CHAPTER 3

MATERIALS AND METHODS

Consistent with the objectives of this study, the methodology is based on (1) a review of the relevant literature, (2) the analysis of primary and secondary sources, such as (a) formal studies and official reports written on similar topics (university research reports, academic monographs and academic journal articles, maps, etc.), (b) public documents (statistics, reports and other official documents issued by ministries), and (c) private sector documents (documents generated and published by the business environment), and (3) the use of the software programs (a) Ref ET, (b) Quantum GIS version 1.7.4 Wroclaw, (c) ArcGIS version 9.3, (d) PC Raster, and (e) the modelling software Land Use Change Impact Assessment (hereafter LUCIA). The software programs and their applications for this study are described in detail below:

3.1 The Study Area

The study area, which is described in detail in Chapter Three, lies within the Naban River Watershed National Nature Reserve, which is located in Jinghong County in the Dai Autonomous Prefecture of Xishuangbanna, in Yunnan Province, southwest China. The NRWNNR lies between latitude 22°04 and 22°17'N and longitude 100°32 and 100°44'E, and covers 267 km^2. The simulation period starts the 1st of January of 1992 and lasts until the 31st of December of 2003. The 29th of February is omitted for every year, as LUCIA works with years of 365 days.

3.2 Software

This study used the modelling software Land Use Change Impact Assessment (LUCIA; Marohn et al., 2012 and Marohn, 2008), which is a spatially explicit dynamic modelling tool based on PCRaster. LUCIA was used for generating data regarding biomass, litter inputs, exported carbon, total soil carbon, harvested yield, soil CO_2 emissions and latex exports of rubber, primary and secondary forests subtropical evergreen broadleaf forests, grasslands, paddy rice, orchards/tea, and maize. PCRaster is software that supports the development of spatial-temporal environmental models, such as LUCIA. PCRaster has functions that allow editing and adapting of raster GIS maps, so that these can be used in LUCIA.

Furthermore, QGIS (Quantum QGIS) version 1.7.4 Wroclaw and ArcGIS version 9.3 were used to process spatial input data. They are software packages designed for geographic information systems (GIS) that allow data viewing, managing, assessing, editing, and presenting information with geographical references. They display information in the form of maps, graphs, and reports, showing relationships, patterns, and trends. In order to make QGIS and ArcGIS compatible with PCRaster, the raster files were converted to ascii files. PCRaster operates with another raster map format, and therefore the ascii format was changed to the PCRaster map format (.map), which is used in LUCIA. Additionally, non-spatial data in excel files used as inputs for LUCIA were converted to text files containing parameters (.par), and time series (.tss).

3.3 Maps

An existing digital elevation map (.tiff) from the Naban River Watershed National Nature Reserve was obtained for this study (Cotter, 2012, personal communication). LUCIA operates better with areas that do not surpass around 50.0 km^2; therefore, a sub-watershed of 68.8 km^2 within the NRWNNR was selected. The core zone of the reserve had to be excluded from the sub-watershed, because of the excessively large size it would have for LUCIA. Furthermore, the core zone does not have agricultural activities, which would hinder the aim of studying the effects of land use change on carbon sequestration, CO_2 emissions, and carbon balance.

The selection of a sub-watershed was done by processing the digital elevation map in the QGIS's GRASS plugin module "Hydrologic modelling" that has the option "Filter and create depressionless elevation map and flow direction map from elevation raster", which fills the map with water. Afterwards the option "Watershed Analysis" is performed, which creates several sub-watersheds, from which a desired sub-watershed can be chosen, and converted from raster to a vector area. The resulting area map and elevation map of the sub-watershed are shown in Figures 1 and 2, respectively.

