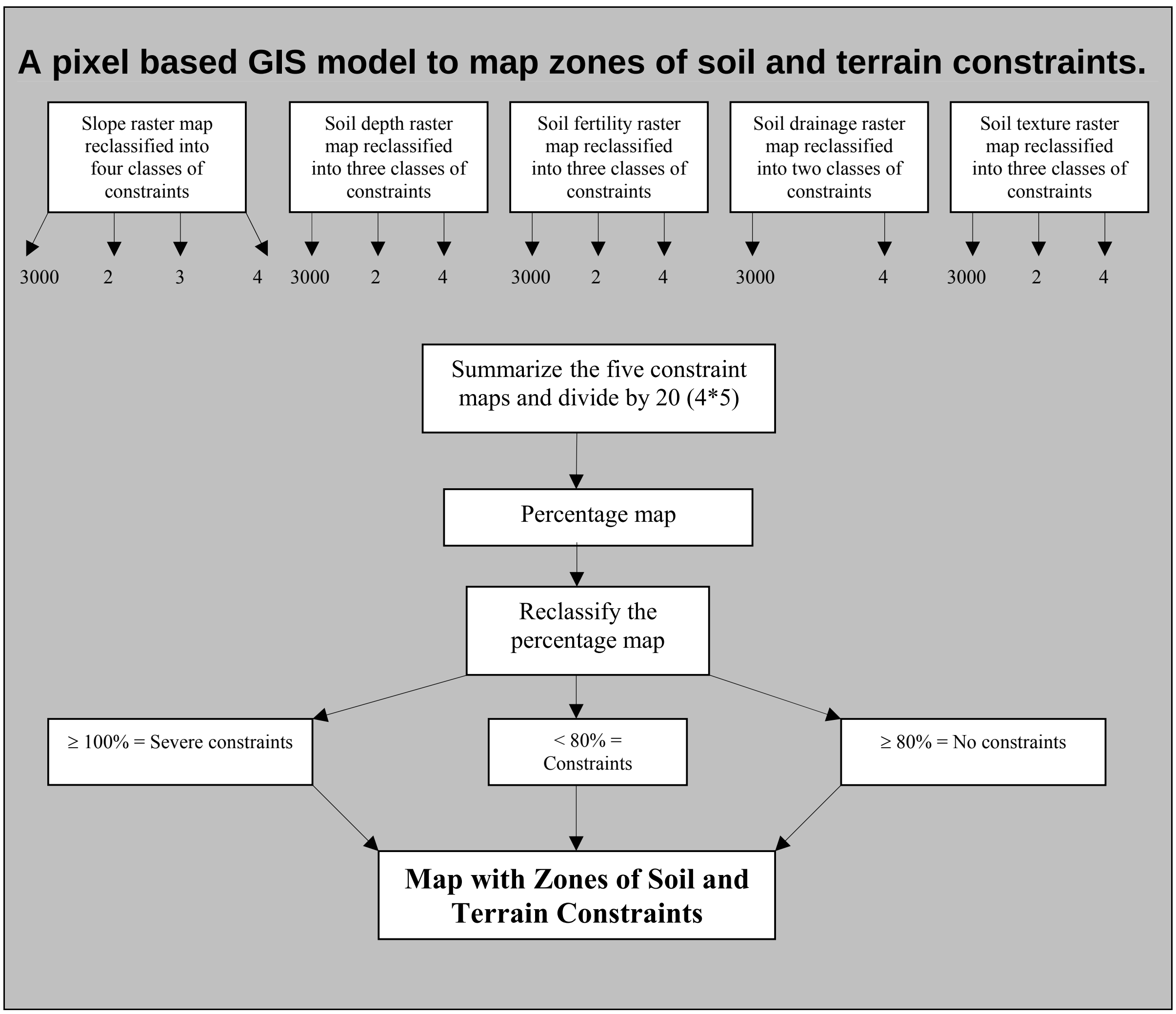


Figure 3.9: The five constraints considered were reclassified into constraint classes. Afterwards they were summarized and divided by the total possible value with the intension to produce a percentage map. The percentage map was thereafter reclassified into the three constraint classes, severe constraints, slight constraints and no constraints producing the final map.

3.10 Suitability Rating for Bananas and Pineapples in Phonxay District

Assessment of land suitability, from a biophysical point of view, was carried out by matching bananas and pineapples crop requirements with temperature, growing period, precipitation and soils conditions. Bananas and pineapples were chosen since they both represent cash crops within Phonxay District. The suitability of each crop was separated into suitability classes (Sys et al 1993). The classes were:

- S1 (≥ 85 %), highly suitable land for crop production: having no significant limitations that restrict the use for this land alternative.
- S2 (≥ 60 % - < 85 %), land well suited for crop production: having only slight limitations that restrict the use for this land alternative.
- S3 (≥ 40 % - < 60 %), land moderately well suited for crop production: having moderate limitations that reduce suitability for these crops and /or require special land management for this land use alternative.
- N (< 40 %), land not suitable for crop production: having very severe limitations that preclude the use for this land alternative.

A GIS model was created to match the crops requirements with the biophysical information spatially distributed in the district (see figure 3.10 showing the model for Banana as an example).

For each requirement, for example the slope, a conditional statement on per pixel basis was written to search and classify the slope map into values between 0 and 4. Number 4 represent S1 and number 0 represent N. This was done for all the requirements given in table 3.1 & 3.2. Afterwards the resulting requirement maps were summarized. The percentage was calculated by dividing the given summarized value by the total possible value and multiplying this result with 100. Finally the banana and pineapple suitability maps were created (see figure 3.10).

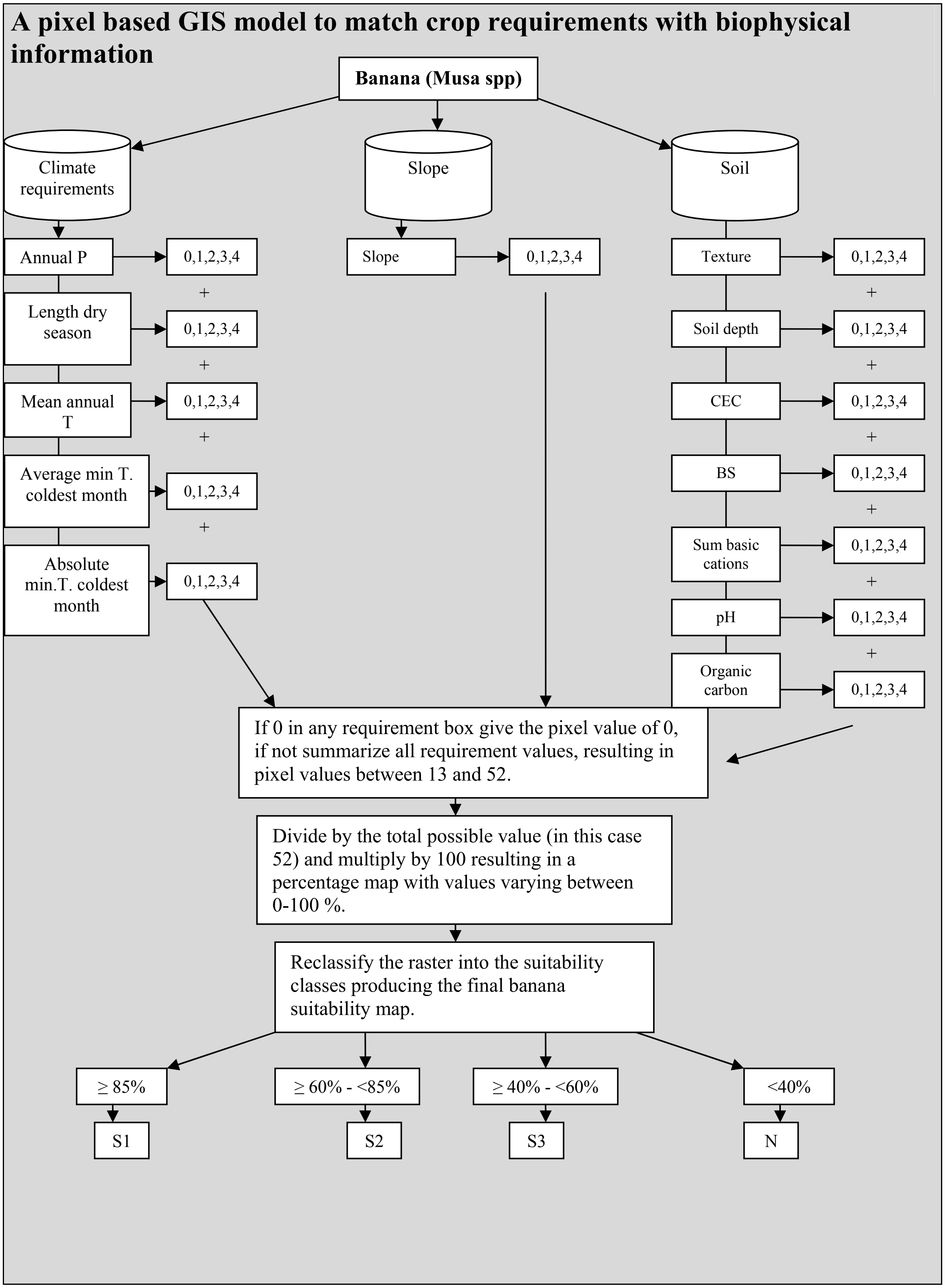


Figure 3.10: A GIS model was created to match the crops requirements in regards to climate, soil and slope. For each requirement, for example the slope, a conditional statement on per cell basis was written to search and classify the slope map into values between 0 and 4. Number 4 represent S1 and number 0 represent N. This was done for all the requirements given in table 8. Afterwards the resulting requirement maps were summarized and the percentage was calculated. Finally the banana suitability maps was created.

3.10.1 Requirements for Banana (Musa spp)

The optimal mean monthly air temperature for the growth of bananas is 25-28° C and a reduced growth is observed at temperatures lower then 22° C. The absolute lowest temperature for growth is 14°C. Maximum temperature for adequate growth is about 38° C, depending on humidity and the radiation intensity (www.4).

The optimal precipitation is 1500-2500 mm/year. A relative humidity over 60 % is preferred (Sys et al 1993).

Soils with freely draining, well aerated, deep, fertile loamy soils are preferred and conservation practices are necessary on sloping land. The pH can range between 4.5 and 8.2 (Sys et al 1993).

Banana climatic requirements according to Sys et al (1993):

Table 3.1: Banana (Musa spp) climatic requirements.

Climatic characteristics	Climate class, degree of limitation and rating				
	S1		S2	S3	N
	4	3	2	1	0
	100% 95%	95% 85%	85% 60%	60% 40%	40% 0%
Annual precipitation (mm)	>1800	1800-1500	1500-1250	1250-1000	<1000
Lengt dry season (months : p<0,5PET)	0-1	1-3	3-4	4-6	>6
Mean annual temperature (C°)	>22	22-18	18-16	16-14	<14
Average min. temp. coldest month (C°)	>20	20-15	15-8	8-2	<2
Absolute min.temp. coldest month (C°)	>12	12-8	8-0	0 to -2	<-2

Landscape and soil requirements according to Sys et al (1993):

Table 3.2: Banana (Musa spp) landform and soil requirements.

Land characteristics	Class, degree of limitation and rating scale				
	S1		S2	S3	N
	4	3	2	1	0
	100% 95%	95% 85%	85% 60%	60% 40%	40% 0%
Topography					
Slope (%)	0-4	4-8	8-16	16-30	>30
Physical soil characteristics					
Texture	C 60s, Co, SiCs, SiCL, CL, SiL	C 60s, C 60v, SC, L	C 60v, SCL	SL, LfS, LS	Cm, SiCM, fS, S, cS
Soil depth (cm)	>100	100-75	75-50	50-25	<25
Soil fertility characteristics					
Apparent CECclay (cmol(+)/kg clay)	>24	24-16	<16 (-)	<16 (+)	-
Base saturation (%) (cmol(+)/kg soil)	>50	50-35	35-20	<20	-
Sum of basic cat ions (cmol(+)/kg soil)	>6.5	6.5-4	4-2.8	-	-
pH H_2O	6.4-5.8	5.8-5.6	5.6-5.2	5.2-4.5	<4.5
	6.4-7.0	7.0-7.5	7.5-8.0	8.0-8.2	>8.2
Organic carbon (%)	>2.4	2.4-1.5	1.5-0.8	<0.8	-

3.10.2 Requirements for Pineapple (Ananas Comosus)

The optimal mean monthly air temperature for the growth of pineapple is 20 to 26° C and a reduced growth is observed at temperatures lower then 22° C. Precipitation more then 600 mm/growing cycle is required. 1 000 mm to 1 600 mm of rainfall is optimal (Sys et al 1993).

The most suitable soils for growing pineapple are moderately deep (0.5-1.0 m) to deep, well-drained, sandy clay loam or sandier soils. The pH should range between 4.0 and 7.8 (Sys et al 1993).

Pineapple climatic requirements according to Sys et al (1993):

Table 3.3: Pineapple (Ananas Comosus) climatic requirements.

Climatic characteristics	Climate class, degree of limitation and rating				
	S1		S2	S3	N
	4	3	2	1	0
	100% 95%	85%	60%	40%	0%
Annual precipitation (mm)	1300-1200 1300-1400	1200-1000 1400-1600	1000-800 1600-2000	800-600 >2000	<600
Length dry season (months: p<0,5PET)	0-1	1-3	3-4	4-6	>6
Mean annual temperature (C°)	23-22 23-24	22-20 24-26	20-18 26-30	18-16 30-35	<16 >35

Landscape and soil requirements according to Sys et al (1993):

Table 3.4: Pineapple (Ananas Comosus) landform and soil requirements.

Land characteristics	Class, degree of limitation and rating scale				
	S1		S2	S3	N
	4	3	2	1	0
	100% 95%	85%	60%	40%	0%
Topography					
Slope (%)	0-8	-	8-16	16-30	>30
Physical soil characteristics					
Texture	SCL,L	SL,SiL,Si,SC	LS,LfS,Co,C>60s,SiC	C><60v, C>60s,fS	Cm, SiCm
Soil depth (cm)	>75	75-60	60-40	40-20	<20
Soil fertility characteristics					
Apparent CECclay (cmol(+)/kg clay)	>24	24-16	<16 (-)	<16 (+)	-
Base saturation (%) (cmol(+)/kg soil)	>50	50-35	35-20	<20	-
pH H_2O	5.7-5.4 5.7-6.0	5.4-5.0 6.0-6.5	5.0-4.3 6.5-7.0	4.3-4.0 7.0-7.8	<4.0 >7.8
Organic carbon (%)	>2	2-1.2	11.2-0.8	<0.8	-

3.11 The Socio-Economic and Demographic Situation in Phonxay District

Population statistics were calculated using the data received by the National Statistic Centre, Lao PDR. This was done both on village and district level for Phonxay. To be noted is that most of the statistics available were only from one population survey and only for one year (State Planning Committee National Statistical Centre 1997). This means that some of the results might not be fully representative.

The infant mortality rate (IMR) was calculated by dividing the number of infant deaths with the number of live births and multiplying the result with 1 000, which gives the number of deaths per 1 000 live births. One should however keep in mind that none of the villages have 1 000 births per year and therefore the result might not completely represent reality.

The crude death rate (CDR) was calculated by dividing the number of deaths with the total population and then multiplying the result with 1 000. This gives the number of deaths per 1 000 people.

After these calculations were finished, some of the demographic data were compared to explore if there was any relationship between the different village characteristics. A comparison between the zones of constraints and three socio-economic factors were also done. The relationship between, for example, the road access and the zones of constraints is interesting since it could highlight where new roads should be prioritised.

The following comparisons were made:

- Population size – Poverty level
- Ethnicity – Poverty level
- Ethnicity – Literacy rate
- CDR – Poverty level
- CDR – Ethnicity
- Poverty level – Road access
- Road access – Ethnicity
- Literacy – Poverty level
- Zones of constraints – Poverty level
- Zones of constraints – Ethnicity
- Zones of constraints – Road access

All socio-economic and demographic data were divided into classes to simplify analysis. The villages Poverty status, the villages Ethnicity and the villages Road Access was already classified by the National Agriculture and Forestry Research Institute of Lao PDR and the district staff. The total population data from 2003, the calculated CDR and the literacy rate was divided into classes by us.

The villages were classified into three poverty classes:

1. Low Poverty
2. Medium Poverty
3. Severe Poverty

The villages were classified into three Ethnic groups:

1. Lao Soung
2. Lao Toung
3. Mixed Villages

None of the villages in the district consists of only the ethnic group Lao Loum. Nevertheless, they are included in the mixed villages.

The village's road access were classified into:

1. Rural with access to road
2. Rural with no access to road
3. Urban

For the total population data from 2003 the population difference between the smallest and the largest village in Phonxay District was divided into three equal intervals, which were:

1. < 518
2. 518-828
3. > 828

The same was done with the CDR, with the classes being:

1. < 37
2. 37-70
3. > 70

The literacy rate was classified into three classes using UNESCO's institute for statistics calculations of the literacy rate in Lao PDR being between 30-50%:

1. < 30 %
2. 30-50 %
3. > 50 %

4 Result

Part 1

4.1 Evaluation of Alternative Methods to Estimate Missing Climate Data

The alternative method to calculate solar radiation showed to overestimate the result at all years and all stations. The mean overestimation for eight stations, where evaluation was possible, was 4.8 MJ m^{-2} day^{-1}, with a standard deviation of 2.2. The alternative method to calculate actual vapour pressure both overestimated and underestimated the result. The mean for the eight stations was an overestimation of 0.08 kPa with a standard deviation of 0.14.

These values resulted in a mean overestimation of the final potential evapotranspiration calculations with 0.6 mm day^{-1} for the solar-radiation and a mean underestimation of -0.2 mm day^{-1} using the alternative method to calculate actual vapour pressure. To overcome the overestimation of the solar radiation, the mean value of 4.8 MJ m^{-2} $day^{-1}$was subtracted from the daily solar radiation values. The small overestimation of the actual vapour pressure was neglected.

4.2 Evaluation to Define Temporal Resolution

The evaluation to explore if mean monthly values of precipitation and potential evapotranspiration could be used, to predict growing period days, instead of daily values showed a mean difference of 14.8 growing period days (see table 4.1). This is a rather small difference considering the quiet large yearly variation in growing periods (see table 4.1). If looking at Luang Phrabang, for example, this station has a growing period of 178 days in 1995 and 282 days in 2002, which is a difference of 104 days (see table 4.2). This large yearly variation resulted in that we decided to interpolate monthly values.

Table 4.1: Growing period, estimated by plotting daily values of precipitation and potential evapotranspiration divided by two and growing period estimated by calculating mean monthly values of precipitation and potential evapotranspiration divided by two.

Station	Mean of daily measurements	Mean of monthly measurements	Difference
Louang Phrabang	218.8	195.6	23.2
VangVieng	233.8	235.4	1.6
Sayabouly	221.3	208	13.3
Vienxay	226.3	242.1	15.8
Oudomxay	227.8	207.7	20.1

Table 4.2: Growing period between 1994 and 2003 at 5 stations. There is a large yearly variation in growing period. Luang Phrabang, for example, has a growing period of 178 days 1995 and 282 days 2002 which is a difference of 104 days.

Station	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	Mean	Min	Max
Louang Phrabang	201	178	199	200	221	237	217	234	282	219	218.8	178	282
Vang Vieng	223	214	235	220	285	237	238	246	257	183	233.8	183	285
Sayabouly	201	235	225	240	171	221	215	214	278	213	221.3	171	278
Viengxay	221	233	232	204	202	237	207	255	170	213	217.4	170	255
Oudomxay	218	174	245	220	175	254	214	238	319	221	227.8	174	254

4.3 Interpolations of Precipitation, Potential - Evapotranspiration and Temperature

The 34 climate stations used to interpolate temperature and precipitation cover an area of approximately 518 400 km ^{2}. The stations are situated in Lao PDR, Thailand, China and Vietnam (see figure 4.1). To interpolate potential evapotranspiration the 12 climate stations in northerna Lao PDR were used.

Climate Stations

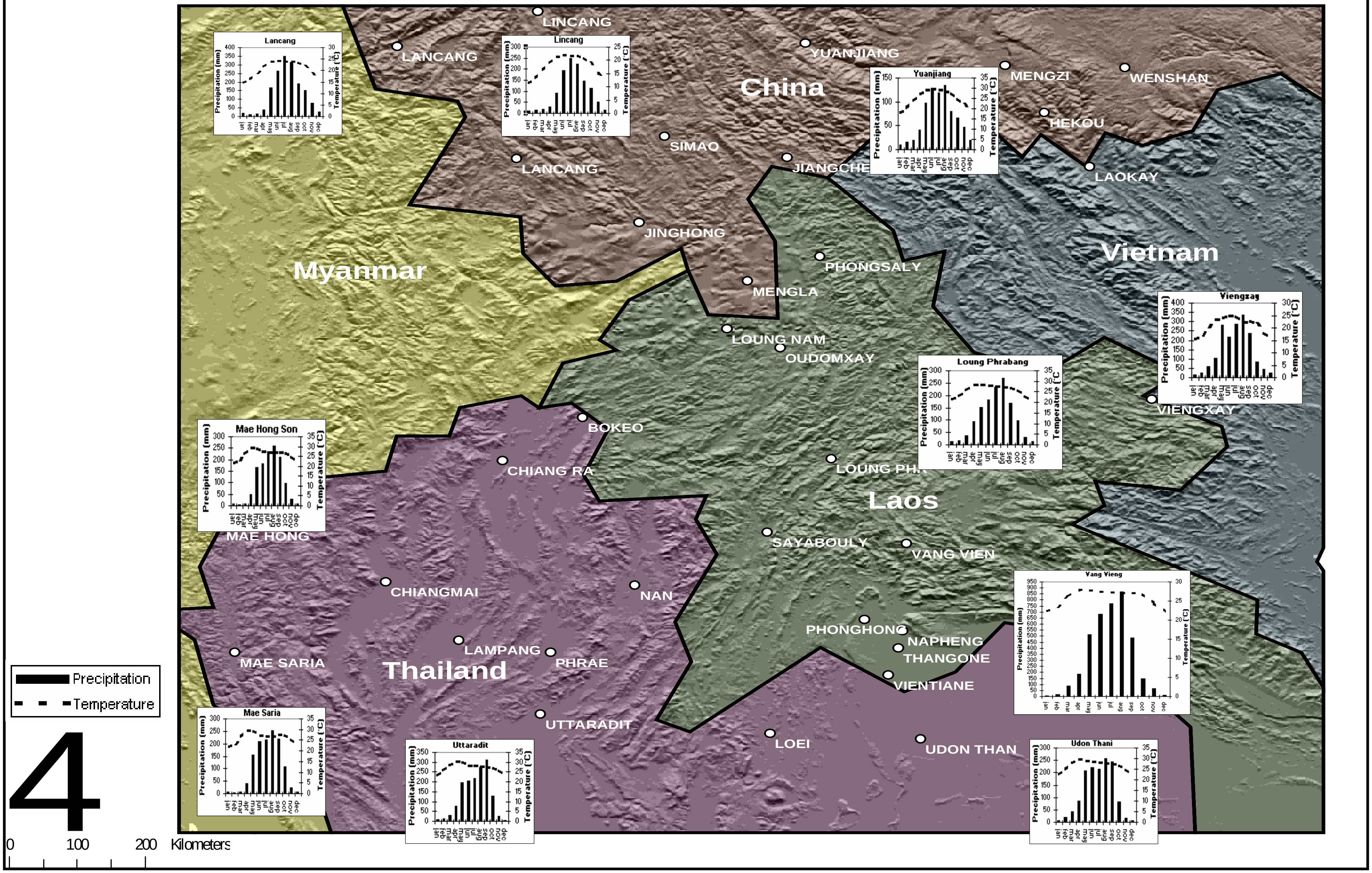


Figure 4.1: The area is located in a tropic climate zone with a monthly mean temperature above 18° C. The coldest station is Lincang, with a mean annual temperature of 18° C. The warmest stations are Uttradit and Napheng, with a mean annual temperature of 27.4° C. The coldest period in the whole area is December and January with a mean monthly temperature of 19° C. The warmest month in China and northern Lao PDR is June with a mean temperature of 25° C. In the southern Lao PDR and Thailand the warmest month is April with a mean monthly temperature of 29° C. The south-westerly monsoon season, is between May and October. The station with the highest annual precipitation is Vang Vieng, with 3 830 mm. The driest station is Yuanjiang, with 777 mm annual precipitation. In general it is dryer in the northern part of the area then in the southern part.

4.3.1 Temperature

The global polynomial interpolation technique was used to interpolate temperature for two resons:

1. A geostatistical technique was not preferable since there was no variance present after detrending.

2. The best deterministic interpolation technique, according to the cross validation, was a polynomial technique.

The significant correlation of -0.91 between mean yearly temperature and altitude made it possible to use the lapse rate to adjust the temperature to the landscape topography. The same adjustment was done for mean yearly minimum and mean yearly maximum temperature, since significant correlations of –0.91 and –0.89 were found.

Table 4.3, 4.4 and 4.5 show the relationship between predicted (interpolated) and calculated mean monthly sea level temperature values. The cross validation of the interpolated surface of mean monthly temperature gave mean errors varying between –0.015 and 0.01. The Root Mean Square (RMS) values varied between 0.78 and 0.97 (see table 4.3).

Table 4.3: Result from cross validation of the interpolated surface of mean monthly temperature at sea level.

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Mean Error	0.01	0.007	-0.004	-0.003	-0.015	-0.001	-0.01	0.003	-0.002	0.016	0.005	-0.002
RMS	0.90	0.82	0.82	0.79	0.96	0.97	0.96	0.78	0.79	0.87	0.82	0.81
Mean T	22.4	24	27	29.5	30	29.8	29.4	30.1	28.8	27.7	25.1	22.4

The cross validation of the interpolated surface of mean monthly maximum sea level temperature gave mean errors varying between –0.014 and 0.032. The Root Mean Square (RMS) values where varying between 0.77 and 1.36 (see table 4.4)

Table 4.4: Result from cross validation of the interpolated surface of mean monthly maximum temperature at sea level.

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Mean Error	0.008	-0.004	-0.012	-0.005	-0.014	-0.005	0.004	-0.001	0.007	0.032	-0.005	-0.006
RMS	1.13	1.29	1.36	1.07	0.99	0.88	0.95	0.77	1	0.90	0.89	1.13
Mean Max T	29.4	31.9	34.8	36.4	35.3	33.9	33.2	33.1	33.2	32.5	30.7	28.8

The cross validation of the interpolated surface of mean monthly minimum sea level temperature gave mean errors varying between –0.015 and 0.018. The Root Mean Square (RMS) values where varying between 0.88 and 1.24 (see table 4.5).

Table 4.5: Result from cross validation of the interpolated surface of mean monthly minimum temperature at sea level.

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Mean Error	0.014	0.018	0.005	-0.012	-0.001	-0.009	-0.015	-0.012	-0.002	-0.003	0.0007	-0.001
RMS	1.18	1.07	1.03	1.09	1.24	1.16	1.22	0.98	0.88	0.97	1.16	1.20
Mean Min T	15.5	16.4	19.4	22.8	24.9	25.9	25.8	25.5	24.6	23.1	19.7	16.2

The results showed that the entire area is located in a tropic climate zone with a monthly mean temperature above 18° C. The coldest station is Lincang (see figure 4.1), situated at 1 465 metres above sea level (m.a.s.l), with a mean annual temperature of 18° C. The warmest stations are Uttradit and Napheng (see figure 4.1), situated at 63 and 181 m.a.s.l respectively, with a mean annual temperature of 27.4° C. The coldest month of the year, in the whole area, is January with a mean temperature between 1.4 and 24° C depending on both altitude and latitude (see figure 4.1). The warmest month in China and northern Lao PDR is June with a mean temperature of 25° C going down to 11° C at high altitudes. In southern Lao PDR and Thailand, the warmest month is April with a mean monthly temperature of 29° C (see figure 4.1). In the northern part of the region the annual temperature varies with 9-10° C and in the south the temperature varies with 6-7° C. April represents the month with the highest air temperatures in the area and the overall mean maximum air temperature varies between 16 and 39 °C depending on both altitude and latitude (see figure 4.2).

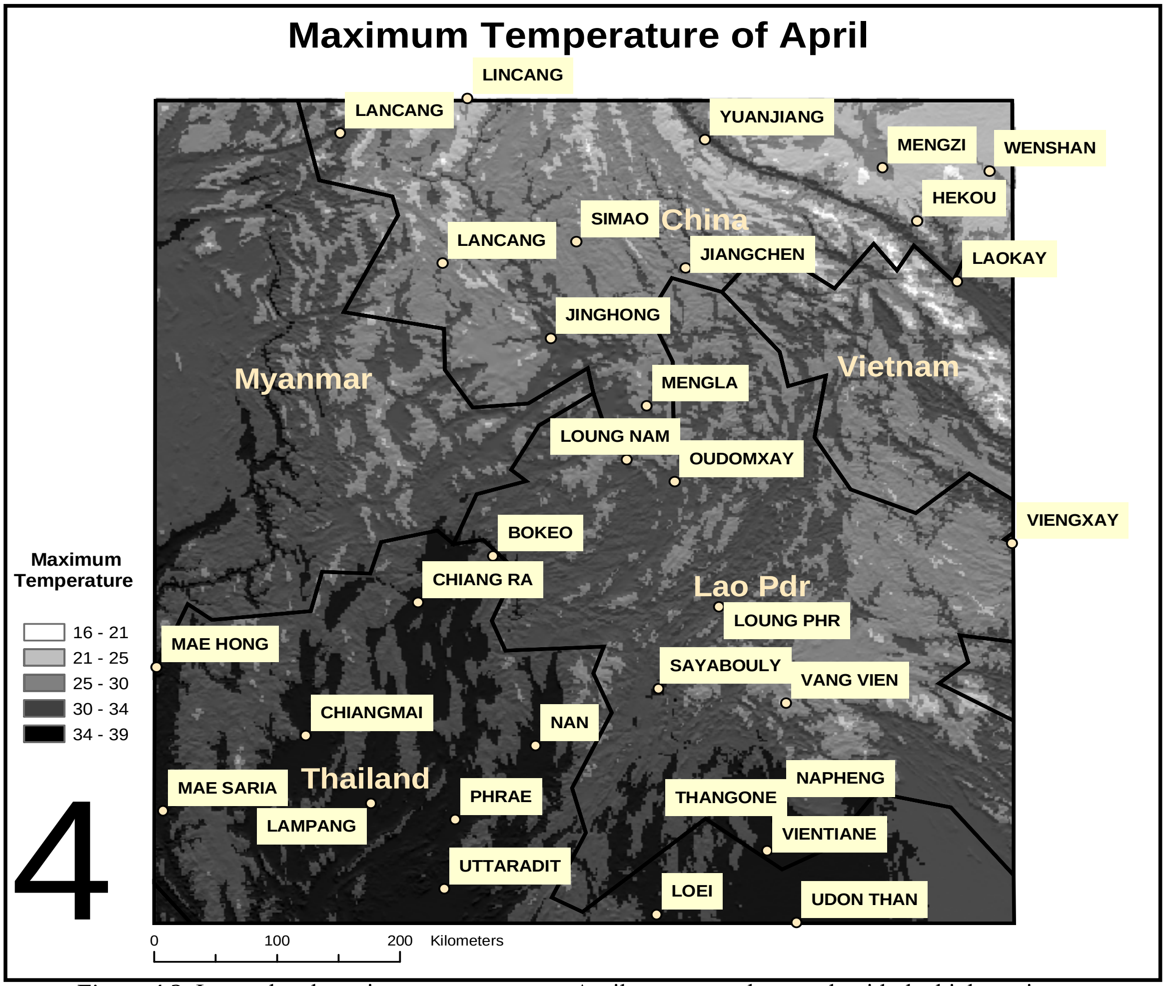


Figure 4.2: Interpolated maximum temperatures. April represents the month with the highest air temperatures in the area.

January represents the month with the lowest air temperatures in the area and the overall mean minimum air temperature varies between –6 and 19° C depending on both altitude and latitude (see figure 4.3). The coldest climate station is Lincang Station situated at 1 465 m.a.s.l. with a mean minimum air temperature of 4.3° C.

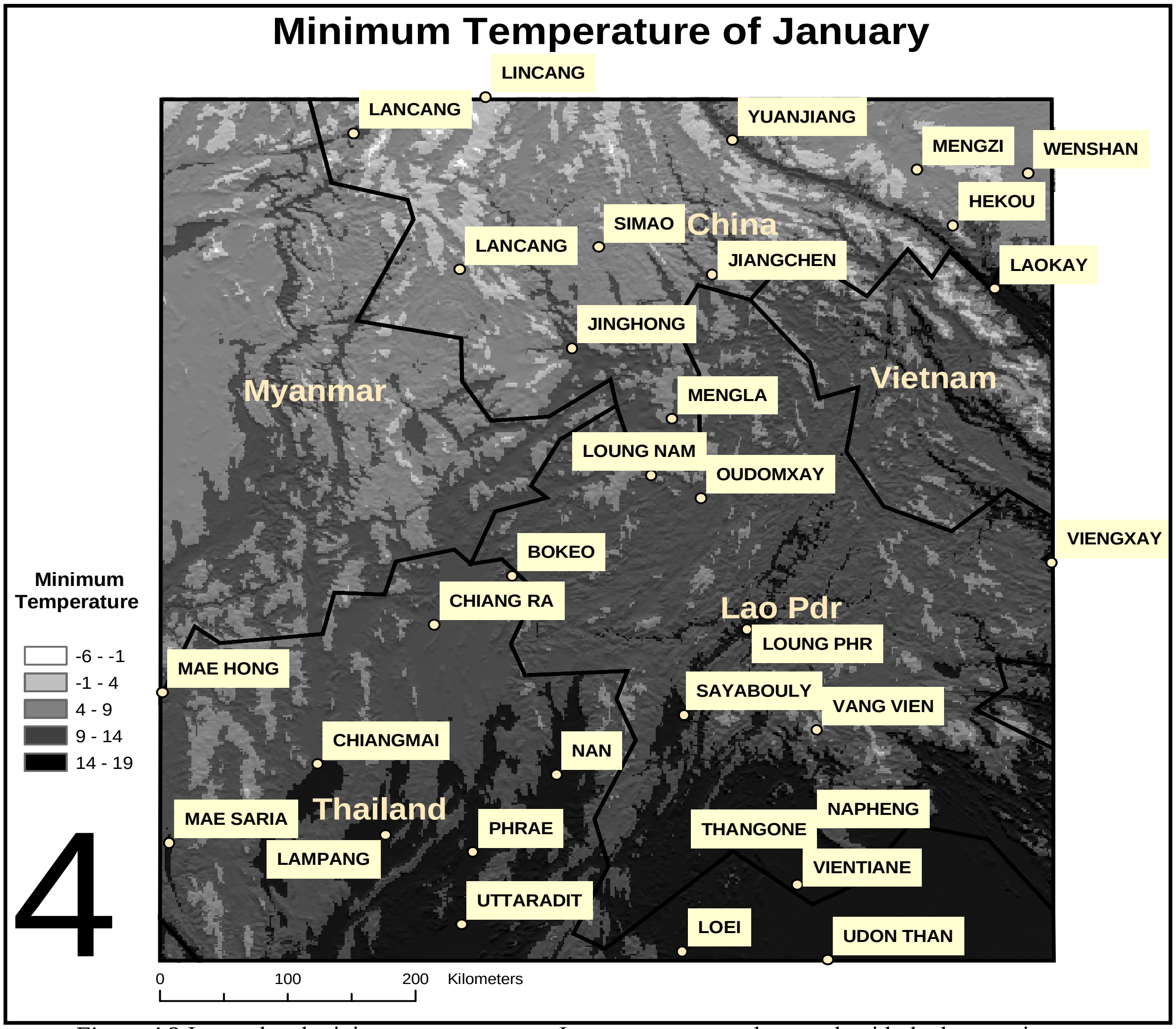


*Figure 4.3:*Interpolated minimum temperatures. January represents the month with the lowest air temperatures in the area.

4.3.1.1 Phonxay District

The calculations showed that Januari is the coldest month of the year in Phonxay District with a monthly mean air temperature varying between 9 and 20° C depending on altitude. The mean monthly minimum temperature in January is 3° C. Most of the district is placed in an area with a minimum temperature of 8 to 11° C.

The warmest month of the year in Phonxay is June with a mean air temperature varying between 16 and 28° C depending on the altitude (see figure 4.4).

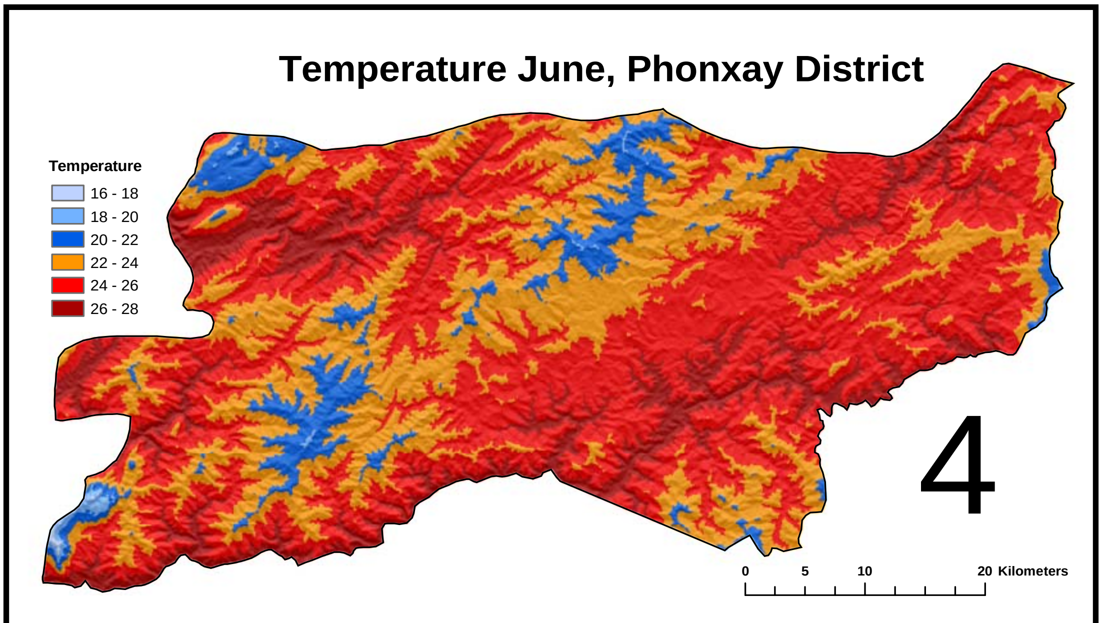


Figure 4.4: Interpolated mean monthly temperatures showed that June is the warmest month in Phonxay District, with a mean monthly temperature between 16 and 28° C.

The mean monthly maximum temperature is highest in April with a temperature of 33.5° C in the valleys.

4.3.2 Potential Evapotranspiration

The global polynomial interpolation technique was used to interpolate potential evapotranspiration for four resons:

1. A geostatistical technique was not preferable since there was no variance present after detrending.

2. The low correlation value of –0.508 between the prediction variable potential evapotranspiration and the co-variable elevation made it impossible to use Cokriging.

3. The small amount of potential evapotranspiration points (12) made geostatistic techniques impossible (Eklundh 2004).

4. The best deterministic interpolation technique, according to the cross validation, was a polynomial technique.

Table 4.6 shows the relationship between predicted (interpolated) and calculated mean monthly potential evapotranspiration. The cross validation of the interpolated surface gave mean errors varying between -0.08 and 0.03. The Root Mean Square (RMS) values were varying between 0.35 and 1.1 (see table 4.6).

Table 4.6: Result from cross validation of the interpolated surface of mean monthly potential evapotranspiration.

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Mean Error	-0.08	0.009	-0.05	-0.03	-0.03	-0.07	-0.06	-0.01	-0.002	-0.021	0.03	-0.053
RMS	0.75	0.72	0.73	0.84	0.7	1.1	0.47	0.35	0.49	0.55	0.72	0.57
Mean PET	3.0	4.0	4.9	4.9	4.0	3.3	2.9	2.9	3.0	3.0	2.8	2.7

Monthly mean values of potential evapotranspiration within northern Lao PDR vary between 1.3-8.6 mm day^{-1}. The yearly average of potential evapotranspiration within the area varies from 2.2 to 4.4 mm day^{-1} (see figure 4.5). The lower value of the two could be found in the northwest and the higher value in the southeast.

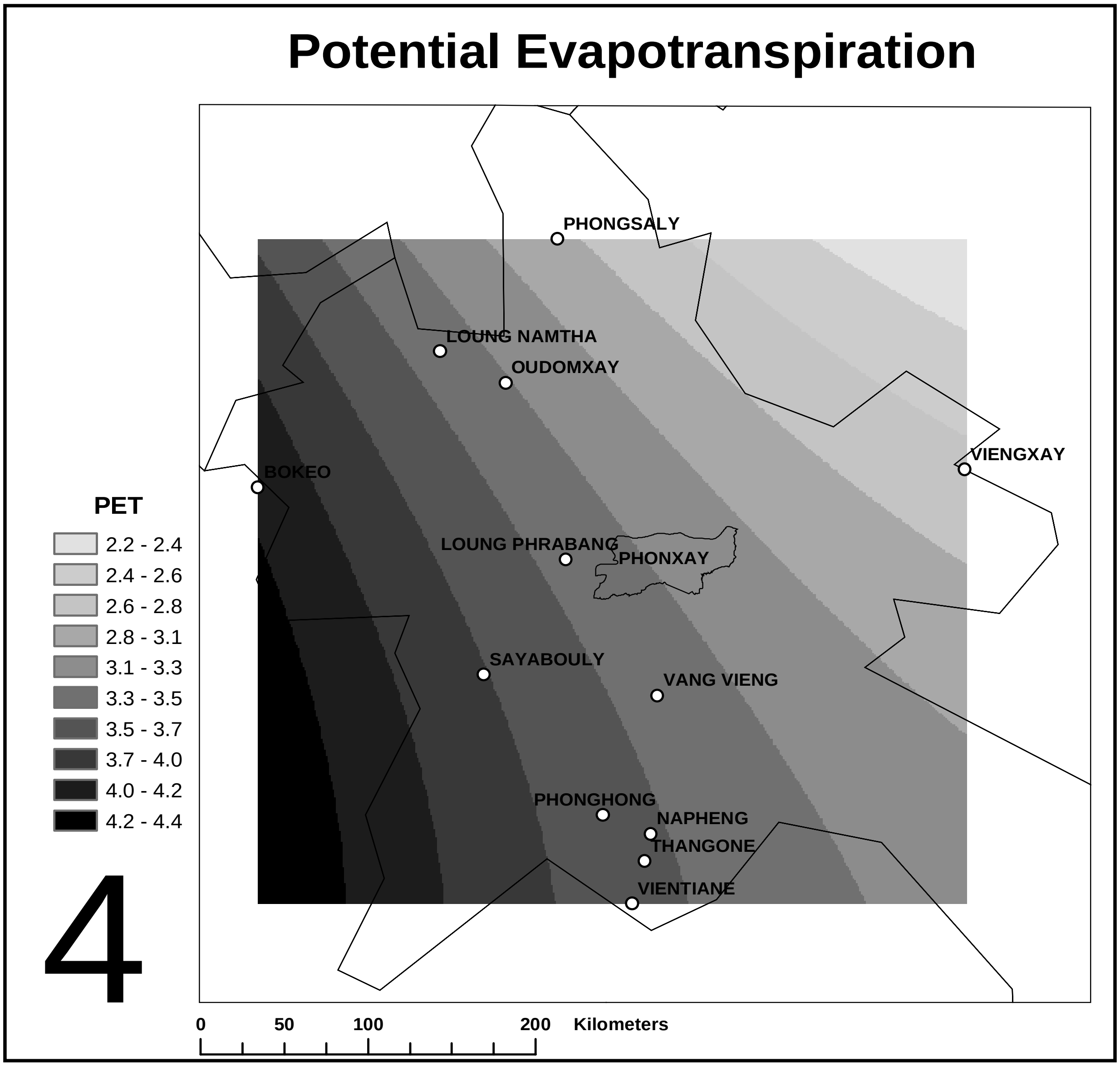


Figure 4.5: Interpolated yearly average of potential evapotranspiration varying between 2.2 to 4.4 mm day^{-1}.