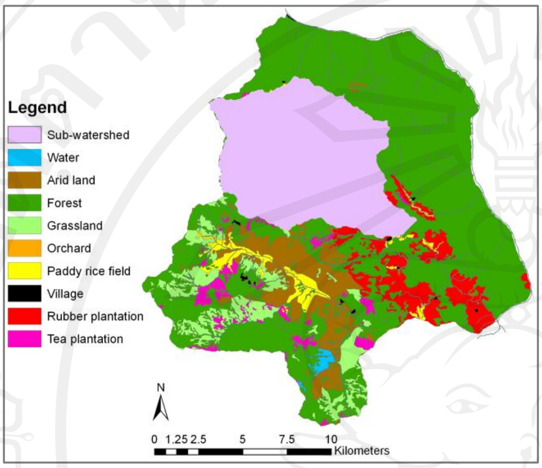

Figure 13 Selected sub-watershed in the NRWNNR

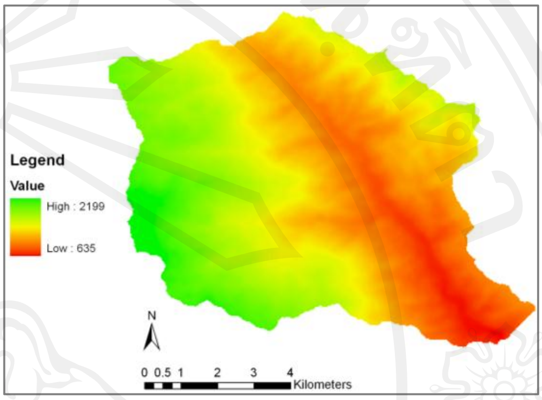

Figure 14 Elevation map of the sub-watershed

The baseline land use map for this study is based on an existing land use map of the NRWNNR from 2006/07 (Cotter, 2012, personal communication). The land use map lacks information regarding the ages of rubber plantations, and does not distinguish between primary and secondary forests. The largest area under forests in the sub-watershed is mostly covered by subtropical evergreen broadleaf forests (Cotter, 2012, personal communication). Furthermore, it was not possible to accurately extract detailed information from satellite images regarding the area's vegetation, which can be explained by the lack of a method that is, e.g., able to precisely distinguish among different rubber ages (Li and Fox, 2012). For evaluating the differences of biomass development at different elevation ranges, it was necessary to assign exact rubber ages, and more exact forest statuses, i.e. primary and secondary. Therefore, the land use map from 2006/07 was modified according to the following criteria and used as a baseline:

The land use map and the digital elevation map were merged and classified into five different elevation ranges with the raster calculator of QGIS. This resulted in the following elevation ranges: (1) below 664 m, (2) between 664 and 835 m, (3) from 836 to 999 m, (4) between 1000 and 1500 m, and (5) above 1500 m. Elevation ranges

1 to 3 were chosen according to Jia (2006) and Song and Zhang (2010), in order to evaluate the different biomass accumulation at different elevations, which mainly results from the different temperatures that prevail at different elevations. Elevation range 4 was selected to contain secondary subtropical evergreen broadleaf forests due to its lower elevation compared to 5, which has primary subtropical evergreen broadleaf forests.

Past land use maps of the NRWNNR or accurate information on the real land use change rates of the different land uses in the sub-watershed between 1992 and 2003 could not be accessed by the author. Alternatively, the baseline map was modified to generate 12 past land use maps from 1992 (no rubber), 1993 (first rubber) until 2003. For this purpose, a cost distance function was generated in ArcGIS, which uses each village centre in the baseline map as a starting point for the yearly contraction of all agricultural land uses, i.e. from 2006/07 until 1992 (Figure 3). The yearly contraction occurs at an equal rate in terms of distance to the village centre (Figure 4). This means that the further agricultural land uses are from a village, the more recent (younger) they are, and the closer they are, the earlier (older) agricultural activity began there (Figure 5 and 6). Furthermore, the contraction of agricultural land simultaneously means the expansion of forests.

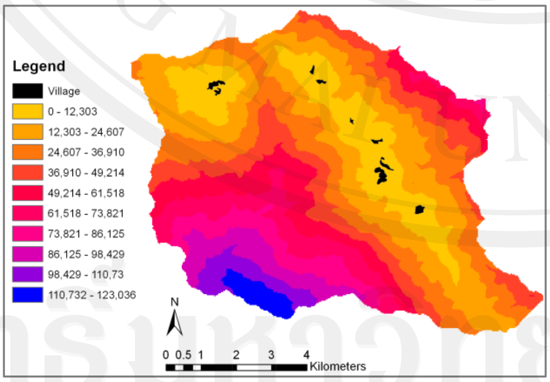

Figure 15 Cost distance map for the contraction of agricultural land uses from each village centre

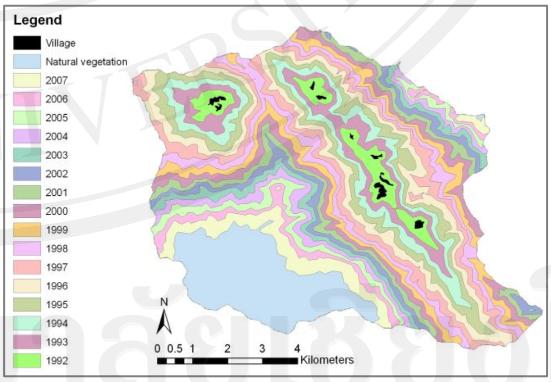

Figure 16 Yearly contraction of agricultural land uses, 2007 to 1992

The chosen yearly contraction was used, because the resulting land use change rate pattern in the sub-watershed was comparable to that of the entire NRWNNR between 1994 and 2004 (Wehner, 2010), and because the ages of the rubber plantations, i.e. seedlings up to mostly 15 to 20 years, in the sub-watershed were known (Cotter, 2012, personal communication), giving an approximate idea of their yearly expansion rate.