The lowest values of potential evapotranspiration within northern Lao PDR could be found in July/August and November/December, with mean values of 2.6-2.8 mm day^{-1}. The period of highest potential evapotranspiration is between March and May with mean values of 4-4.9 mm day^{-1}.

4.3.2.1 Phonxay District

Monthly mean values of potential evapotranspiration within Phonxay vary between 2.3 and 4.4 mm day^{-1}. The lower value could be found in December and the higher value in March. The yearly average of potential evapotranspiration within the District varies from 3.02-3.62 to mm day^{-1} (see figure 4.5). The lower value of the two could be found in the northeast and the higher value in the southwest.

4.3.3 Precipitation

The radial basis function interpolation technique was used to interpolate precipitation for three resons:

1. The reason for not using Kriging as an interpolation technique was that after detrending the variance became extremely low, which means that there was not much variance except from the trend. This lead to that the major range distance became very short (the range of the semivariogram is the distance beyond which the variance no longer shows spatial dependence) (Hartkamp et al 1999). The short range in turn lead to that only a few values lying within the major range distance were weighted. With such a small amount of values with high weights (values that are spatially autocorrelated receives high weights) to predict a value, the prediction surface became very irregular and showed an unreliable precipitation pattern.

2. The low correlation value of –0.32 between the prediction variable potential evapotranspiration and the co-variable elevation made it impossible to use Cokriging.

3. The best deterministic interpolation technique, according to the cross validation, was a radial basis function.

Table 4.7 show the relationship between predicted (interpolated) and calculated mean monthly precipitation values. The cross validation of the interpolated surface gave mean errors varying between 0.01 and 5.27. The Root Mean Square (RMS) values where varying between 4.6 and 111.3 (see table 4.7).

Table 4.7: Result from cross validation of the interpolated surface of mean monthly precipitation.

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Mean Error	0.15	0.19	0.33	1.0	0.01	0.67	3.35	5.27	1.03	1.37	-0.21	0.33
RMS	4.6	6.7	11.8	24	62.7	95	101	111.3	62.55	22.63	12.68	6.57
Mean P	12.3	17.2	35.2	78.2	194.8	227.9	282.5	308.6	219.6	104.0	40.7	15.0

The interpolated mean annual precipitation is shown in figure 4.6. The station with the highest annual precipitation is Vang Vieng (see figure 4.1 and 4.6), situated at 241 m.a.s.l, with 3 830 mm. The driest station is Yuanjiang (see figure 4.1 and 4.6), situated at 398 m.a.s.l, with 777 mm annual precipitation. In general, it is dryer in the northern part of the area than in the southern part.

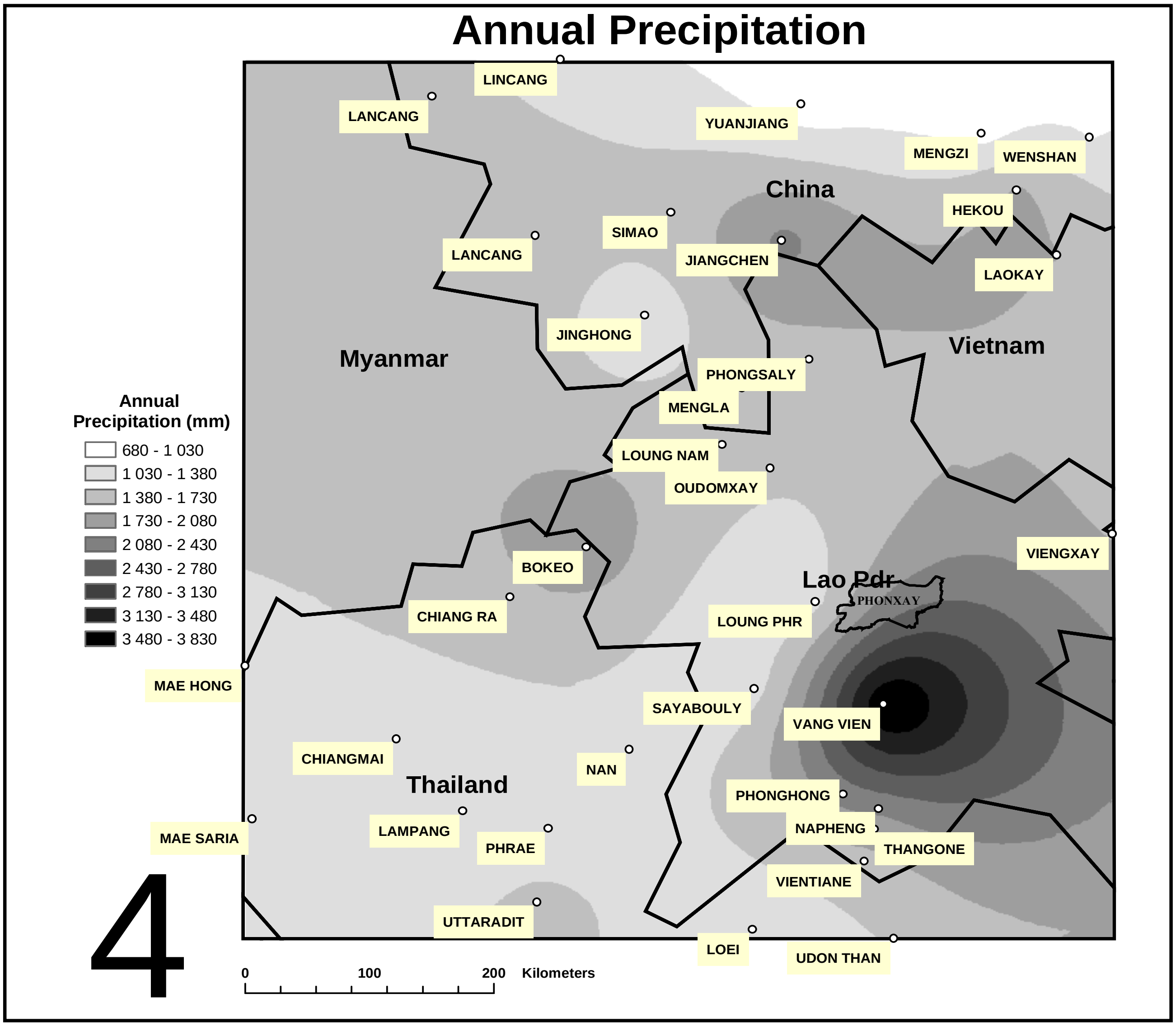


Figure 4.6: The interpolated mean annual precipitation in the area varies from 680 mm in the north to 3 830 mm in the northern central area of Lao PDR.

The south-westerly monsoon season, which is when most of the precipitation that falls in the area is between May and October (see figure 4.1). The month with the highest precipitation is august with values ranging from 171 mm at Mengzi climate station in China to 867 mm at Vang Vieng (Vang Vien) climate station in Lao PDR. The northeast monsoon season during November to March is mostly visible in the north-east of the area (see figure 4.1, notice the higher precipitation at Yuanjiang and Viengxay, comparable to Mae Hong Son or Lancang). The month with the least precipitation is januari with values ranging from 2 mm at Thangone climate station in Lao PDR to 31 mm at Jiangcheng climate station in China.

4.3.3.1 Phonxay District

The month with least precipitation is January with a monthly total of 10 to 12 mm. The highest amount of rain falls in August with a total monthly precipitation from 350 to 650 mm. The southeastern corner of the district receives the most and the northwestern corner the least. The mean annual precipitation in the northwest is 1 600-2 000 mm and in the southeast 2 300-2 700 mm (see figure 4.6).

Part 2

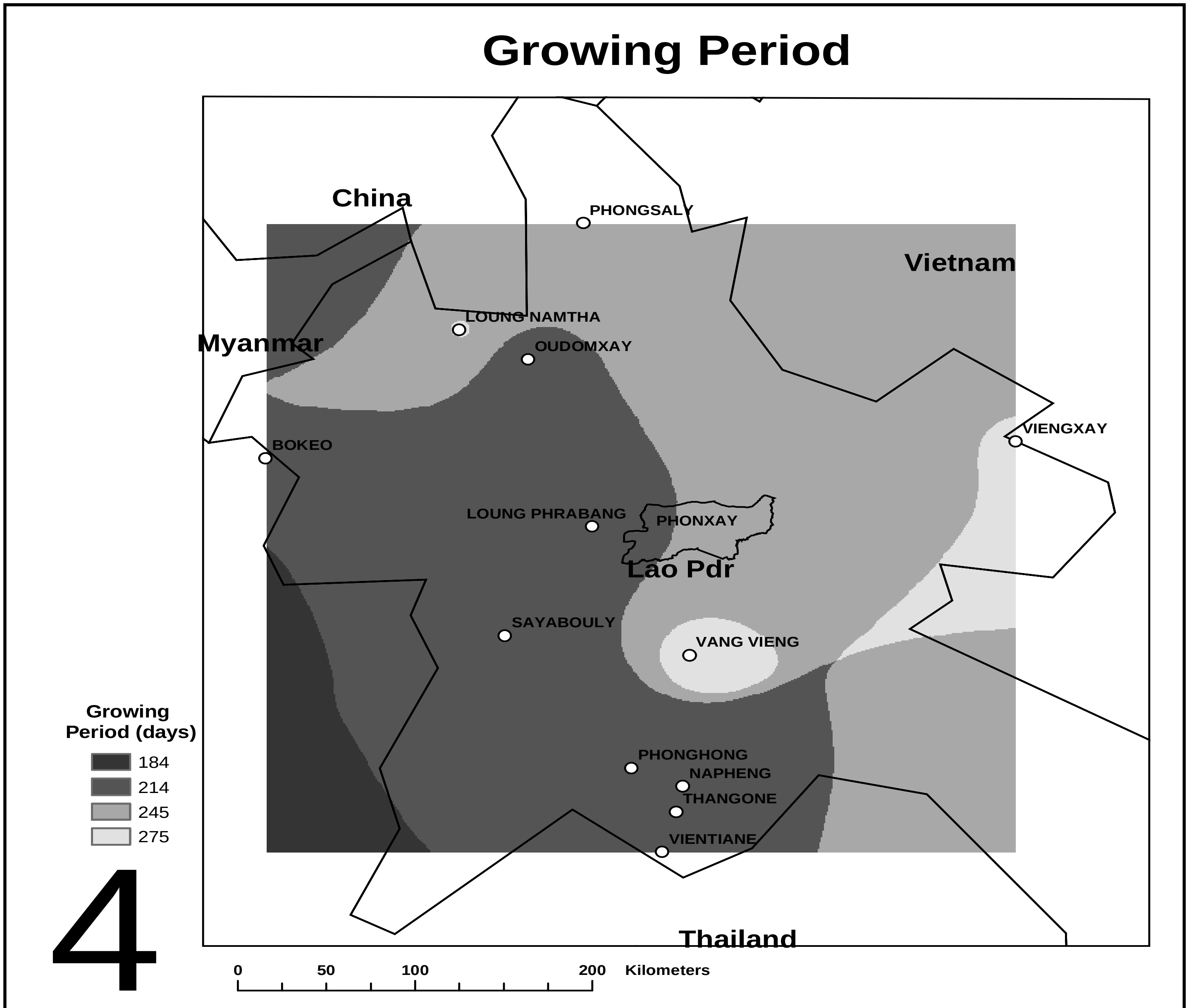
4.4 Growing Period Zones

The area of northern Lao PDR has what is considered a normal growing period where the precipitation exceeds the potential evapotranspiration for part of the year (see figure 4.7). The mean growing period in northern Lao PDR varies between 184 and 275 days per year (see figure 4.7). During April to October, the precipitation exceeds half the potential evapotranspiration (see figure 4.7), at 10 stations, and is considered to be the beginning and the end of the growing period. At two stations, the growing period starts in March (Vang Vieng and Viengxay) and ends in November (see figure 4.7). Furthermore, the mean temperature in Phonxay District during the period, when precipitation exceeds potential evapotranspiration, varies between 11 and 27° C. Therefore the temperature is never a limiting factor during the growing period (FAO 1985).

The start of the humid period is when the precipitation exceeds the potential evapotranspiration and the end is when the potential evapotranspiration exceeds the precipitation again (see figure 4.7). At 10 stations, the start takes place in May. At the two other stations, Vang Vieng and Luang Phrabang, it takes place in April and June. September or October represents the time when the humid period ends.

4.4.1 Phonxay District

Phonxay is divided into two zones of growing period. The eastern part has 245 days of growing period and the western part 214 days. This is due to the higher annual precipitation in the western part.


Growing Period
China
Vietnam
Myanmar
Lao Pdr
Thailand
PHONGSALY
LOUNG NAMTHA
OUDOMXAY
BOKEO
VIENGXAY
LOUNG PHRABANG
PHONXAY
SAYABOULY
VANG VIENG
PHONGHONG
NAPHENG
THANGONE
VIENTIANE
Growing Period (days)
184
214
245
275
4
0
50
100
200
Kilometers

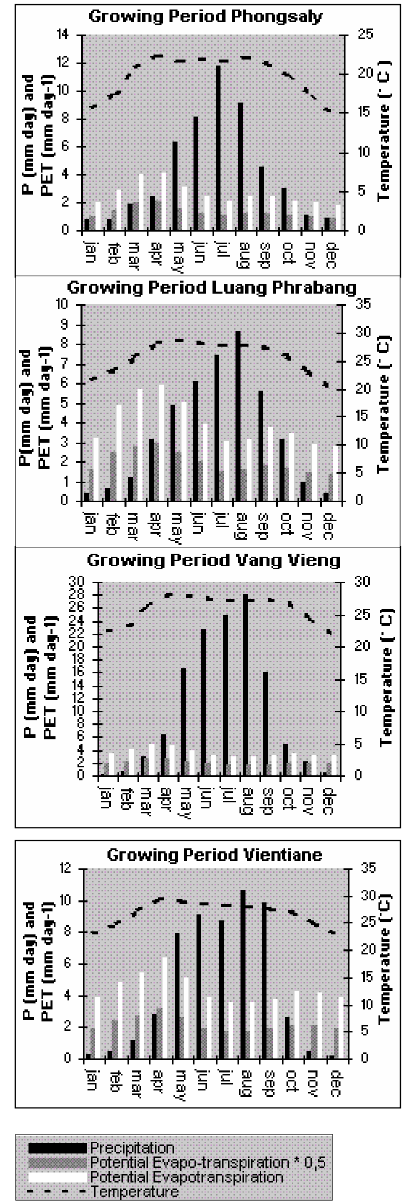

Growing Period Phongsaly
Growing Period Luang Phrabang
Growing Period Vang Vieng
Growing Period Vientiane
P (mm day) and PET (mm day-1)
Temperature (°C)
jan
feb
mar
apr
may
jun
jul
aug
sep
oct
nov
dec
Precipitation
Potential Evapo-transpiration * 0,5
Potential Evapotranspiration
Temperature

Figure 4.7: The area of northern Lao PDR has what is considered a normal growing period where the precipitation exceed the potential evapotranspiration for part of the year. During April to October, the precipitation exceeds half the potential evapotranspiration, at most stations, and is considered to be the beginning and the end of the growing period. The start of the humid period is when the precipitation exceeds the potential evapotranspiration and the end is when the potential evapotranspiration exceeds the precipitation again. September or October represents the time when the humid period ends.

4.5 Slope in Phonxay District

The topography of Phonxay District consists of narrow valleys and steep mountain slopes (see figure 4.8). 0.4 % of the total area is classified as slopes between 0-2 %. 1.5 % of the District is between 2-5 %, 2.1 % between 5-8 %, 8.4 % between 8-16 %, 27.2 % between 16-30 %, 36.7 % between 30-45 % and 23.7 % is over 45 % (see figure 4.8).

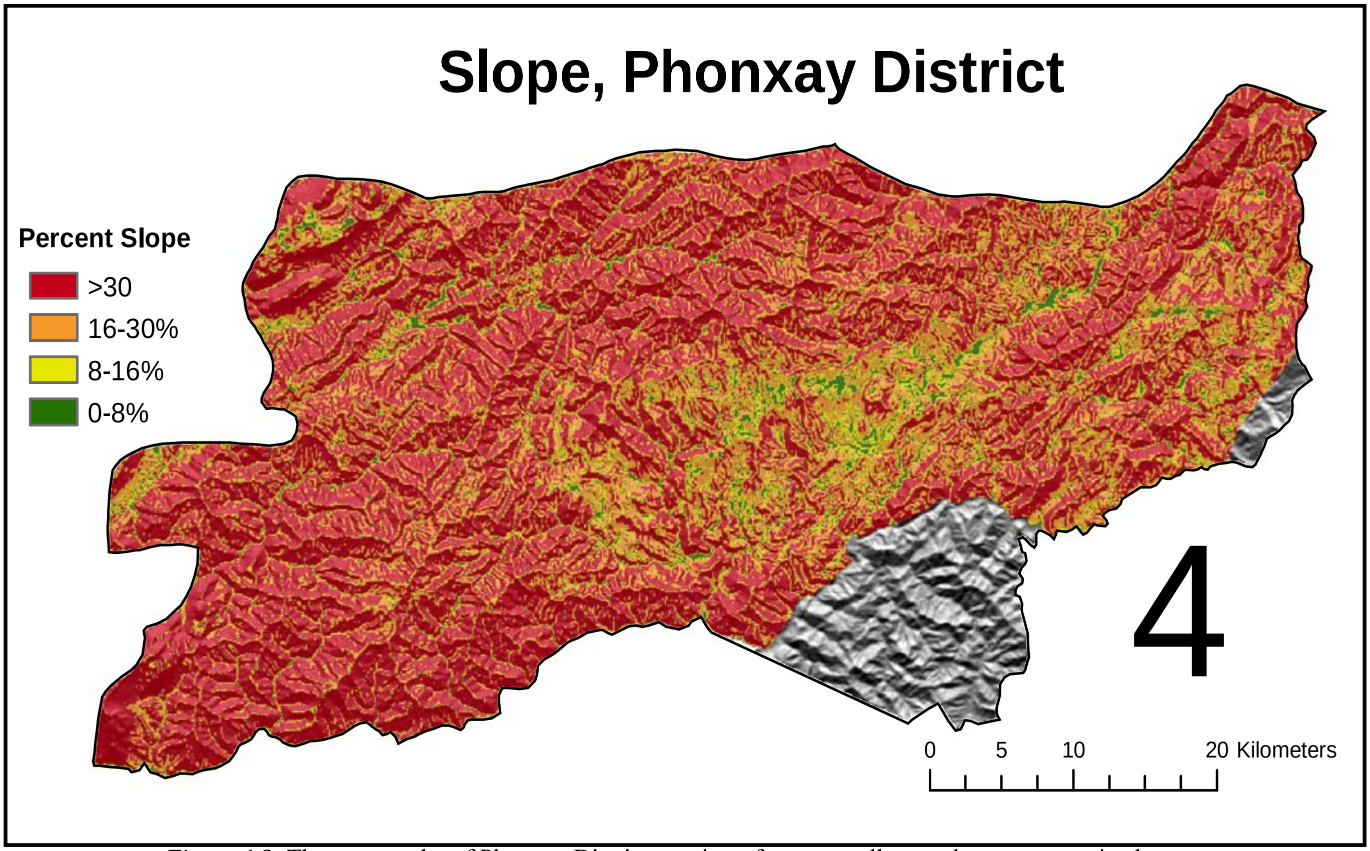


Figure 4.8: The topography of Phonxay District consists of narrow valleys and steep mountain slopes. The shaded areas represent areas with no information about the slope.

4.6 Agro-Ecological Zones in Phonxay District

There are 16 distinct agro-ecological zones in Phonxay District (see figure 4.9):

	Soil	Slope	T ºC
1.	Acrisol	0-8 %	19-23º C
2.	Acrisol	0-8 %	23-27º C
3.	Cambisol	0-8 %	23-27º C
4.	Acrisol	8-30 %	19-23º C
5.	Cambisol	8-30 %	19-23º C
6.	Leptosol	8-30 %	19-23º C
7.	Acrisol	8-30 %	23-27º C
8.	Cambisol	8-30 %	23-27º C
9.	Leptosol	8-30 %	23-27º C
10.	Leptosol	>30 %	15-19º C
11.	Acrisol	>30 %	19-23º C
12.	Cambisol	>30 %	19-23º C
13.	Leptosol	>30 %	19-23º C
14.	Acrisol	>30 %	23-27º C
15.	Cambisol	>30 %	23-27º C
16.	Leptosol	>30 %	23-27º C

Phonxay is divided into two zones of different growing periods, which could be seen in figure 4.9 as a black line going across the district. The area to the west has 214 days of growing period and the area to the east has 245 days. There is one National Biological Conservation Area, which is situated in the eastern corner of the district and three Provincial Protection Areas (see figure 4.9).

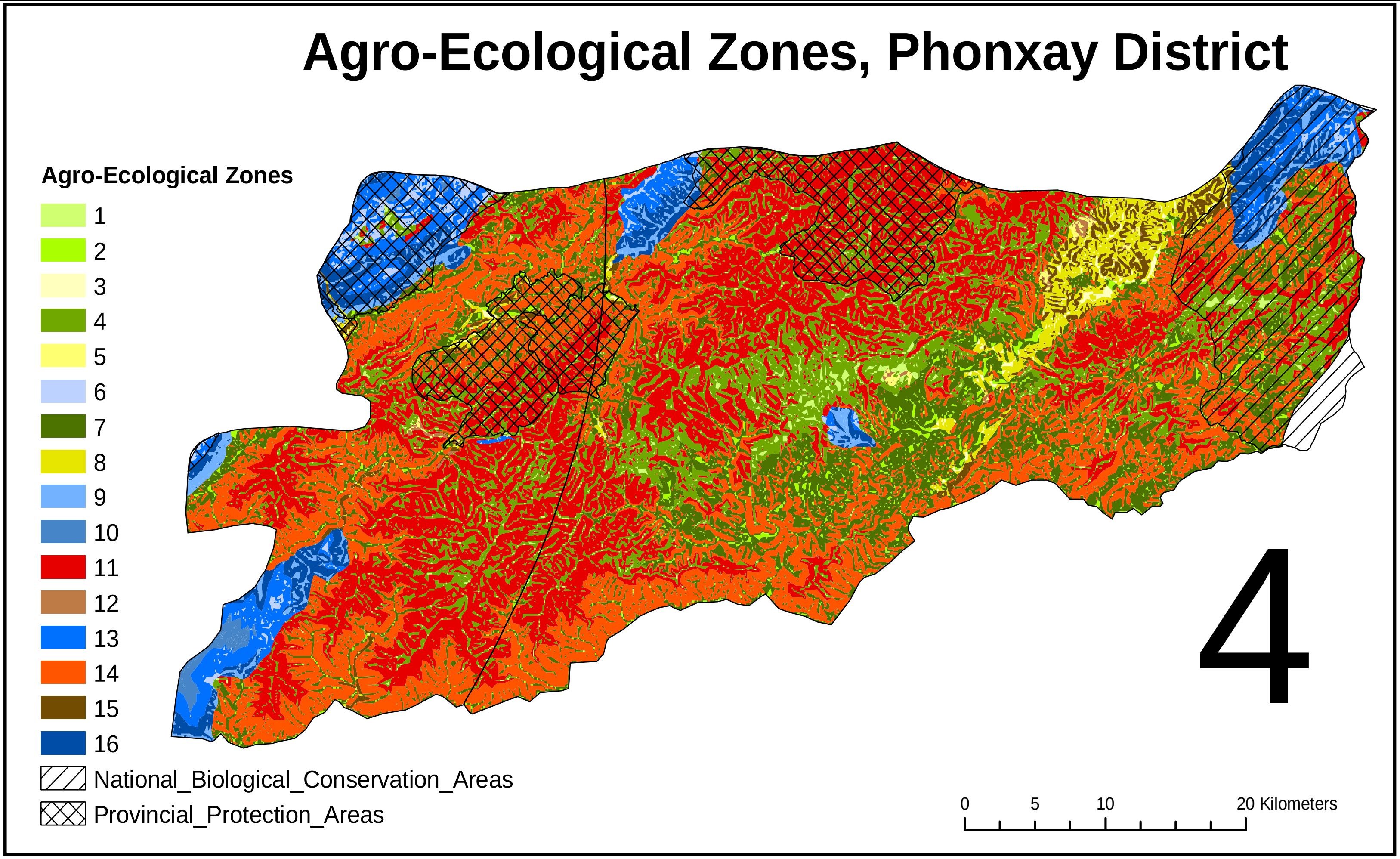


Figure 4.9: There are 16 distinct agro-ecological zones in Phonxay District. Phonxay is divided into two growing periods, which could be seen in as a black line going across the district. The area to the west has 214 days of growing period and the area to the east has 245 days. There is one National Biological Conservation Area and there are three Provincial Protection Areas in Phonxay. The green tone represents areas with Acrisols with < 30 % slope. The yellow tone represents areas with Cambisols < 30 % Slope. The blue tone represents areas with Leptosols. The red/orange tones and the brown tone are represented by areas with Acrisols or Cambisols with > 30 % Slope.

4.7 Zones of Soil and Terrain Constraints in Phonxay District

The characterization of Phonxay according to the prevailing soil and terrain constraints show that 68.3 % (149 443 Ha), is considered being land classified to Severe Constraints, 26.4 % (57 654 Ha) Slight Constraints and
5.3 % (11 518 Ha) of the land No Constraints. 61 villages in the district, out of a total of 90, are situated in the class of severe constraint, 22 villages are situated in areas of slight constraint and 5 villages are situated in areas of no constraint (see figure 4.10).

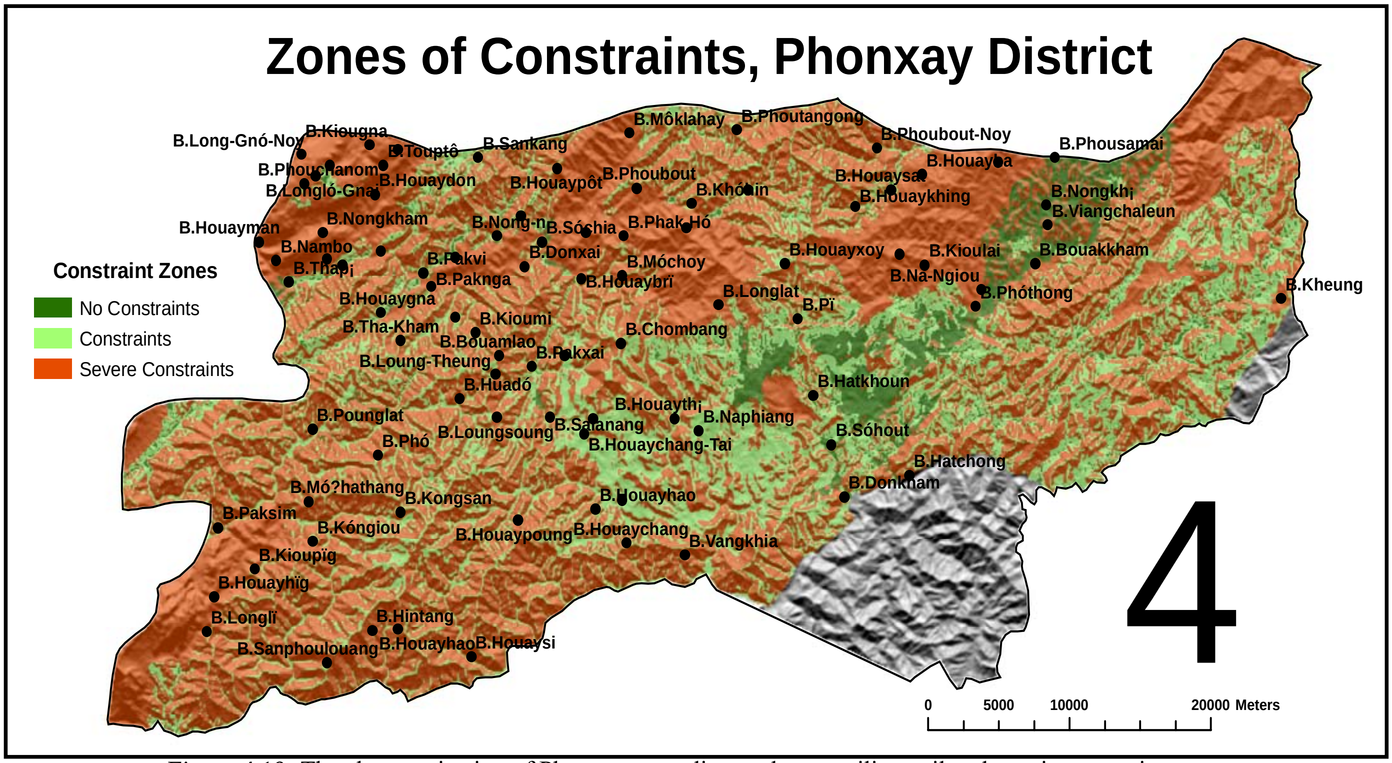


Figure 4.10: The characterization of Phonxay according to the prevailing soil and terrain constraints. The shaded areas represent areas with no information.

4.8 Suitability Rating for Bananas (Musa spp) and Pineapples (Ananas Comosos) in Phonxay District

The suitability rating, from a biophysical point of view, for bananas show that 68 % (149 970 Ha) of the analyzed area was considered not suitable for banana production, 3.9 % (8 613 Ha) was considered moderately suited, 27 % (60 047 Ha) was considered well suited and only 0.038 % (84 Ha) was considered highly suitable for banana production. The suitable areas are situated in the valleys and in the eastern part of the district (see figure 4.11).

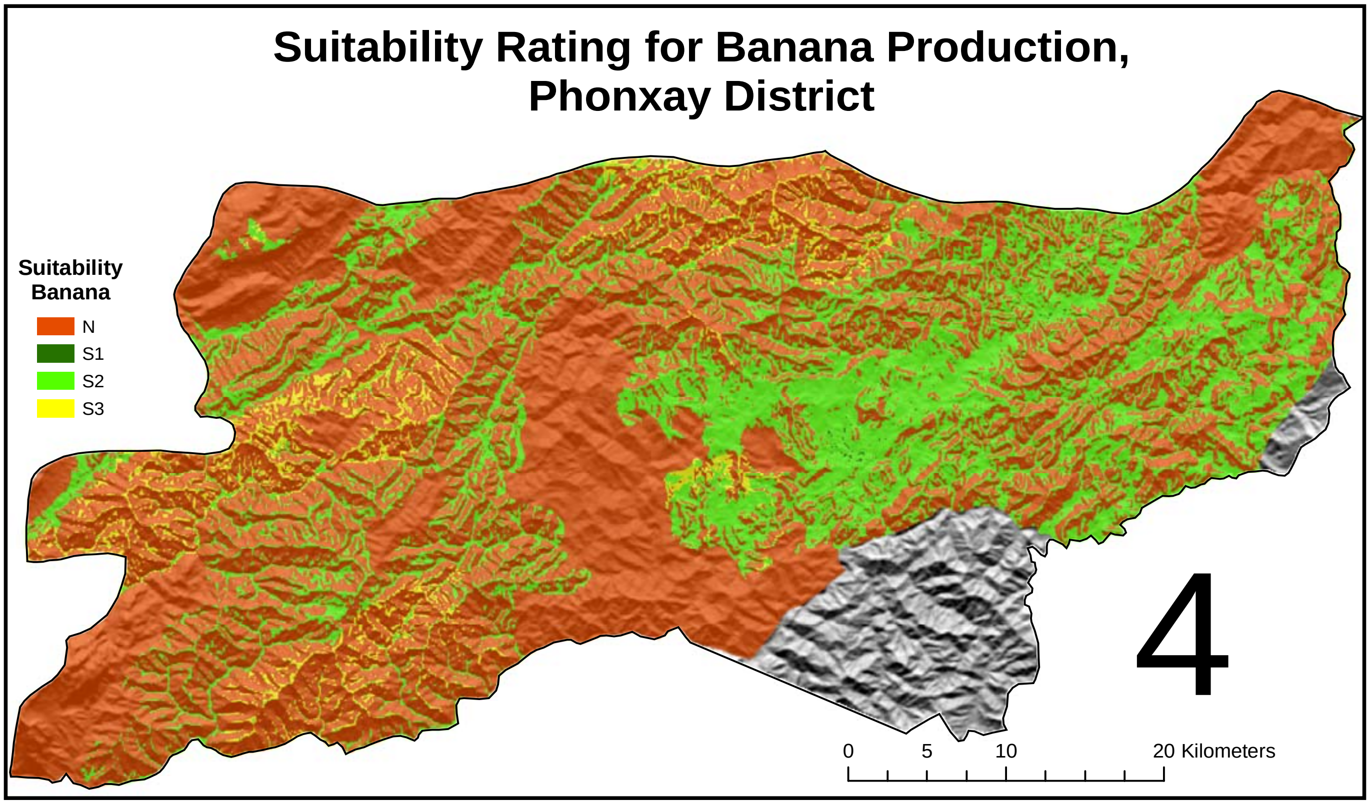


Figure 4.11: The suitability rating, from a biophysical point of view, for bananas, show that 68 % of the analysed area was considered not suitable for production, 3.9 % was considered moderately suited, 27 % was considered well suited and only 0.038 % was considered highly suitable for production. The shaded areas represent areas with no information.

The suitability rating, from a biophysical point of view, for pineapple, show that 64 % (139 044 Ha) of the analyzed area was considered not suitable for pineapple production, 7.8 % (17 174 Ha) was considered moderately suited, 28 % (61 530 Ha) was considered well suited and only 0.4 % (944 Ha) was considered highly suitable for pineapple production. The suitable areas are like for bananas, situated in the valleys and in the eastern part of the district (see figure 4.12).

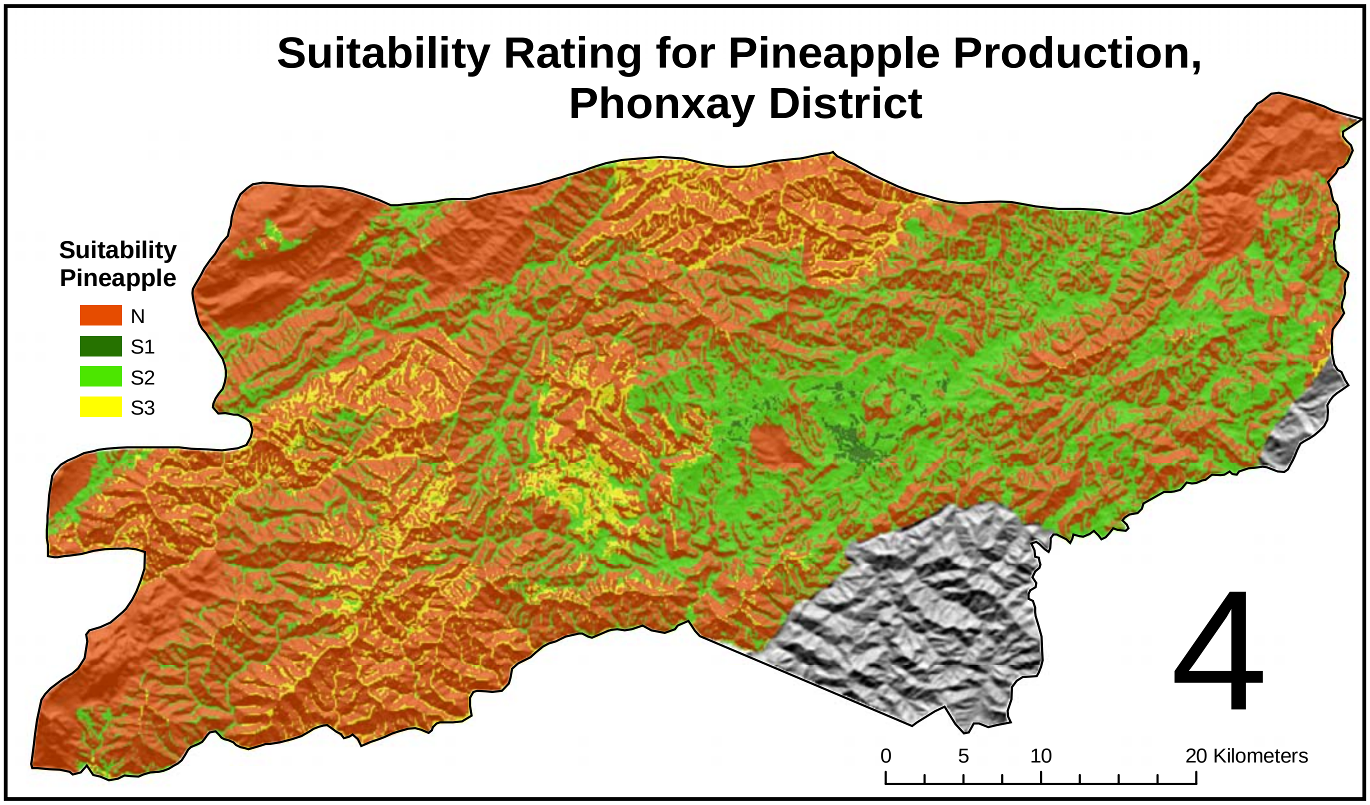


Figure 4.12: The suitability rating, from a biophysical point of view, for pineapple show that 64 % of the analyzed area was considered not suitable for production, 7.8 % was considered moderately suited, 28 % was considered well suited and only 0.4 % was considered highly suitable for pineapple production. The shaded areas represent areas with no information.

4.9 The Socio-Economic and Demographic Situation in Phonxay District

Phonxay District has a young population as can be seen in figure 4.13. The population growth, between 1995 and 2000 was 15 % or an annual population growth rate of 5 % (see table 4.8). Year 2003 the population was back on the same number as 1995 (se table 4.8). The total population in Phonxay in 2003 was 23 541. B. Houaykhing was the largest village with 1 138 people. The smallest village was B. Tha-Kham with 208 inhabitants.

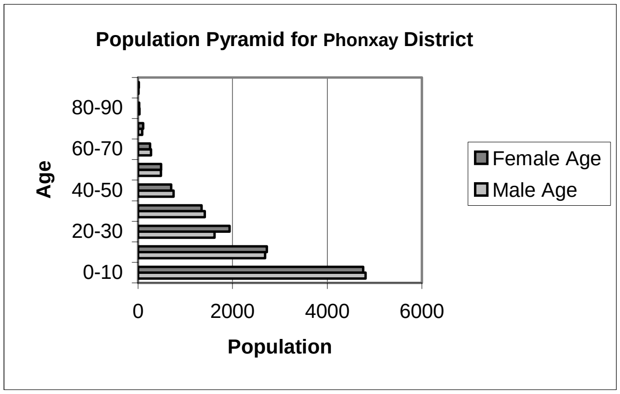


Figure 4.13: The age distribution of men and women in Phonxay District, 1995.

Table 4.8: The population development between 1995 and 2003.

Year	Population	Female	Male
1995	23.586	11.902	11.684
2000	27.156	12.333	14.823
2003	23.541	11.867	11.674

The women's average age at first birth in Phonxay District is 19.9 years.

In 1995, 1 581 infants were borne but of these, 188 died within the same year. The infant mortality rate in Phonxay District in 1995 was 118.9 deaths per 1 000 live births. The highest infant mortality in the district was 579 per 1 000 live births (see table 4.9).

Table 4.9: The live births, the infant deaths and the infant mortality rate in Phonxay District during 1995.

Infants Borne	1 581
Infants Died	188
IMR	118.9
Highest IMR	579

The main religion in Phonxay district was animist, which 90 % of the population is devoted to (see table 4.10). 9.59 % of the people are Buddhists, 0.07 % Christians and 0.004 % are Muslims.

Table 4.10: The different religions in Phonxay, and the number and shares of followers.

Religon	Number of People	Per cent of People
Animist	21.305	90.33
Buddhist	2.261	9.59
Christian	16	0.07
Muslim	1	0.004
Other Religon	3	0.02
Total	23.586	100

The main activity in Phonxay District was own work such as farming which represents 43.4 % of the population (see table 4.11). Unpaid work such as household work and gathering represents 27 % of the population and studies represents 20 % (see table 4.11).

Table 4.11: The different main activities in Phonxay and the number of people participating in them.

Main Activity	Number of people	Per cent of population
Employee	512	3.38
Employer	1	0.007
Other Work	16	0.11
Own Worker	6.588	43.43
Student	3.033	19.99
Unemployed	925	6.10
Unpaid Work	4.095	26.99
Total	15.170	100

The average literacy rate in the district was 34 %.

4.9.1 Population Size Compared to Poverty

47 villages, out of 89, were used to study if there was a relationship between the villages poverty status (classified into low poverty, medium poverty and high poverty) and the village population size (classified into population smaller then 518, between 518-828 and larger than 828). 33 villages had a population smaller then 518 people, 11 villages had a population between 518 – 828 people and 3 had a population larger then 828 people. 35 villages were classified as high poverty, 8 as medium poverty and 4 as low poverty (see figure 4.14).

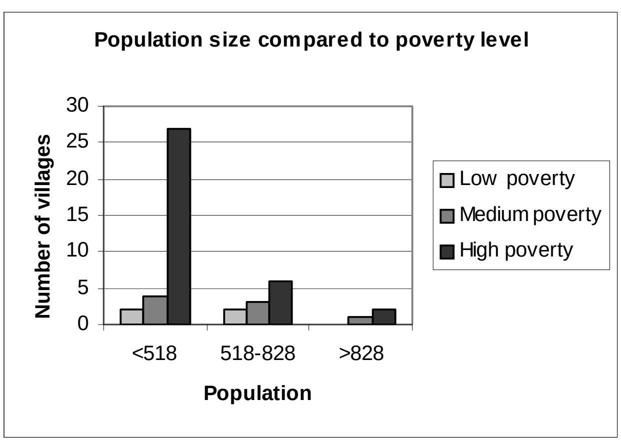


Figure 4.14: The villages population size compared to poverty.