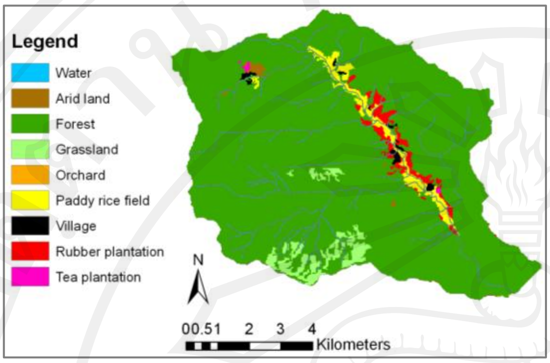

Figure 17 Land use map from 1993

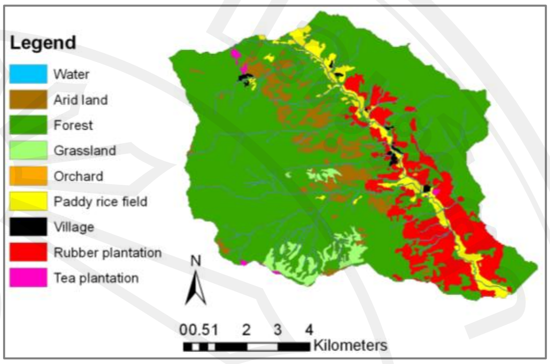

Figure 18 Land use map from 2006/07

The study area's soil classification is land cover-based, i.e. that areas under forests, grasslands, and maize are Ferralsols, soils under rubber and orchards/tea are Acrisols, and areas under rice paddies are Gleysols. Soil characteristics were taken from information on 9 soil profiles under different land uses in the NRWNNR that correspond to Ferralsols, Gleysols, and two Acrisols (Langenberger et al., 2010, p. 11-12). A soil type map was created in QGIS, and categorizes the entire study area into the soils mentioned above (Figure 7).

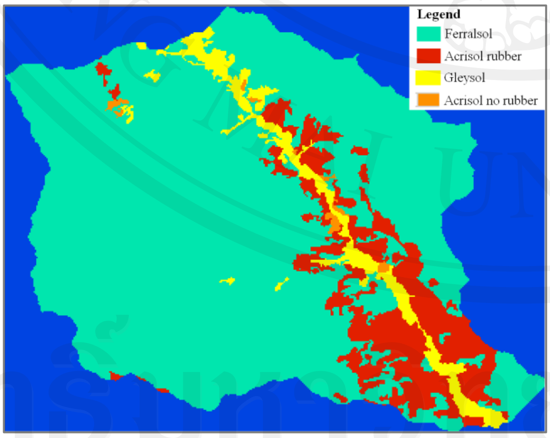

Figure 19 Soil type map

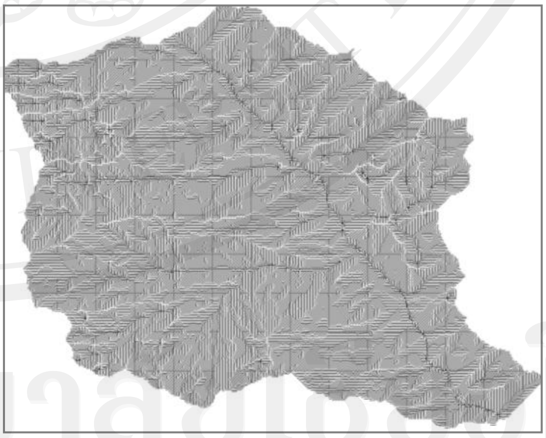

Figure 20 Local drain direction map

A local drain direction map (.ldd; Figure 8) was created from the digital elevation map. The outflow point is the lowest elevation on the map to which all water drains, and from where it drains to a neighbouring watershed. As there are no lakes in the study area, the lakes map includes "false" in every cell. Furthermore, 19 test points that represent the different evaluated land use classes at the different elevation ranges were selected. The same test points were used in all maps. Biomass, total soil carbon, harvested yield, latex exports, soil CO_2 emissions and exported carbon were computed at each test point in order to evaluate the impacts of land use change on carbon balance. Finally, the vector maps were rasterized and extracted within the same sub-watershed of the digital elevation map in QGIS and ArcGIS using the area map as a mask.