When comparing the three groups to each other it shows that 2 (5 %) of the villages that were classified high poverty had a population larger then 828 people, 6 (17 %) had a population between 518 – 828 people and 27 (77 %), had a population smaller then 518 people (see figure 4.14). 1 (12.5 %) of the villages that was classified medium poverty had a population larger then 828 people, 3 (37.5 %) had a population between 518–828 people and 4 (50 %) had a population smaller then 518 people. 2 (50 %) of the villages that were classified low poverty had a population between 518 – 828 people and 2 (50 %), had a population smaller then 518 people.

After comparing between the groups we also looked at the internal structure of the three population size groups in regards to poverty status (see table 4.12).

Table 4.12: The internal structure of the three population groups in regards to poverty.

	Number of villages					
	Low		Medium		High	
Population	Number	%	Number	%	Number	%
< 518	2	6	4	12	27	81
518 - 828	2	18	11	27	6	54
> 828	-	-	1	33	2	67

4.9.2 Ethnicity Compared to Poverty

47 villages, out of 89, were used to study if there was a relationship between the villages poverty status (classified into low poverty, medium poverty and high poverty) and the ethnicity of the villagers (classified into Lao Toung, Lao Soung and Mixed). 35 villages were classified high poverty, 8 as medium poverty and 4 as low poverty. 7 villages had a mixed population, 10 villages were Lao Soung and 30 were Lao Toung (see figure 4.15).

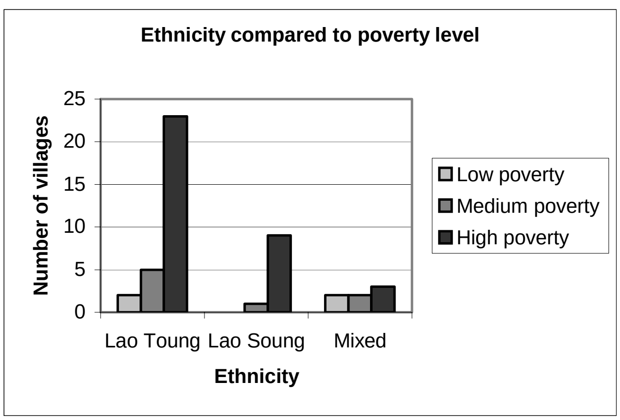


Figure 4.15: The ethnicity of the villages compared to the poverty level.

When comparing the three groups to each other it shows that 3 (8 %) of the villages that were classified to the group high poverty had a mixed population, 9 (25 %) were Lao Soung population and 23 (66 %) were Lao Toung (see figure 4.15). Of the villages classified as medium poverty 2 (25 %) had a mixed population, 1 (2.5 %) were Lao Soung and 5 (62.5 %) were Lao Toung. Of the villages classified as low poverty 2 (50 %) had a mixed population and 2 (50 %) were Lao Toung.

After comparing between the groups we also looked at the internal structure of the three ethnic groups in regards to poverty classification (see table 4.13).

Table 4.13: The internal structure of the three ethnic groups in regards to poverty classification.

	Number of villages					
	Low		Medium		High	
Ethnicity	Number	%	Number	%	Number	%
Lao T.	2	7	5	17	23	77
Lao S.	-	-	1	10	9	90
Mixed	2	29	2	29	3	43

4.9.3 Ethnicity Compared to Literacy Rate

51 villages, out of 89, where used to study if there was a relationship between the villages ethnicity (classified into mixed, Lao Soung and Lao Toung) and the literacy rate of the villagers (classified into literacy less than 30 %, 30-50 % and more than 50 %) (see figure 4.16). 8 of the villages had a mixed population, 13 had a Lao Soung population and 30 had a Lao Toung population. 20 villages had a literacy rate smaller than 30 %, 22 villages had a literacy rate between 30 – 50 % and 9 villages had a literacy rate higher than 50 % (see figure 4.16).

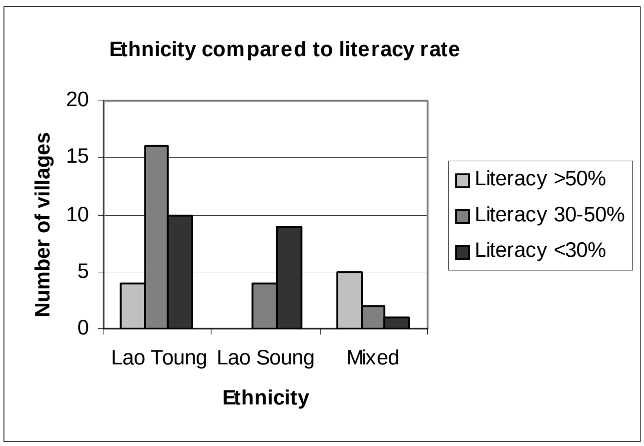


Figure 4.16: A comparison between ethnicity and literacy rate.

When comparing the three groups to each other it shows that 1 (5 %) of the villages with a literacy rate less than 30 % had a mixed population, 9 (45 %) were Lao Soung and 10 (50 %) were Lao Toung (see figure 4.16). Of the villages with a literacy rate between 30 – 50 %, 2 (9 %) had a mixed population, 4 (18 %) were Lao Soung and 16 (72 %) were Lao Toung. Of the villages with a literacy rate higher than 50 %, (56 %) had a mixed population and 4 (44 %) were Lao Toung.

After comparing between the groups we also looked at the internal structure of the three ethnicity groups in regards to literacy rate (see table 4.14).

Table 4.14: The internal structure of the three ethnicity groups in regards to literacy rate.

	Number of villages					
	Literacy < 30 %		Literacy 30 – 50 %		Literacy > 50 %	
Ethnicity	Number	%	Number	%	Number	%
Lao T.	10	33	16	53	4	13
Lao S.	9	69	4	31	-	-
Mixed	1	12.5	2	25	5	62.5

4.9.4 Crude Death Rate Compared to Poverty

39 villages, out of 89, were used to study if there was a relationship between the villages poverty level (classified into high poverty, medium poverty and low poverty) and the Crude Death Rate (CDR) of the villagers (classified into CDR less than 37, 37-70 and more then 70). 28 of the villages were classified as high poverty, 8 as medium poverty and 3 as low poverty. 32 villages had a CDR smaller then 37, 5 villages had a CDR between 37 – 70 % and 2 villages had a CDR higher than 70 (see figure 4.17).

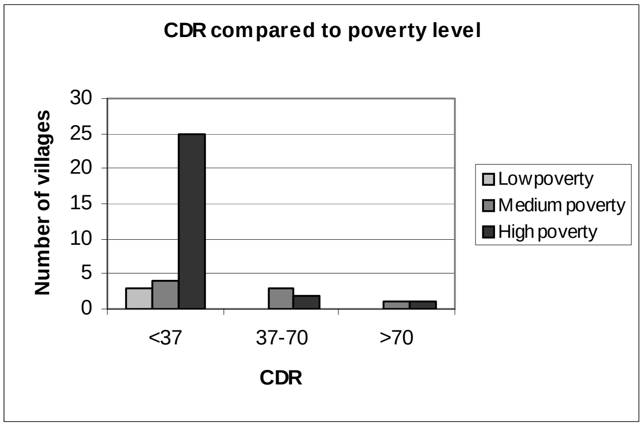


Figure 4.17: The village CDR compared to the poverty level. None of the villages with low poverty have a CDR higher than 37.

When comparing the three groups to each other it shows that 1 (3.6 %) of the villages classified as high poverty had a CDR higher than 70, 2 (7 %) had a CDR between 37 – 70 and 25 (89 %) had a CDR smaller then 37 (see figure 4.17). Of the villages classified as medium poverty 1 (12.5 %) had a CDR higher than 70 and 4 (50 %) had a CDR less than 37 (see figure 39). Of the villages classified as low poverty 3 (100 %) had a CDR less than 37 (see figure 4.17).

After comparing between the groups we also looked at the internal structure of the three CDR groups in regards to poverty level (see table 4.15).

Table 4.15: The internal structure of the three CDR groups in regards to poverty level.

	Number of villages					
	Low		Medium		High	
CDR	Number	%	Number	%	Number	%
< 37	3	9	4	12.5	25	78
37-70	-	-	3	60	2	40
> 70	-	-	1	50	1	50

4.9.5 Crude Death Rate Compared to Ethnicity

41 villages, out of 89, were used to study if there was a relationship between the villages ethnicity (classified into mixed, Lao Soung and Lao Toung) and the Crude Death Rate (CDR) of the villagers (classified into CDR less then 37, 37-70 and more then 70). 6 of the villages were mixed, 10 were Lao Soung and 25 were Lao Toung. 34 villages had a CDR smaller than 37, 5 villages had a CDR between 37 – 70 and 2 villages had a CDR higher than 70 (see figure 4.18).

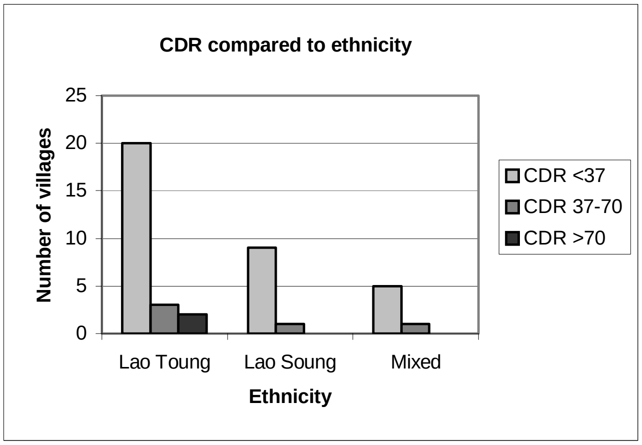


Figure 4.18: The villages CDR compared to the ethnicity group.

When comparing the three groups to each other it shows that 2 (100 %) of the villages with a CDR higher than 70 are located in Lao Toung villages. Of the villages with a CDR between 37 – 70, 1 (20 %) is located in villages with a mixed population, 1 (20 %) are located Lao Soung villages and 3 (60 %) are located in Lao Toung villages (see figure 4.18). Of the villages with a CDR lower then 37, 5 (14.7 %) are located in mixed villages, 9 (26.5 %) are located in Lao Soung villages and 20 (59 %) are located in Lao Toung villages.

After comparing between the groups we also looked at the internal structure of the three-ethnicity groups in regards to crude death rate (see table 4.16).

Table 4.16: The internal structure of the three ethnicity groups in regards to crude death rate.

	Number of villages					
	< 37		37-70		> 70	
Ethnicity	Number	%	Number	%	Number	%
Lao T.	20	80	3	12	2	8
Lao S.	9	90	1	10	-	-
Mixed	5	83	1	17	-	-

4.9.6 Poverty Compared to Road Access

47 villages, out of 89, were used to study if there was a relationship between the villages poverty status (classified into high poverty, medium poverty and low poverty) and road access to the villages (classified into urban, road access and no road access). 35 villages were classified as high poverty, 8 as medium poverty and 4 as low poverty. 2 villages were classified urban, 15 had road access and 30 had no road access (see figure 4.19).

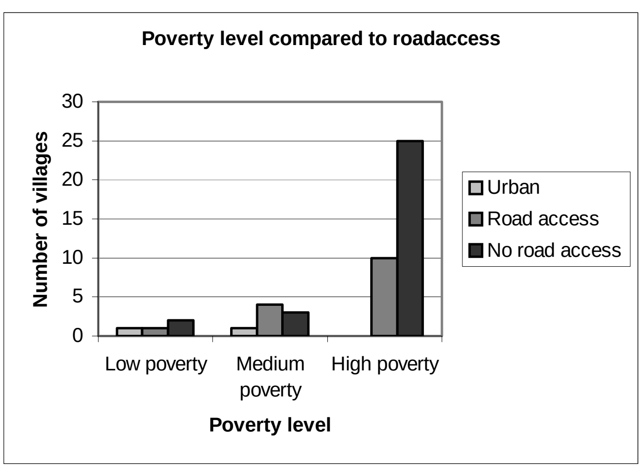


Figure 4.19: A comparison between Road access and poverty rate.

When comparing the three groups to each other it shows that of the villages with no road access 25 (83 %) were classified as high poverty, 3 (10 %) are classified as medium poverty and 2 (6.7 %) are classified as low poverty (see figure 41). Of the villages with road access 10 (67 %) were classified as high poverty, 4 (27 %) were classified as medium poverty and 1 (6.7 %) were classified as low poverty. Of the villages that were classified urban 1 (50 %) were classified as medium poverty and 1 (50 %) are classified as low poverty (see figure 4.19).

After comparing between the groups we also looked at the internal structure of the poverty groups in regards to road access (see table 4.17).

Table 4.17: The internal structure of the poverty groups in regards to road access.

	Number of villages					
	No Road Access		**Road Access**		**Urban**	
Poverty	Number	%	Number	%	Number	%
Low	2	50	1	25	1	25
Medium	3	37.5	4	50	1	12.5
High	25	71	10	28.5	-	-

4.9.7 Road Access Compared to Ethnicity

50 villages, out of 89, were used to study if there was a relationship between the villages ethnicity (classified into mixed, Lao Soung and Lao Toung) and road access to the villages (classified into urban, road access and no road access). 30 villages were Lao Toung, 12 were Lao Soung and 8 were mixed. 2 villages were classified urban, 18 had road access and 30 had no road access (see figure 4.20).

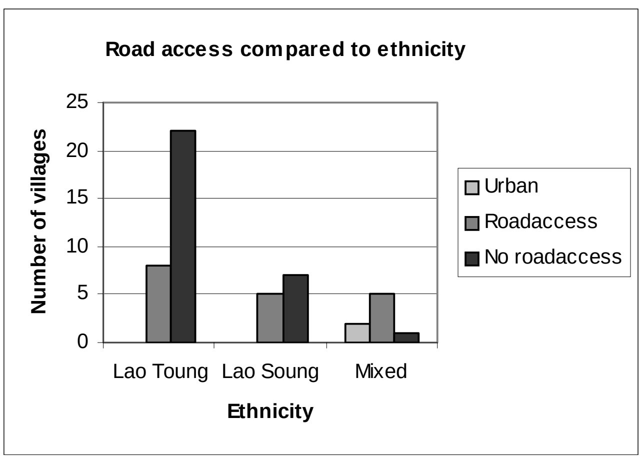


Figure 4.20: A comparison of road access and ethnicity.

When comparing the three groups to each other it shows that 1 (3 %) of the villages with mixed ethnicity have no road access, 7 (23 %) of the Lao Soung villages had no road access and 22 (73 %) of the Lao Toung villages had no road access (see figure 4.20). Of the villages with road access 5 (28 %) had mixed ethnicity, 5 (28 %) were Lao Soung villages and 8 (44 %) were Lao Toung (see figure 42). Of the villages that were classified urban, 2 (100 %) were mixed villages.

After comparing between the groups we also looked at the internal structure of the three ethnicity groups in regards to road access (see table 4.18).

Table 4.18: The internal structure of the three ethnicity groups in regards to road access.

	Number of villages					
	No Road Access		Road Access		Urban	
Ethnicity	Number	%	Number	%	Number	%
Lao T.	22	73	8	27	-	-
Lao S.	7	58	5	42	-	-
Mixed	1	12.5	5	62.5	2	25

4.9.8 Literacy Compared to Poverty

47 villages, out of 89, were used to study if there was a relationship between the villages poverty level (classified into high poverty, medium poverty and low poverty) and literacy rate of the villages (classified into less then 30 %, 30 – 50 % and more then 50 %). 35 villages were classified as high poverty, 8 as medium poverty and 4 as low poverty. 17 villages had a literacy rate below 30 %, 21 had a literacy rate between 30 – 50 % and 9 villages had a literacy rate above 50 % (see figure 4.21).

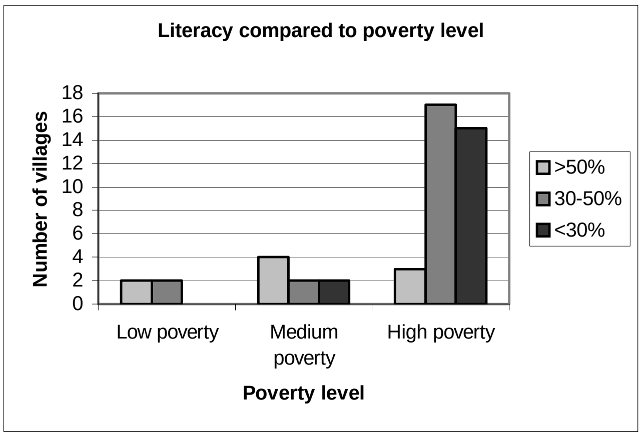


Figure 4.21: Poverty level compares to literacy rate.

When comparing the three groups to each other it shows that 15 (88 %) of the villages with a literacy rate below 30 % were classified as high poverty, 2 (12 %) were classified as medium poverty (see figure 4.21). 17 (80 %) of the villages with a literacy rate between 30 – 50 % were classified as high poverty, 2 (9.5 %) were classified as medium poverty and 2 (9.5 %) were classified as low poverty (see figure 4.21). 3 (33 %) of the villages with a literacy rate above 50 % were classified as high poverty, 4 (44 %) were classified as medium poverty and 2 (22 %) were classified as low poverty (see figure 4.21).

After comparing between the groups we also looked at the internal structure of the three poverty groups in regards to literacy rate (see table 4.19).

Table 4.19: The internal structure of the three poverty groups in regards to literacy rate.

	Number of villages					
	< 30 %		30 – 50 %		> 50 %	
Poverty	Number	%	Number	%	Number	%
Low	-	-	2	50	2	50
Medium	2	25	2	25	4	50
High	15	43	17	49	3	8.6

4.9.9 Poverty Compared to Zones Of Soil and Terrain Constraints

46 villages, out of 90, were used to study if there was a relationship between the villages poverty status (classified into low poverty, medium poverty and high poverty) and the zones of constraints. 34 villages were classified as high poverty, 8 were classified as medium poverty and 4 were classified as low poverty (see figure 4.22). 31 villages were in areas of severe constraints, 10 villages were in areas of slight constraints and 5 villages were in areas of no constraints (see figure 4.22).

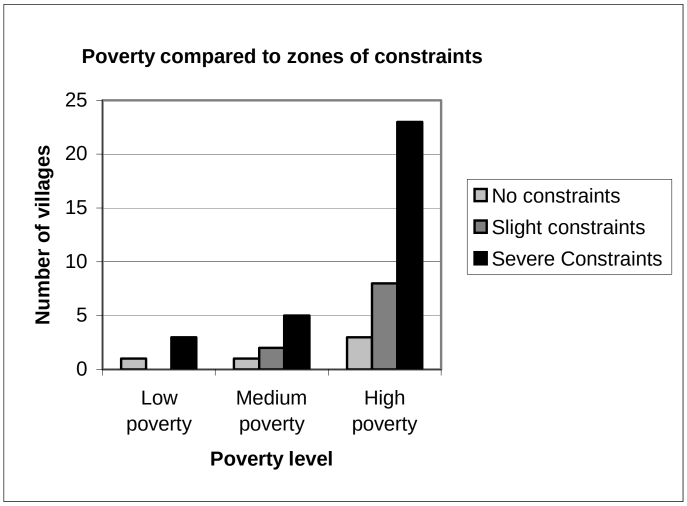


Figure 4.22: Poverty level compares to zones of constraints.

When comparing the three groups to each other it shows that 23 (75 %) of the villages that were situated in areas of severe constraints were classified as high poverty villages, 5 (16 %) of villages that were situated in areas of severe constraints were classified as medium poverty villages and 3 (9 %) of villages that were situated in areas of severe constraints were classified as low poverty villages (see figure 4.22). 8 (80 %) of the villages situated in areas of slight constraints were classified as high poverty villages and 2 (20 %) were classified as medium poverty villages. 3 (60 %) of the villages situated in areas of no constraints were classified as high poverty village, 1 (20 %) of the villages situated in areas of no constraints were classified as medium poverty villages and 1 (20 %) of the villages situated in areas of no constraints were classified as low poverty villages.

After comparing between the groups we also looked at the internal structure of the three poverty groups in regards to constraints (see table 4.20).

Table 4.20: The internal structure of the three poverty groups in regards to soil and terrain constraints.

	Number of villages					
	Severe Constraints		**Slight Constraints**		**No Constraints**	
Poverty	Number	%	Number	%	Number	%
Low	3	75	-	-	1	25
Medium	5	62.5	2	25	1	12.5
High	23	67	8	23.5	3	9

4.9.10 Ethnicity Compared to Zones Of Soil and Terrain Constraints

50 villages were used to study the relationship between the ethnicity (villages divided into Mixed, Lao Soung and Lao Toung) and the zones of constraints. 29 villages were considered being Lao Toung villages, 13 Lao Soung and 8 Mixed villages (see figure 4.23). 33 villages were in areas of severe constraints, 12 villages were in areas of slight constraints and 5 villages were in areas of no constraints (see figure 4.23).

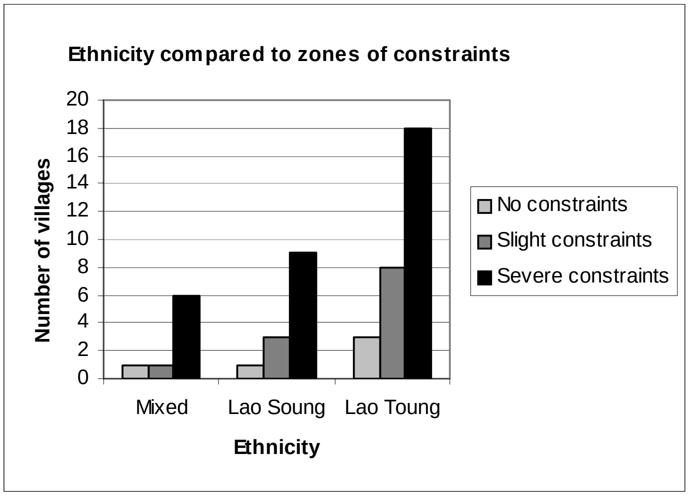


Figure 4.23: Ethnicity compared to zones of constraints.

When comparing the three groups of ethnicity to each other it shows that 18 (54 %) of the villages situated in areas of severe constraints were classified as Lao Toung villages, 9 (27 %) of villages situated in areas of severe constraints were classified as Lao Soung villages and 6 (18 %) of villages situated in areas of severe constraints were classified as Mixed villages (see figure 4.23). 8 (66 %) of the villages situated in areas of slight constraints were classified as Lao Toung villages, 3 (25 %) of the villages situated in areas of slight constraints were classified as Lao Soung villages and 1 (8.3 %) of the villages situated in areas of slight constraints were situated in Mixed villages. 3 (60 %) of the villages situated in areas of no constraints were classified as Lao Toung villages, 1 (20 %) of the villages situated in zones of no constraints were classified as ao Soung and 1 (20 %) of the villages situated in areas of no constraints were classified as Mixed villages (see figure 4.23)

After comparing between the groups we also looked at the internal structure of the three ethnicity groups in regards to the constraints (see table 4.21).

Table 4.21: The internal structure of the three ethnicity groups in regards to soil and terrain constraints.

	Number of villages					
	Severe Constraints		Slight Constraints		No Constraints	
Ethnicity	Number	%	Number	%	Number	%
Mixed	6	75	1	12.5	1	12.5
Lao S.	9	69.3	3	23	1	7.7
Lao T.	18	62	8	27.5	3	10.5

4.9.11 Road Access Compared to Zones Of Soil and Terrain Constraints

49 villages were used to study the relationship between the villages road access and the constraint zones in which they are situated in. 30 (60 %) of the villages were within the class of rural with no road access, 18 (36 %) within the class of rural with road access and 2 (4 %) in the class of urban villages (see figure 4.24).

The relationship showed that 70.6 % of the villages situated in zones of no constraint or slight constraints have no road access (see figure 4.24) while 29 % of the villages in the same class have road access. In comparison, 56 % of the villages situated in areas of severe constraint have no road access while 43 % of the villages situated in the same class have road access (see figure 4.24).

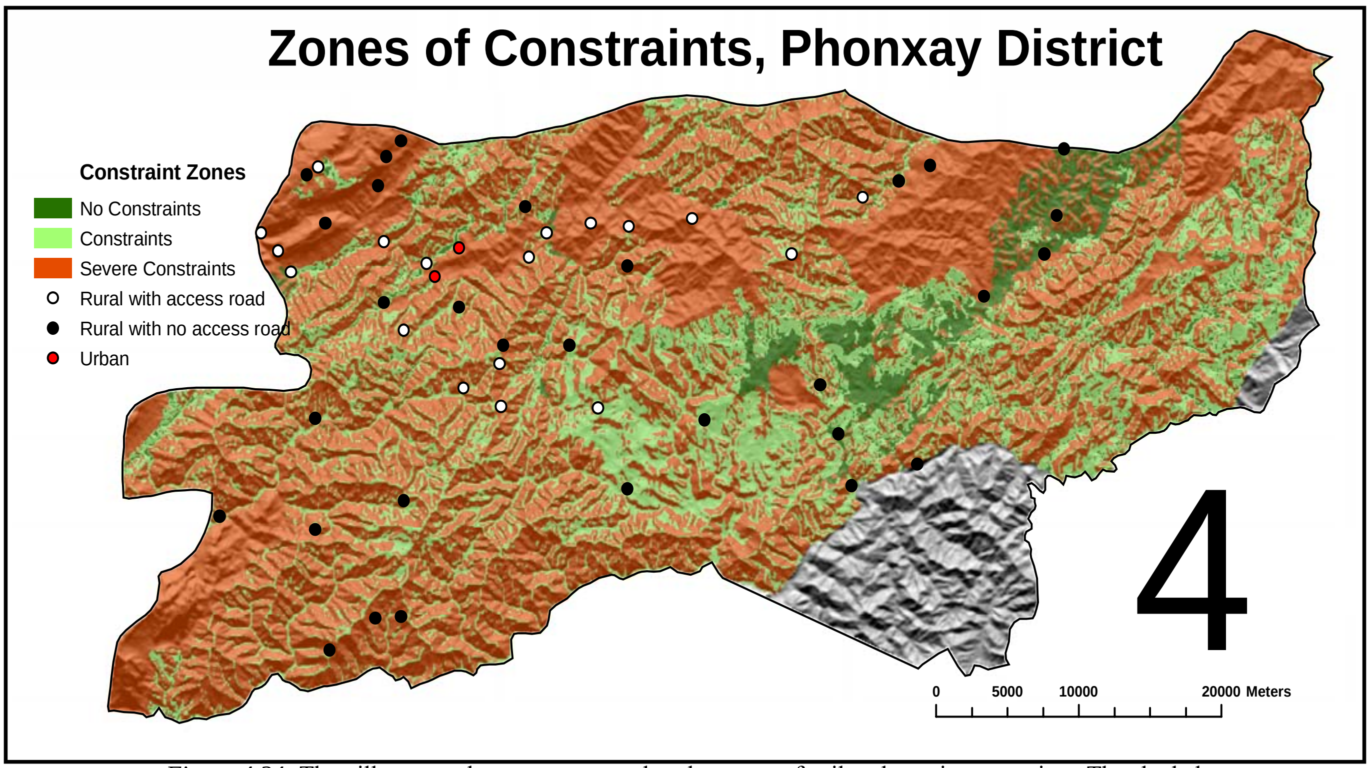


Figure 4.24: The villages road access compared to the zones of soil and terrain constraints. The shaded areas represent areas with no information.

5 Discussion

5.1 Transformation of Geographic Coordinate Systems

The need for accurate databases is a very important aspect for the development of a country. Without spatial information, planning and management is more demanding, and in many instances, not possible. Databases and maps often exist, but to be able to share the data between organisations and institutions, as well as to use the information for analysis, they need to be within the same coordinate system. Knowledge in this field is often lacking but is necessary in order to use geographical (spatial) data for analysis.

In Lao PDR there have been many geographic coordinate systems in use and the data we collected belonged to five of them. We came across several challenges involved while collecting data, as well as while transforming the data. Some of these problems are specific for Lao PDR, but many of them would also be present while working in other areas:

- The knowledge within this field was very low in Lao PDR and most people that are working with maps know very little, or nothing, about the coordinate systems in use. We came across this while collecting data and only a few people knew what system the data we received belonged to. This leads to the first very demanding part, which is identification of the geographical coordinate system. The only way to identify what system the data belonged to was to compare with data in known systems. In our case this was most often possible, but where it was not we could not use the data at all. This "trial and error work" of identification is definitely not an optimal way of working, and of course there is a possibility that the identification of the systems could have been wrong and the accuracy evidently lowered.

- There is rarely anything documented about the data, for example what transformations that have been done before etc. This largely influences the quality of the data and increases the risk for error of propagation.

- We were restricted to a three parameters transformation method since we only had three known parameters. A seven-parameter transformation is, according to Environmental Systems Research Institute Inc (1994-2000), a more complex and accurate transformation method.

- The geographic coordinate system of the soil map was very difficult to identify, but since the river system fitted perfectly to the soils we assumed that it belongs to the system Indian Datum 1954 (see figure 5.1). Therefore, we suspect that the soil map was made using a background map belonging to the system Indian 1954. Furthermore, we belive that during the production, a district boarder map in the system Lao National Datum 1997 was used.

  This means that when we transform the soil map to Lao National Datum 1997, the outer soil boundaries does not fit with the real district administrative boundary. The resulting transformed map is displaced by approximately 500 m (see figure 5.1 & 5.2).

Overall, we thought that the transformation went well but was extremely time consuming. We do believe that by using existing information, the transformations could not have been done either faster or better.

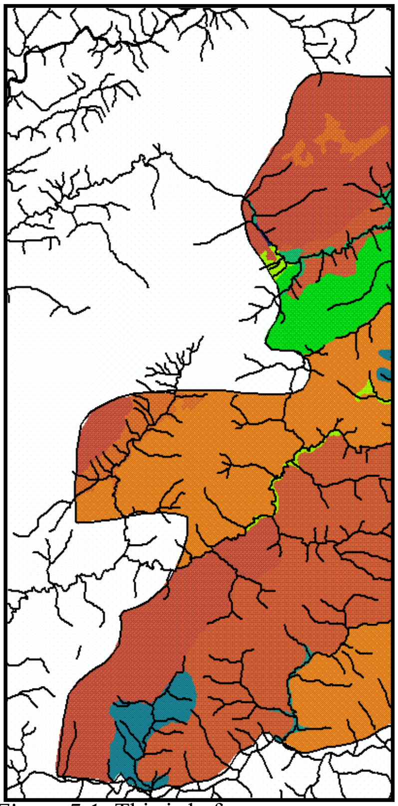
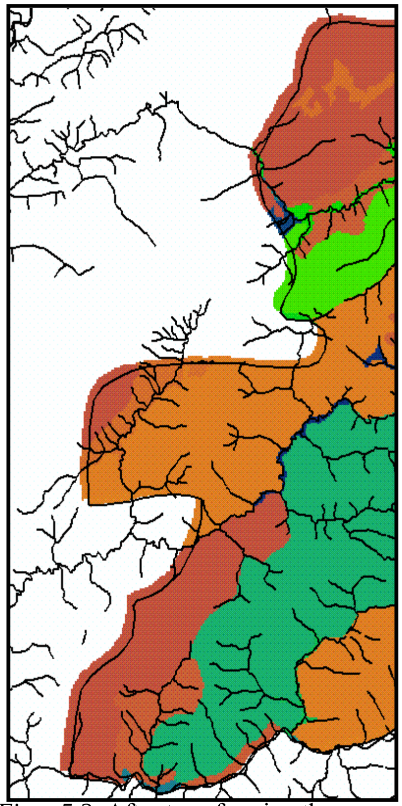


Figure 5.1: This is before transforming any maps. The rivers belongs to the geographic coordinate system Indian Datum 1954, the district boundary to Lao National Datum 1997 and the soils to Indian Datum 1954. As can be seen the rivers follow the soil map very well, which was the reason for us to believe that the soil map belongs to the same system.



Figur 5.2: After transforming the rivers and the soils to Lao National Datum 1997 the soil does not fit to the district boundary anymore. The probable reason for this is that the soil map was done, using a map in Indian Datum 1954 as a background, but on the same time using a district boundary map in Lao National Datum 1997. This makes the soil map being misplaced approximately 500 m.

5.2 Quality of the Climate Data and Calculation of Potential Evapotranspiration

Estimation of potential evapotranspiration is no better than the climate data upon which they are based. There are many factors influencing the quality of the recorded data.

The instrumentation used to measure climate variables could largely influence the data. For example, the accuracy of the sunshine duration, which is most commonly measured with a Cambell-Stokes Heliograph, depends on if the recording paper is placed in the right position according to the relative position of the sun (FAO 1998). Another example is the accuracy of wind speed measurements, which depends on the upwind fetch as well as the instrumentation. A large upwind fetch that is free of building and trees is definitely required for representative measurements. Optimally, these factors should be evaluated to lower the source of error (FAO 1998). This has not been done in this study due to the involved time frame.

Other influences on measurements could be the location of the climate station and the continuity and knowledge of the person in charge of the station. The calculation of potential evapotranspiration is based on the fact that the climate data is measured in environmental conditions that correspond to the definition of reference evapotranspiration. In other words, the data are to be measured above an extensive grass crop that is actively evapotranspiring, or in an environment with healthy vegetation not short of water. This is something we have to assume but undoubtedly nothing we would know for certain. To perform a better study, an evaluation of at least some climate stations should have been done. Microclimatic differences depending on the location of the station also influence how representative the data is since the microclimate differs to the conditions prevailing over the area as a whole. Microclimates could be caused by urban obstacles, which would create local wind systems influencing both wind, and precipitation measurements.

Another factor influencing the accuracy of the calculated potential evapotranspiration is the length of the data series. We had data series varying from five to nineteen years of recorded data, which will strongly influence the quality of the calculations. According to FAO (1998) data series of 30 years should be used. In Lao PDR, like in most developing countries, this does not exist. This means that the long-term variation in climate not is taken into consideration and the result is more or less misleading. Nevertheless, we do think that you have to start somewhere to develop a methodology and further continue to develop better results and increase the accuracy in the future. Furthermore it should be noted that data and resulting maps of climate always are simplifications of the reality, which should be taken into account while using such information. Nevertheless, it is always debatable where the limit goes for if decision makers should use such information at all.

At the stations where climate variables were missing, for example solar radiation, relative humidity or wind speed, we used alternative methods to calculate potential evapotranspiration and corrected this alternative method by calculating a correction factor (see evaluation of alternative methods).

This correction factor was calculated by taking the mean difference between the "real" method and the "alternative" method at the stations. Afterwards a mean correction factor was calculated for all stations. To make a better correction factor a mean difference per station, instead of a mean difference of all stations, should have been used because the factor differs from place to place.

An even more difficult feature is that some stations did not have any solar radiation or relative humidity data at all, which meant that we could not calculate correction factors at these climate stations. This in turn made it impossible to evaluate if the values used to overcome the overestimation was correct at this particular station.

5.3 Interpolation of Climate Variables

To produce more accurate interpolations of temperature, precipitation and potential evapotranspiration the number of climate stations in northern Lao PDR need to increase a lot. The mountainous terrain makes the predictions very complicated since there are pronounced microclimatic differences, as in all mountainous areas. Therefore the climate maps must be regarded as very generalized approximations of the reality, which should be thought of while using them. The maps could probably be accurate enough for national studies but should be improved if using them at district level studies.

Climate data is important for many purposes including prediction of droughts, flooding and erosion hazards etc. These are all related to development issues since they affect the agriculture and therefore the livelihood of people. Consequently the Lao Government and the Development Organizations working in Lao PDR should be highly encouraged to increase the number of climate stations.

5.3.1 Temperature

The temperature interpolation was the climate variable that we thought generated the best results. The reason for this is that the results of the cross validation was better for this variable than the other interpolations. If comparing the cross validation results for temperature with the cross validation results for precipitation there is a large difference. An example of this is the comparison between monthly minimum temperature of januari, with a temperature of 15.5° C and a RMS of 1.18, and precipitation for the same month with mean precipitation of 12.3 mm and a much higher RMS of 4.6 (see figure 4.5 & 4.7). We also found a quite good correlation between temperature and elevation, which made us able to use the elevation as a co-variable. Most climate stations in the northern part of Lao PDR are situated in the valleys but if they were placed at different elevations the correlation could have been even better. This should definitely be taken into consideration when placing new stations. To make an even more accurate prediction surface, the lapse rate should have been based on the calculated laps rate for this particular area, instead of a general laps rate of 0.6. According to Chapman & Danh (1997), it may be convenient to predict temperatures at various elevations using Adiabatic Lapse Rates, but there is no substitute for hard site data, particularly where the terrain is broken and very mountainous, like in northern Lao PDR.

The low values of mean error indicates that mean monthly temperature, mean monthly minimum temperature and mean monthly maximum temperature can be predicted sufficiently accurat with a global polynomial interpolation technique.

The temperature in the area is both dependent on the altitude, the latitude as well as the different monsoon seasons in the areas. The latitude difference between the north and the south is very obvious since it is colder at all stations in the northern part of the area than in the southern part. This latitude difference in temperature is due to the distance to the sun, which is further in the north then in the south. The warmest month also differs from north to south, which is not so obvious. The highest temperature in Northern Lao PDR and China is June and the warmest period in the south is April. This temperature shift could be explained by the south-westerly summer monsoon hitting Thailand and Lao PDR in May before reaching the northern part in June. This means that the cloud cover increase earlier in the south than in the north, which in turn makes the temperature drop.

5.3.2 Precipitation

The precipitation interpolation generated quiet bad results in comparison to the temperature interpolations. The high values of mean error and RMS indicate that the precipitation can not be predicted accurately with a radial basis function, even though it actually gave better results than all the other interpolation methods. The reason for this is the small number of climate stations and the distribution of the stations (most of them in the valleys). The small number of stations made it impossible to use Kriging and the distribution of the points made it impossible to find a correlation with elevation.

The belt of higher precipitation across northern Thailand, Myanmar, Lao PDR, Vietnam and southern China with a concentration in Vang Vieng Lao PDR (see figure 4.6) could be due to the increase in elevation in this area. When the southwest monsoon season hit the area, first passing through the flat delta lands of southern Thailand and Lao PDR, it approaches a mountain chain, which causes forced lifting of the air mass (orographic uplift). This lifting produces cooling and if the air is humid, cloud form, which can cause the increase in precipitation found in this belt. In Viang Vieng there is an especially sharp increase in elevation, which could describe the very high precipitation.

The northeast monsoon season during November to March is mostly visible in the north eastern corner of the area (notice the higher precipitation at Yuanjiang and Viengxay, comparable to Mae Hong Son or Lancang) (see figure 4.1).

5.3.3 Potential Evapotranspiration

The potential evapotranspiration interpolation also generated good results according to the cross validation. The low values of mean error and RMS indicate that potential evapotranspiration can be predicted accurately with a global polynomial interpolation technique. Nevertheless, like the other two climate variables, an increase of climate stations as well as better distribution of them would increase the accuracy significantly. More stations would also increase the chance of finding a correlation to elevation.

The low values of potential evapotranspiration in July and August are probably due to the high precipitation during these months. This leads to increased moisture in the air and less potential evapotranspiration.

During November and December, the air starts to cool but there is still more humidity in the air comparable to the spring months, which leads to a low potential evapotranspiration. The high values in spring are due to the very warm and dry conditions at this time.

5.4 Growing Period Zones

The distribution of growing period zones found in this study is approximately the same as the calculations performed by the FAO (2002). They have growing period days between 180 and 269 with shorter periods in the south than in the north.

The growing period pattern in the area is mainly influenced by the precipitation and the potential evapotranspiration since the temperature is never a limiting factor. In Vang Vieng, the high number of growing period days is due to the extremely high precipitation. In the south the growing period days are slightly less, which could be due to that it is drier hence the precipitation exceeds the potential evapotranspiration divided by two less months of the year.

The growing period and the moisture available for the plants is also affected by the soils drainage ability and water holding capacity. A soil high in clay content will have decreased drainage ability in the beginning of the growing period and a high water holding capacity in the end of the growing period. A sandy soil on the other hand works the opposite way with a high drainage ability, and a low water holding capacity. To make a better estimation of the growing period the spatial distribution of the soils water holding capacity should have been taken into consideration. By doing so, the growing period should probably have been extended a few more weeks. Due to limitations in soil data this could not be done. Nevertheless FAO have a methodology to perform this (www.5).

The mountainous terrain makes the predictions of growing period zones very complicated. There should have been a great deal more growing period zones if elevation was taken into consideration, while interpolating the climate variables precipitation and evapotranspiration. This simplification of the growing period zones causes the maps to be very generalized approximations of the reality. The maps are accurate enough if using them for national studies but more information is needed to produce a good zoning of Phonxay District.

5.5 Agro-Ecological Zones in Phonxay District

The soil and the topography are the two main factors affecting the agro-ecological zones and the potential for agriculture in Phonxay District. The reason for this is that the temperature never is a limiting factor and the growing period does not differ much from east to west.

According to FAO (2000) the leptosols (zone 6, 9, 10,13, and 16) are less fertile then the Acrisols (zone 1, 2, 4, 7, 11 and 14) and the Cambisols (zone 3, 5, 8, 12, and 15). Therefore, large scale agricultural production in these zones should be avoided. Cambisols is according to FAO (2000) slightly more fertile then Acrisols, hence agricultural production in zone 3, 5 and 8 should be encouraged. Class 12 and 15, which are also Cambisols, are most probably to steep for agricultural production. Nevertheless, many of these steep areas could be used for forestry and conservation areas. The zones 1, 2, 4 and 7 with Acrisols and steepness between 0-30 % should also be considered potential land for large scale agricultural production.

The two conservation areas within the district are situated in zones that are either very steep or belongs to a low fertility soil. This distribution seems logic both from a biological point of view and from an agricultural view. The motivation for this is that the biodiversity often is bigger in areas of great topographic differences. Furthermore, we believe that land with any potential for agricultural production should be set aside since people are starving and agricultural land within the district is very limited.

According to the forestry law of Lao PDR, the main purpose of the conservation forests is to protect and conserve the animal species, plant species, environment, and for educational and scientific research values. Considering the very small amount of forest in the whole area (see figure 5.3) we think that, to accomplish the goals of the conservation areas, it is exceedingly important to protect and increase the forest in these areas.

The purpose of the protection forests is to protect the watershed areas and to protect the land against soil erosion (The Forestry Law Lao PDR). In these zones very little forest was left in 2000 (see figure 5.3). To stop erosion, as well as to protect watershed areas, forest is very importance. An increase in forest within the protected areas is therefore a must.