3.4 Parameterization of the LUCIA Model

Climatic data, including average daily air temperature, precipitation (TuTiempo, 1992-2003), solar radiation (Yang, 2012, personal communication), reference evapotranspiration, and soil temperature were parameterized for the time period from the 1st of January of 1992 until the 31st of December of 2003. Missing data were filled in excel manually beforehand by using daily data averages of a same day in other years.

The reference evapotranspiration (ET_0) calculator "Ref ET" version 3.1.08 was used to calculate the average daily ET_0 at Jinghong meteorological station. The station lies at 579 m and meteorological data are validated against 555 m (Weather Quality Reporter). The input data consist of daily maximum and minimum temperature, average relative humidity, wind speed, and solar radiation. Missing input data were filled in excel beforehand by using daily data averages of a same day in other years. Ref ET produced results using the different ET_0 calculation models ASCE (American Society of Civil Engineers) Penman-Monteith, ASCE Standardized Penman-Monteith, and FAO 56 Penman-Monteith. As the results did not vary significantly, they were averaged.

The daily average soil temperature in Jinghong was calculated for a soil depth of 5 cm using Horton and Corkrey's model, which is dependent on air temperature and on rainfall (Horton and Corkrey, 2011, p. 307-311). Manure, urea and compound fertilizer application was parameterized for rubber (Golbon, 2012, personal communication and Tang et al., 2009, p. 33).

Vegetation and soil data for the parameterization of LUCIA were directly entered into the model. The input data are the result of an exhaustive literature review and the use of data from validated models. Rubber was completely parameterized, except for lignin content in leaves and polyphenol in stems, which were taken from *Croton marcostachyus* (Euphorbiaceae). The inputs for the other land uses, i.e. maize, paddy rice, mango orchards/tea, grasslands, and primary and secondary evergreen broadleaf forests are based on existing input datasets for the model. As there was no available dataset for tea plantations, orchards were used instead, as they have a similar biomass (Li et al., 2008) and are also an agricultural land use. Furthermore, most data for soil parameterization are derived from the information regarding the 9 soil profiles in the NRWNNR (Langenberger et al., 2010).

3.5 Model Outputs

This study focuses on the outputs of the model at each test point, which include biomass [Mg/ha], total carbon in topsoil [Mg C per ha], total carbon in subsoil [Mg C per ha], litter inputs [Mg per ha], soil erosion [Mg per ha], soil CO_2 release [Mg CO_2 per ha], latex export [Mg per ha], and average yield per land use [Mg per ha]. Outputs for the entire watershed area include total biomass [Mg], total soil CO_2 release [Mg CO_2], and latex export [Mg]. Outputs used for control of the model's correctness comprise water stress [non-dimensional, 0-1], nitrogen constraint [non-dimensional, 0-1], phosphorus constraint [non-dimensional, 0-1], potassium constraint [non-dimensional, 0-1], soil evaporation [mm], topsoil depth [cm], rooting depth [cm], soil loss [Mg per ha], and daily latex flow [Mg per ha]. Additionally, the mentioned outputs per ha are also used for estimating biomass, total soil carbon, soil CO_2 emissions, yield and carbon balance of the entire area of every land use, as well as of the entire watershed area.

3.6 Calibration of the LUCIA Model

The LUCIA model was calibrated manually by adjusting parameters through iteration. The aim of the calibration was to make the model output fit the documented biomass growth in Xishuangbanna. All relevant vegetation types for this study were calibrated, i.e. rubber, paddy rice, maize, orchards/tea, grasslands, and primary and secondary forests. Rubber biomass growth was calibrated with biomass estimates for Xishuangbanna from a review of published data, as well as from allometric equations resulting from the analysis of field data (i.e. tree height and girth at breast height) from 2009 and 2010 (Golbon, 2012, personal communication). The biomasses of the other vegetation types were calibrated with biomass data for Xishuangbanna that resulted from a review of published data. Further calibration was done regarding the phenology stages of rubber, paddy rice and maize in Xishuangbanna, and the management practices of the NRWNNR's farmers. The model calibration required over 200 simulation runs, in which the data selected for calibration were adjusted to fit the reported biomass amounts. The calibration of the model was done with data from several different years.