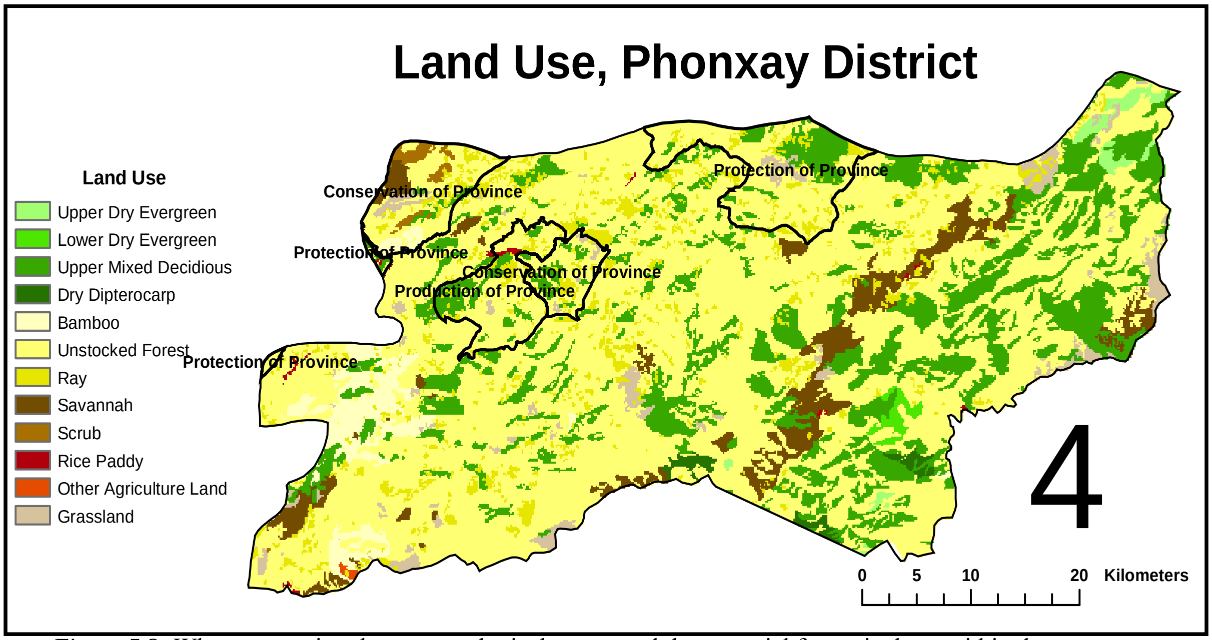


Figure 5.3: When comparing the agro-ecological zones, and the potential for agriculture within them, to the Land Use map from 2000 we noticed that, an extremely small amount of land is used for rice paddy production or other agricultural production even though larger areas have agricultural potentials.

When comparing the agro-ecological zones, and the potential for agriculture within them, to the land use of 2000 we noticed that extremely small amounts of land is used for rice paddy production or other agricultural production (see figure 5.3), even though larger areas have agricultural potentials. This is mostly evident in the large piece of land stretching across the district (green and yellow in figure 4.9), which does not seem to be used for agriculture at all even though great potentials exist. According to the land use map this stretch of land is classified to be Savannah, Upper Mixed Deciduous Forest or Unstocked Forest (see figure 5.3). We are very skeptical to if its savannah at all, since savannah according to this classification scheme should be situated in areas where the soil conditions are unsuitable for agriculture. Our agro-ecological zones, however, gave the opposite result.

The consensus of this comparison is that land use planning within Phonxay evidently is very important since the distribution of land use classes does not follow the lands potential for agriculture. Considering the growing population and the lack of food in Phonxay, we believe that it is necessary to use the land for what it has the greatest potential for.

We therefore think that:

- Low lying lands with fertile soils should be used for intensive agricultural production.
- To limit erosion and increase biodiversity, steep lands should be used for forestry or set aside to conservation or protected areas.

5.6 Zones of Soil and Terrain Constraints in Phonxay District

The limitation in this analysis is, like in most other analysis in this study, the accuracy of the data used. The soil map is quite detailed but is only based on soil samples with one pit per 60 Ha. There is neither any kind of accuracy assessment available. This means that the map of soil and terrain constraints should be used as a general indicator.

Similarly to the agro-ecological zones this analysis gave a quite large area stretching across Phonxay with great potential for agricultural production (see figure 4.10 Slight Constraints and No Constraints). Overall Slight Constraints and No Constraints make up approximately 32 % (70 000 ha) with most of it situated in this stretch of potential agricultural land. According to the land use map, very little or none of this land is used for intensive agriculture, but should in the future definitely be encouraged.

5.7 Suitability Rating for Bananas and Pineapples in Phonxay District

The limitation of this analysis is also related to the data quality. Some of the requirement variables, like the soil depth, the base saturation, the soil fertility etc, are very subjective considering the low level of details in the soil map. Therefore, the suitability analysis should be used as a general overview or guideline. If there is interest in one specific crop, for example pineapple, one could perform such an analysis and afterwards use it as a first field indicator of where this crop could perform the best. Nevertheless, this could never replace the importance of thorough fieldwork studies where farmers are involved to make decisions. Farmers usually have an excellent understanding of their biophysical environment, which is nearly impossible to be captured by different kind of analysis and land resource professionals. Therefore we think that local knowledge is complementary to scientific knowledge and that the integration between them is extremely important. Furthermore we believe that it is important that decision makers do not get the impression that this analysis could be used as an absolute finished product, since this could result in wrong decisions taken in regards to an areas agriculture.

This study has further demonstrated that Bananas and Pineapples suitability classification in the area corresponds well with the zones of constraint and the agro-ecological zones. Where suitability is high for the two crops, the zones of constraint are classified to No or Slight constraint.

5.8 The Socio-Economic and Demographic Situation in Phonxay District

The total population in Phonxay District in 2003 was 23 541, of which 50.4 % (11 867) were women and 49.6% (11 674) were men. However, the statistics from year 2003 only covers some of the villages. This might be because villages have emerged or because there are no information from these villages.

In 2000 the population in the district was 27 156, which indicates that not all villages were surveyed in 2003, since it is very likely that the population would have grown over the three years as can be seen between 1995 and 2000 with a population increase of 3 570 people (23 586 in 1995 and 27 156 in 2000).

The age distribution in the district is typical of many developing countries, with a large young population and a very small old population. It is likely that Lao PDR is in the beginning of a demographic transition with high birth and death rates. This leads to a rapid population increase and further into the transition the death rates decreeses but the birth rates stay the same. The number of people in Phonxay is going to keep increasing even if the total fertility rate (TFR, the average number of children born during a women's reproductive years) decreases rapidly. This is because of the population momentum where a large number of women are in or entering their childbearing years.

The population growth rate in Lao PDR is 2.5 %; in Phonxay it is 5 % between 1995 and 2000, twice as high. This might be because Phonxay is more rural and therefore not yet as developed as other parts of the country, since development usually leads to a lower TFR. In Phonxay, women traditionally bear more children and at a younger age (19-20 years). However, it is also possible that the data is incorrect.

The infant mortality rate for Phonxay District is 118.9. This rate is very high compared to the rest of Lao PDR with an average IMR of 88.94 according to the Geography IQ (www.6). The highest IMR in the world is in Mozambique with 199 and the lowest is in Iceland with 3.30. The highest IMR for a single village in Phonxay is 579, more than half of the infants died. The high IMR in Phonxay district can be due to malnutrition, epidemics, accidents, and low healthcare density for example.

On a country basis, the Buddhist religion is the largest with 65 % of the total population and Animist comes second with 33%. In Phonxay, it is the other way around with 90 % being Animist and only 9.6 % being Buddhist. This is probably because the Buddhist religion has not yet spread from the rest of the country into the district. During our field stay, we did not see any temples or monks.

69 % of the population in Phonxay either work without pay or work for themselves. It is hard to know which category includes housework and farming since no guidelines were available. Most of the farms in the district are self-sustained with food, seeds for sowing, building material and some even with cloths. In the very poor households self-sustainability is a problem since the harvest might not be large enough and the seeds for sowing have to be eaten to avoid starvation.

According to UNESCO's Institute of Statistics (www.7) the literacy rate in Lao PDR is between 30 and 50 %. In Phonxay the average literacy rate is 34 %, which is in the lower part of the scale, and many of the villages have a much lower literacy rate. The adult literacy according to UNDP and the National Statistic Centre is 60 % in Lao PDR. The difference compared to the estimates done by UNESCO is probably caused by age differences (for example the reading and writing ability in Phonxay district is estimated for people older than six).

When comparing the village population size and the poverty level we found that a large number of villages were classified as high poverty and that many villages were small. This might have caused the results to be misleading since most of the villages were therefore classified as small and having high poverty.

None of the Lao Soung villages have been classified as low poverty and 90 % of them are classified as high poverty. For the Lao Toung 77 % of the villages are high poverty villages. This could be because most villages are Lao Toung and most villages are classified as high poverty.

Half of the villages classified as low poverty are mixed villages and half are Lao Toung. When looking at the structure within the ethnicity groups, 29 % of the mixed villages are classified low poverty compared to 7 % of the Lao Toung. A very little part of the mixed villages are severely poor compared to villages with only one ethnicity. This might be because more governmental resources have been available for these villages and because they are more often located near a road. Unfortunately, we do not know the poverty indicators used to classify the poverty level of the villages in the district. If we had, we would probably have been able to draw more conclusions.

The Lao Soung are the ethnic group with lowest literacy. 69 % of the villages have a literacy rate below 30 %. Of the mixed villages however 62.5 % have a literacy rate above 50 % and only 12.5 % have a literacy rate below 30 %. As said earlier, this might be because of more governmental financial aid and resources. None of the Lao Soung villages had a literacy rate above 50 %. Most of the Lao Toung villages had a literacy rate between 30-50 %.

90 % of the high poverty villages had a CDR below 37. This might be because of the division in the CDR, where most villages fall in the category below 37 and also because most villages are classified as high poverty. None of the villages with a low poverty level had a CDR higher then 37. This indicates that these villages are better of in a number of ways; for example they might have access to medical centres, schools, and no malnutrition. It might also be that CDR is one of the indicators used when classifying poverty.

When comparing ethnicity and CDR, the Lao Toung villages are the only ones with a CDR higher then 70. They also have the largest number of villages with a CDR below 37. Again this could be because a larger number of villages are Lao Toung and a larger number have a CDR below 37.

When looking at road access it becomes obvious that none of the high poverty villages are classified urban and that more then 70 % of them are without access to a road. For the medium poor villages 50 % have road access and 10 % are classified urban, the last 40 % are without road access. Again this might be because most villages are severely poor and most villages have no road access. It is also possible that road access was used when classifying poverty level.

From an ethnical point of view it is only the mixed villages that have been classified urban. 73 % of the Lao Toung villages are without road access compared to 58 % of the Lao Soung. This might be because many of the Lao Toung villages are located in more remote areas.

62 % of the mixed villages have road access and 25 % are classified urban. It is likely that the government have organised for the mixed villages to get road access.

A large portion of the village's classified as high poverty had a literacy rate below 50 %. Only 8 % had a literacy rate above 50 %, 49 % had a literacy rate between 30-50 % and 43 % had a literacy rate below 30%. In the low poverty villages, the literacy rate is above 30 % in all villages. In the medium poverty and the low poverty villages, 50 % had a literacy rate above 50 %. It is possible that the literacy rate has been an indicator when classifying the poverty status.

When comparing the zones of constrains with the villages poverty level, we found that more villages classified as high poverty villages were situated in severe constraints zones then low poverty villages. This is rather expected since zones of severe constraint have no or very little potential for agriculture, which in turn could lead to high poverty. Nevertheless, this result could also be caused by that there are more high poverty villages then low poverty villages. This leads to that the "chance" of falling in this group is larger. To perform a more statistically correct analysis the number of villages within the three poverty groups should be the same. This was not possible in Phonxay.

When comparing the ethnicity of the villages and the zones of constraints we found that more Lao Toung villages were situated in zones of severe constraints then the other two ethnic groups. This result could be caused by that there are more Lao Toung villages than Lao Soung and Mixed villages. When comparing the internal structure of the three groups, the mixed villages have the highest share of villages falling into zones of severe constraints.

When comparing the road access of the villages with the constraint zones we found that a large part of the villages, that are situated in zones of no constraints or slight constraint, do not have any road access. This is rather inconvenient since roads are a necessity to transport goods to the market. This lack of roads could further be a reason that the large stretch of land, mentioned earlier as very potential for agricultural production, is not used for agricultural purposes. Therefore, construction of roads should be part of land use planning to easier specify where roads should be prioritized. In Phonxay roads should probably be prioritized towards the area in the middle, which belongs to the zones of slight or no constraints. However, roads could be equally important in other areas where people have other life strategies, which also need transport to the market. Therefore this matter has to be further analyzed before major decisions are taken.

6 Conclusion

6.1 The Land Resource Database

The land resource database created in this study consists of spatially distributed data including maps of potential evapotranspiration, temperature, precipitation, soil, terrain, land use, district boundaries, roads, rivers, villages, growing period zones, zones of constraint, agro-ecological zones and suitability maps for bananas and pineapples. All these maps are within the geographic coordinate system "Lao National Datum 1997". Additionally, the database contains socio-economic and demographical data, which is spatially tied to the village points. The diversity of the database, the fact that data belongs to the same coordinate system and that most variables cover the whole of northern Lao PDR makes the applicability enormous. The GIS analysis done within this study could easily be repeated for other districts covered by the database.

The main problem with the agro-ecological zoning assessment methodology is that the methodologies, objectives and data sets used in different studies can be quite different, which results in completely different results. The term agro-ecological zones are also used indiscriminately in the literature, covering agro climatic zones, or even crop suitability zones. This wide spread use of the methodology and the changeable definitions makes it rather confusing for a first time user and emphasize the importance of detailed documentation of methodology and data.

The limitation of the land resource database is influenced by the accuracy of the input variables and the accuracy of the operations performed (transformations, calculations of evapotranspiration, interpolations).

In Lao PDR there have been many geographic coordinate systems in use and the data we collected belonged to five of them. Several difficulties were present while transforming the data, which affects the accuracy. These include, the absence of documentation about data, difficulty in defining to what system the maps belonged to, and the fact that we were restricted to a three parameters transformation method.

Estimation of potential evapotranspiration is no better than the climate data upon which they are based. There are many factors influencing the quality of the recorded data including, instrumentation and situation of the climate station, the person in charge of the measures and the length and variability of the data series. The short data series in Lao PDR leads to that long-term climatic changes is not taken into consideration.

The mountainous terrain and the large microclimatic differences in northern Lao PDR makes interpolation of temperature, potential evapotranspiration and precipitation very difficult. A global polynomial interpolation technique gave the best result when interpolating temperature. The strong correlation found between temperature and elevation further improved the interpolated surface model by adjusting the interpolated sea level temperatures to the topography.

A global polynomial interpolation technique also gave the best results when interpolating evapotranspiration. For this variable there was no gain from using elevation as a co-variable since no correlation could be found. A radial basis function gave the best results when interpolating precipitation. No correlation with elevation was found with this variable either. To improve the accuracy of the interpolated climate variables, the number of climate stations and the number of years of recorded data need to increase. The interpolations could further be improved by distributing the climate stations at different elevations, which would increase the possibility to find correlations between potential evapotranspiration, precipitation and elevation.

To increase the quality of the soil map a correction regarding the offset needs to be done, more samples need to be taken and an accuracy assessment should be performed.

The limitation of the socio-economic and demographic data is largy influenced by the carefulness during data collection, which could make statistic calculations unreliable. In some instances, for example, information is missing for part of the year, for a full year or even for a whole village. Moreover, the system of classification for some of the socio-economic variables is unknown.

This study shows that to increase the accuracy of the land resource database, the Lao PDR need an increase of both quality and amount of input data. Today the database must be regarded as very generalized approximations of the reality, which should be thought of while using it. The maps are good enough for large-scale studies but should be improved to give accurate results at district level studies.

Our consensus as a whole is that the land resource databases and a Geographical Information Systems (GIS) is invaluable, in planning and management of land resources, to ensure that land is allocated to the use providing the greatest sustainable benefit. The database is especially valuable while improving the interaction between farm level management and district level management since decisions should be based on a holistic view. However, the database should never replace the importance of a thorough field visit were farmers are involved to make decisions. Local knowledge is complementary to scientific knowledge and the integration between them is the main key to success.

6.2 Key Findings in Phonxay District

This study shows that the mean annual temperature in Phonxay varies between 14-25° C depending on the elevation. The warmest month of the year is June with a mean air temperature of 16 to 28° C and the coldest month is January with temperatures of 9 to 21° C. The mean annual precipitation is 1 380 to 2 780 mm/year depending on were you are in the district. The south eastern part generally receives more precipitation than the north western part. The monthly average of potential evaprtranspiration within Phonxay varies from 3.2-3.4 mm day^{-1}, being the highest in March and the lowest in December.

According to this study, Phonxay is divided into two zones of growing period. The eastern part has 245 days and the western part 214.

The agro-ecological zoning gave 16 distinct zones, in which seven of the zones have great potential for agricultural production. The other zones are either to steep or have soils not fertile enough for productive agriculture. When comparing the agro-ecological zones with the present land use map, the results shows that, even though quite large areas have great agricultural potentials, only small areas are used for such.

The constraint zones showed that 31.7 %, or approximately 70 000 ha of land in Phonxay, was suitable for agriculture, being classified to zone of slight or no constrains.

The comparison between land use and both agro-ecological zones and constraint zones indicates that an increase of forest is needed to accomplish both the goals of the conservation and the protection areas as well as to accomplish Luang Phrabang's Development Goal of 2000. The comparison further lead us to believe that the distribution of land use classes in Phonxay does not follow neither the lands potential for agriculture nor the need of protection. This together with the fact that the population in Phonxay is growing should further highlight the increasing need of future land use planning within the district. The agro-ecological zoning and the zones of constraints within this study could therefore be used as a guide for further field studies to more precisely identify potential land for both agriculture and conservation purposes.

One of the reasons for that potential land is not used for agriculture could be the absence of roads in these areas. The relationship between zones of constraints and road access shows that 70.6 % of the villages situated in zones of no constraint or slight constraints (potential for agriculture) have no roads. This leads to that transport of products to the market is impossible. The agro-ecological zoning and the zones of constraints could therefore be used as a guidance in future planning of roads within the district. We suggests that roads should be prioritized towards the area in the middle eastern part of the district, situated in areas of no or slight constraints, with the greatest potential for agriculture.

This study has demonstrated that bananas and pineapples suitability classification in the area corresponds well with the zones of constraint and the agro-ecological zones. Where suitability is high for the two crops, the zones of constraint are classified to no or slight constraint.

The demographic analysis in this study showed that the population growth in Phonxay between 1995 and 2000 was 5 % annually and that the total population in 2003 was 23 541 persons.

According to UNESCO's Institute of Statistics (www.7), the literacy rate in Lao PDR is between 30 and 50 %. In Phonxay the average literacy rate is 34 %, which is in the lower part of the scale, and many of the villages have an even lower literacy rate. The Lao Soung are the ethnic group with lowest literacy 69 % of the villages have a literacy rate below 30 %. Of the mixed villages however, 62.5 % have a literacy rate above 50 % and only 12.5 % have a literacy rate below 30 %. In general the villages with a mixed ethnic population seems to be better of then other villages. This might be because more governmental resources have been available for these villages and because they are more often located near a road.

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8 Appendix

8.1 Geographic Coordinate Systems and Transformations; Terminology in ESRI'S GIS Software

A geographic coordinate system (GCS) uses a three dimensional spherical surface to define locations on the earth. A GCS is often incorrectly called a datum, but a datum is only one part of a GCS. A GCS includes an angular unit of measure, a prime meridian, and a datum (based on a spheroid) (Environmental Systems Research Institute, Inc 1994-2000).

A point is referenced by its longitude and latitude values. Longitude and latitude are angles measured from the earth's center to a point on the earth's surface. The angles are often measured in degrees (see figure 8.1).

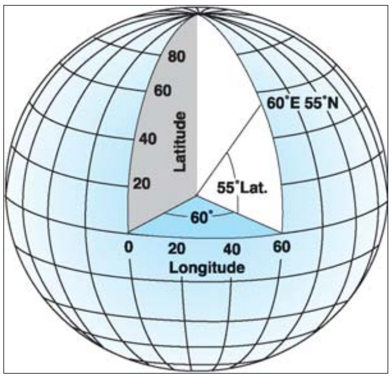

Figure 8.1: A point is referenced by it's longitude and latitude values. Longitude and latitude are angles measured from the earth's center to a point on the earth's surface. The angles are often measured in degrees or in grads (Environmental Systems Research Institute, Inc 1994-2000).

In the spherical system, 'horizontal lines', or east–west lines are lines of equal latitude, or parallels. 'Vertical lines', or north–south lines, are lines of equal longitude, or meridians. The line of latitude midway between the poles is called the equator. It defines the line of zero latitude. The line of zero longitude is called the prime meridian. For most geographic coordinate systems, the prime meridian is the longitude that passes through Greenwich, England (Environmental Systems Research Institute, Inc 1994-2000). Latitude and longitude values are traditionally measured either in decimal degrees or in degrees, minutes, and seconds (DMS). Latitude values are measured relative to the equator and range from -90° at the South Pole to +90° at the North Pole. Longitude values are measured relative to the prime meridian. They range from -180° when traveling west, to +180° when traveling east.

The spherical system assumes that the Earth is a perfect sphere. Unfortunately this is not correct. The earth is actually an oblate spheroid with flatter poles (see figure 8.2). To complicate matters further the surface of earth is far from smooth and regular (Environmental Systems Research Institute, Inc 1994-2000).

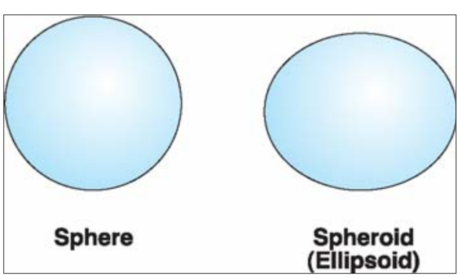

Figure 8.2: A representation of earth as a sphere or a spheroid (Environmental Systems Research Institute, Inc 1994-2000).

Ellipsoid models use the major and minor axes of the earth and mathematically account for flattening at the poles (see figure 8.3).

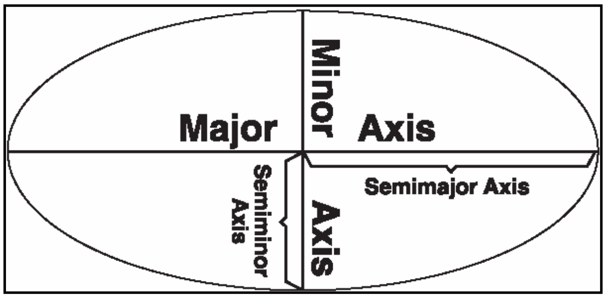

Figure 8.3: Ellipsoid models use the major and minor axes of the earth and mathematically account for flattening at the poles (Environmental Systems Research Institute, Inc 1994-2000).

For historical and other reasons there are several such ellipsoids in use for mapping different countries of the world. Each of these ellipsoids is generally matched to one or several countries. An ellipsoid appropriate for one region of the earth is not always appropriate to other regions (Lao National Geography Department 1997).

Another property is needed to uniquely specify geographical positions. This is the position and orientation of the ellipsoid relative to the earth. The term used to describe this fitting of an ellipsoid to the earth is the geodetic datum. Many geodetic datums exist throughout the world, usually defined by the national survey of a particular country or continent. More recently several new geodetic datums have been successively derived, from steadily accumulating satellite and other data, to provide for a best worldwide fit (Environmental Systems Research Institute, Inc 1994-2000).

A local datum aligns its spheroid to closely fit the earth's surface in a particular area. A point on the surface of the spheroid is matched to a particular position on the surface of the earth. This point is known as the origin point of the datum. The coordinates of the origin point are fixed, and all other points are calculated from it. The coordinate system origin of a local datum is not at the center of the earth. The center of the spheroid of a local datum is offset from the earth's center (see figure 8.4). Because a local datum aligns its spheroid so closely to a particular area on the earth's surface, it is not suitable for use outside the area for which it was designed. The Lao national datum 1997 is an example of a local datum, which has a spheroid with a good approximation to the size, and shape of the sea-level surface in the region of Lao PDR.

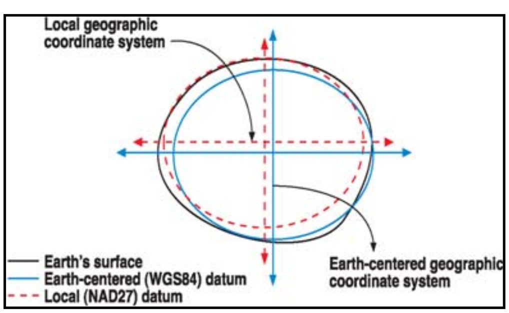

Figure 8.4: A local datum aligns its spheroid to closely fit the earth's surface in a particular area. A point on the surface of the spheroid is matched to a particular position on the surface of the earth. This point is known as the origin point. The coordinates of the origin point are fixed, and all other points are calculated from it. The coordinate system origin of a local datum is not at the center of the earth. The center of the spheroid of a local datum is offset from the earth's center (Environmental Systems Research Institute, Inc 1994-2000).

In Lao PDR there have been several different geographic coordinate systems or "Datums" used, including Indian Datum 1954, Indian Datum 1960, Vientiane Datum 1982, Lao Datum 1993, WGS 84 and the new Lao National Datum 1997.

A projected coordinate system is any coordinate system designed for a flat surface such as a printed map or a computer screen. Whether you treat the earth as a sphere or a spheroid, you must transform its three-dimensional surface to create a flat map sheet. This mathematical transformation is commonly referred to as a map projection. A map projection uses mathematical formulas to relate spherical coordinates on an ellipsod to flat, planar coordinates. There are three main ways to project a map: Azimuthal or Planar Map Projections, Conical Map Projections and Cylindrical Map Projections.

8.2 Geographic Coordinate systems used in Lao PDR

The Information in this section is received from the National Geography Department of Lao PDR.

8.2.1 The Lao National Datum 1997, Definition and Parameters

Spheroid	**Krassovsky (a = 6378245.000, b = 6356863.018)**
Origin Station	**Vientiane (Nongteng) Astro Pillar (36201)**
Latitude	**N 18° 01' 31.3480"**
Longitude	**E 102° 30' 57.1367"**
Spheroidal Height	**223.824 meters**

Note:

- The latitude and longitude of the origin station are derived from the 1982 Soviet astronomic observation, which defined the Vientiane (1982) datum. The 1982 observations were taken at the original Nongteng ground mark rather than the newer astro pillar.

  The original ground mark still exists but is surrounded by the structure of a tower, making it unsuitable for GPS observations. The astro pillar, which is approximately 15 meters from the original mark, has been connected to the original station. Vientiane datum (1982) coordinates have been calculated for the astro pillar and adopted as the Lao National Datum 1997 origin values.

- The spheroidal height has been defined as being equal to the mean sea height for the station. The geoid-spheroid separation at Vientiane (Nongteng) Astro Pillar is therefore zero.

- The Cartesian coordinate axes of the Lao National Datum (1997) are defined as being parallel to those of WGS 84.

8.2.2 Parameters for WGS 84, and the Relationship to Lao National Datum 1997

WGS 84 coordinates for stations in Laos have been derived using GPS technology and a series of 25 GPS point positions were observed, at network stations distributed throughout the country.

The WGS 84 coordinate values for Vientiane (Nongteng) Astro Pillar are as follows.

Spheroid	**GRS 80 (a = 6378137.000, b = 6356752.314)**
Latitude	**N 18° 01' 31.56303"**
Longitude	**E 102° 30' 56.62368"**
Spheroidal Height	**188.851 meters**

The transformation parameters to be added to Lao national datum 1997 Cartesian coordinates to produce WGS 84 Cartesian coordinates are:

ΔX = +44.585 meters
ΔY = -131.212 meters
ΔZ = -39.544 meters

To transform WGS 84 coordinates to Lao National Datum 1997, reverse the signs on the three transformation parameters before applying.

The Global Positioning System GSP generates positions in WGS 84 coordinate system. These GPS point coordinates will have a significant difference compared to Lao 1997 coordinates and a transformation is usually needed. There is one exception from this:

GPS baselines, which are output as XYZ vectors, may be directly used in conjunction with Lao National datum 1997 Cartesian coordinate if the vector is in XYZ format. Any vector expressed in terms of latitude, longitude and height must go through a transformation process. The direct use is possible because the axes of the Lao datum are parallel to those of the WGS 84 system.

8.2.3 Parameters for Vientiane Datum 1982, and the Relationship to Lao National Datum 1997

The Vientiane Datum 1982 was established to support survey work undertaken in cooperation with the Soviet Union. It is defined by the following parameters:

Spheroid	**Krassovsky (a = 6378245.000, b = 6356863.018)**
Origin Station	**Vientiane (Nongteng)**
Latitude	**N 18° 01' 31.6301"**
Longitude	**E 102° 30' 56.6999"**
Spheroidal Height	**223.56 meters**

Note:

- The latitude and longitude of the origin station are derived from the 1982 Soviet astronomic observation. The spheroidal height has been defined as being equal to the mean sea height for the origin station. The geoid-spheroid separation at Vientiane (Nongteng) Astro Pillar is therefore zero.

- The transformation parameters to be added to Lao National Datum 1997 Cartesian coordinates to produce Vientiane datum 1982 Cartesian coordinates are:

ΔX = +2.227 meters (Standard Error = 0.79 meter)
ΔY = -6.524 meters (Standard Error = 1.46 meter)
ΔZ = -2.178 meters (Standard Error = 0.79 meter)

To transform Vientiane Datum 1982 coordinates to Lao National Datum 1997, reverse the signs on the three transformation parameters before applying.

Note:

- The horizontal displacement between the two coordinate systems is approximately 3 meters. This is insignificant at map scales of 1:5 000 or smaller. The existing 1:100 000 and 1:250 000 topographic mapping provided under technical assistance from the Soviet Union are therefore unaffected.

- The parameter generation assumed that Vientiane Datum 1982 spheroidal heights were the same as mean sea level height in all parts of Laos. As this assumption is incorrect, extreme caution should be exercised when interpreting transformed height information.

8.2.4 Parameters for Indian Datum 1954, and the Relationship to Lao National Datum 1997

The Indian datum was introduced to Lao PDR in 1967/68. Its purpose was to support survey for a hydropower project on the Mekong River. The datum is believed to have been an extension of the Thai datum at that time. It appears only to have been used in the vicinity of Vientiane.

There is no specific origin station for the datum but it’s spheroid is:

Everest 1830 (a = 6377276.345, b = 6356075.413)

In the vicinity of Vientiane, the transformation parameters to be added to Lao National Datum 1997 Cartesian coordinates to produce Indian Datum 1954 Cartesian coordinates are:

ΔX = -168.711 meters (Standard Error = 0.034 meter)
ΔY = -951.115 meters (Standard Error = 0.034 meter)
ΔZ = -336.164 meters (Standard Error = 0.034 meter)

To transform Indian Datum 1954 coordinates to Lao National Datum 1997, reverse the signs on the three transformation parameters before applying.

Note:

- The effect of the transformation is very large on all mapping scales up to 1:1 000 000 (approximately 400 meters in horizontal position). Map users in the Vientiane area should exercise caution.

- The transformation parameters are not valid outside the Vientiane area.

8.2.5 Parameters for Indian Datum 1960, and the Relationship to Lao National Datum 1997

This datum is understood to have been extensively used to support U.S. sponsored 1:50 000 mapping between 1963 and 1975. France established the mapping utilised control in 1902. However it is not clear whether France originated the Indian Datum 1960 or whether the control values were recomputed by other agencies.

It is considered unlikely that any French control marks still exist. Consequently, it has not been possible to compute new transformation parameters as part of the Lao National Datum Project. Parameters relating Indian Datum 1960 to WGS 84 have been obtained from the U.S. National Imagery & Mapping Agency (NIMA).

They have been combined with the parameters relating Lao National datum 1997 to WGS 84 to provide the following estimates:

The spheroid used is:

Everest 1830 (a = 6377276.345, b = 6356075.413)

The transformation parameters to be added to Lao National Datum 1997 Cartesian coordinates to produce Indian Datum 1960 Cartesian coordinates are:

ΔX = -153 meters
ΔY = -1012 meters
ΔZ = -357 meters

The accuracy of these parameters is unknown. To transform Indian Datum 1960 coordinates to Lao National Datum 1997, reverse the signs on the three transformation parameters before applying.

Note:

- The effect of the transformation is very large on all mapping scales up to 1:100 000 (approximately 400 meters in horizontal position). Map users should exercise caution.

8.3 Derivation to the Penman Monteith Combination Method

8.3.1 Penman method

In 1948, Penman published the first of what has become known as combination methods (Burman & Pochop 1994). This method combined the theoretical energy balance with an empirical wind function (Burman & Pochop 1994). The Penman equation have been further developed by many researches and extended to cropped surfaces by introducing resistance factors (FAO 1998). The Penman method was generalized to a significant extent by Monteith. Monteith's variation of the Penman method involves the use of a plant resistance parameter and a more general use of an aerodynamic resistance parameter (Burman & Pochop 1994). The aerodynamic resistance, r_a, describes the resistance upwards from the vegetation and involves friction from air flowing over vegetative surfaces (FAO 1998) (see figure 8.5).

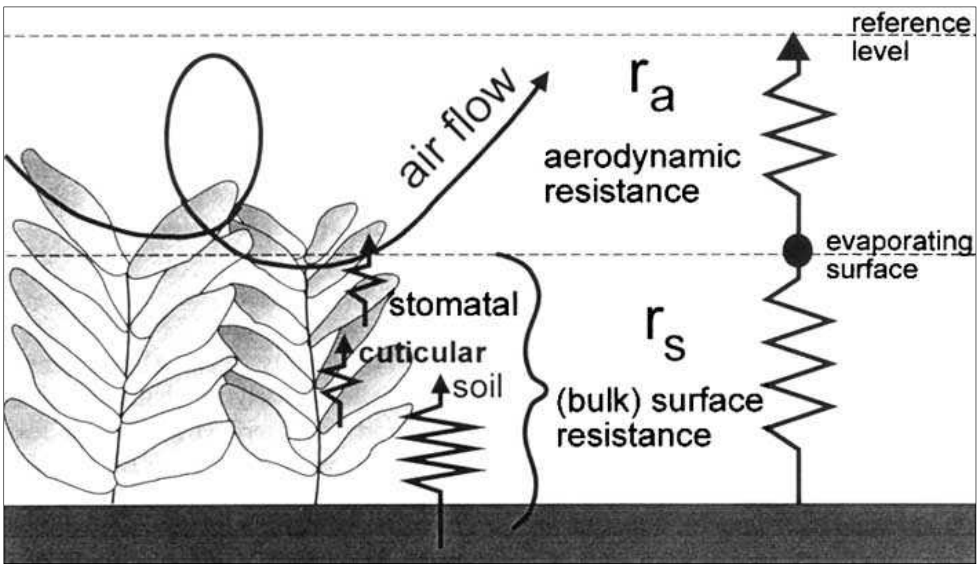

Figure 8.5: The aerodynamic resistance, r_a, describes the resistance from the vegetation upward and involves friction from air flowing over vegetative surfaces (FAO 1998).

$$r_a = \frac{\ln\left[\frac{z_m - d}{z_{om}}\right]\ln\left[\frac{z_h - d}{z_{oh}}\right]}{k^2 u_z}$$

r_a Aerodynamic resistance [s m^{-1}]
z_m Height of wind measurements [m]
z_h Height of humidity measurements [m]
d Zero plane displacement height [m]
z_{om} Roughness length governing momentum transfer [m]
z_{oh} Roughtness length governing transfer of heat and vapour [m]
k Von Karman's constant 0.41 [-]
u_z Wind speed at height z [m s^{-1}]

According to FAO (1998) the equation is restricted to neutral stability conditions where the atmospheric parameters follow nearly adiabatic conditions. The factors z_{om} *and* z_{oh} depend upon the crop height and architecture and there are, according to FAO, many equations to estimate the values. The aerodynamic resistance for the grass reference surface have been derived by FAO as can be seen in Box 1:

BOX 1. The aerodynamic resistance for a grass reference surface.

For a wide range of crops the zero plane displacement height, d [m], and the roughness length governing momentum transfer, z_{om} [m], can be estimated from the crop height h [m] by the following equations:

$d = 2/3\ h$

$z_{om} = 0.123\ h$

d Zero plane displacement height [m]
h Crop height [m]
z_{om} Roughness length governing momentum transfer [m]

The roughness length governing transfer of heat and vapour, z_{oh} [m], can be approximated by:

$z_{oh} = 0.1\ z_{om}$

z_{oh} Roughness length governing transfer of heat and vapour [m]
z_{om} Roughness length governing momentum transfer [m]

Assuming a constant crop height of 0.12 m and a standardized height for wind speed, temperature and humidity at 2 m ($z_m = z_h = 2$ m), the aerodynamic resistance r_a [s m^{-1}] for the grass reference surface becomes:

$$r_a = \frac{\ln\left[\frac{2-2/3(0.12)}{0.123(0.12)}\right]\ln\left[\frac{2-2/3(0.12)}{(0.1)0.123(0.12)}\right]}{(0.41)^2 u_2} = \frac{208}{u_2}$$

r_a Aerodynamic resistance [s m^{-1}]
u_2 The wind speed [m s^{-1}] at 2 m.

The"bulk" surface resistance, r_s, describes the resistance of vapour flow through stomata openings, total leaf area and soil surface (FAO 1998) (see figure 9.5). According to FAO an acceptable approximation to a much more complex relation of the surface resistance of dense full vegetation cover is:

$$r_s = \frac{r_l}{LAI_{active}}$$

r_s (Bulk) surface resistance (crop specific) [s m^{-1}]
r_l Bulk stomatal resistance is the average resistance of an individual leaf [s m^{-1}]
LAI_{acrive} Active sunlit leaf area index [m^2 (leaf are) per m^2 (soil surface)]

The "bulk" surface resistance, r_s for the grass reference surface have been derived by FAO (1998) (see box 2):

BOX 2. The (bulk) surface resistance for a grass reference crop.

A general equation for LAI_{active} is:

LAI_{active} = 0.5 LAI

LAI_{acrive} Active sunlit leaf area index [m^2 (leaf are) per m^2 (soil surface)]
LAI Leaf Area Index [m^2 m^{-2} or dimensionless]

which takes into consideration the fact that generally only the upper half of dense cut grass is actively contributing to the surface heat and vapour transfer. For cut grass a general equation for LAI is:

LAI = 24 h

LAI Leaf Area Index [m^2 m^{-2} or dimensionless]
h Is the crop height [m]

The stomatal resistance, r_l, of a single leaf has a value of about 100 s m^{-1} under well-watered conditions. By assuming a crop height of 0.12 m, the surface resistance, r_s [s m^{-1}], for the grass reference surface becomes:

$$r_s = \frac{100}{0.5(24)(0.12)} \approx 70 sm^{-1}$$

r_s surface resistance [s m^{-1}]

FAO Penman-Monteith equation
From the original Penman-Monteith Equation (1965) and the equation of the aerodynamic and surface resistance, the FAO Penman Monteith Combination Method can be derived by (see box 3 and the equation below):

BOX 3. Derivation of the FAO Penman-Monteith equation for the hypothetical grass reference crop.

With standardized height for wind speed, temperature and humidity measurements at 2 m ($z_m = z_h = 2$ m) and the crop height h = 0.12 m, the aerodynamic and surface resistances become:

$r_a = 208/u_2$ s m^{-1}, (with u_2 wind speed at 2 m height)
$r_s = 70$ s m^{-1}
$(1 + r_s/r_a) = (1 + 0.34\ u_2)$

r_a Aerodynamic resistance [s m^{-1}]
u_2 The wind speed [m s^{-1}] at 2 m.
r_s Surface resistance [s m^{-1}]

R_n and G is energy available per unit area and expressed in MJ m^{-2} day^{-1}. To convert the energy units for radiation to equivalent water depths (mm) the latent heat of vaporization, l is used as a conversion factor. The conversion from energy values to equivalent depths of water or vice versa is given by:

$$Radiatior\left[mm/day\right] \approx \frac{Radition\left[MJm^{-2}day^{-1}\right]}{2.45} = 0.408 Radiatior\left[MJm^{-2}day^{-1}\right]$$

By substituting c_p with a rearrangement of:

$$C_p = \frac{\gamma\varepsilon\lambda}{P}$$

c_p Specific heat at constant pressure [MJ kg^{-1} °C^{-1}],
P Atmospheric pressure [kPa],

and considering the ideal gas law for r a:

$$\rho_a = \frac{P}{T_{Kv}R}$$

T_{Kv} Virtual temperature,
P Atmospheric pressure [kPa],
R Specific gas constant = 0.287 kJ kg^{-1} K^{-1},

T_{Kv} may be substituted by:

$T_{Kv} = 1.01(T+273)$

T_{Kv} Virtual temperature,
T Air temperature [°C],

results in:

$$\frac{C_p \rho_a}{r_a} = \frac{\gamma \varepsilon \lambda}{1.01(T+273)R(208)} u_2 \quad [\text{MJ m}^{-2}\ °\text{C}^{-1}\ \text{day}^{-1}]$$

C_p Specific heat at constant pressure [MJ kg^{-1} °C^{-1}],
r a Mean air density at constant pressure [kg m^{-3}],
r_a Aerodynamic resistance [s m^{-1}],
g Psychrometric constant [kPa °C^{-1}],
e Ratio molecular weight of water vapour/dry air = 0.622,
l Latent heat of vaporization [MJ kg^{-1}],
u_2 Wind speed at 2 m [m s^{-1}],
R Specific gas constant = 0.287 kJ kg^{-1} K^{-1},
T Air temperature [°C],
P Atmospheric pressure [kPa],

$$= 86400 \frac{\gamma (0.622) \lambda}{1.01(T+273)(0.287)(208)} u_2 \quad [\text{MJ m}^{-2}\ °\text{C}^{-1}\ \text{day}^{-1}]$$

T Air temperature [°C],
u_2 Wind speed at 2 m [m s^{-1}],

or, when divided by l (l = 2.45),

$$\approx \gamma \frac{900}{T+273} u_2 \quad [\text{mm}\ °\text{C}^{-1}\ \text{day}^{-1}]$$

u_2 wind speed at 2 m [m s^{-1}],

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 U_2)}$$

Where

ET_0 Reference potential evapotranspiration [mm day^{-1}]
R_n Net radiation at the crop surface [MJ m^{-2} day^{-1}]
G Soil heat flux density [MJ m^{-2} day^{-1}]
T Mean daily air temperature at 2 m height [°C]
U_2 Wind speed at 2 m height [m s^{-1}]
e_s Saturation vapour pressure [kPa]
e_a Actual vapour pressure [kPa]
e_s - e_a Saturation vapour pressure deficit [kPa]
Δ Slope vapour pressure curve [kPa °C^{-1}]
γ Psychrometric constant [kPa °C^{-1}]

The potential evaporation is converted from MJ $m^{-2}day^{-1}$ to mm day^{-1} by multiplying by 0.408.

8.4 Slope Calculation

An example of a window for calculation of slope. The cell values represent the altitude in meters and the mesh size is 10*10 meters (Eklundh et al 1999).

6	6	5
7	7	7
9	9	8

$$(dz/dx) = \frac{((6+2*7+9)-(5+2*7+8))}{8*10}$$

$$(dz/dx) = \frac{29-27}{80}$$

$$(dz/dx) = 0.025$$

$$(dz/dy) = \frac{((6+2*6+5)-(9+2*9+8))}{8*10}$$

$$(dz/dy) = \frac{23-35}{80}$$

$$(dz/dy) = -0.15$$

$$rise\_run = \sqrt{(0.025)^2 + (-0.15)^2}$$

$$rise\_run = \sqrt{(0.000625) + (0.0225)}$$

$$rise\_run = \sqrt{0.023125}$$

$$rise\_run = 0.15$$

The slope in the window is 15 %.