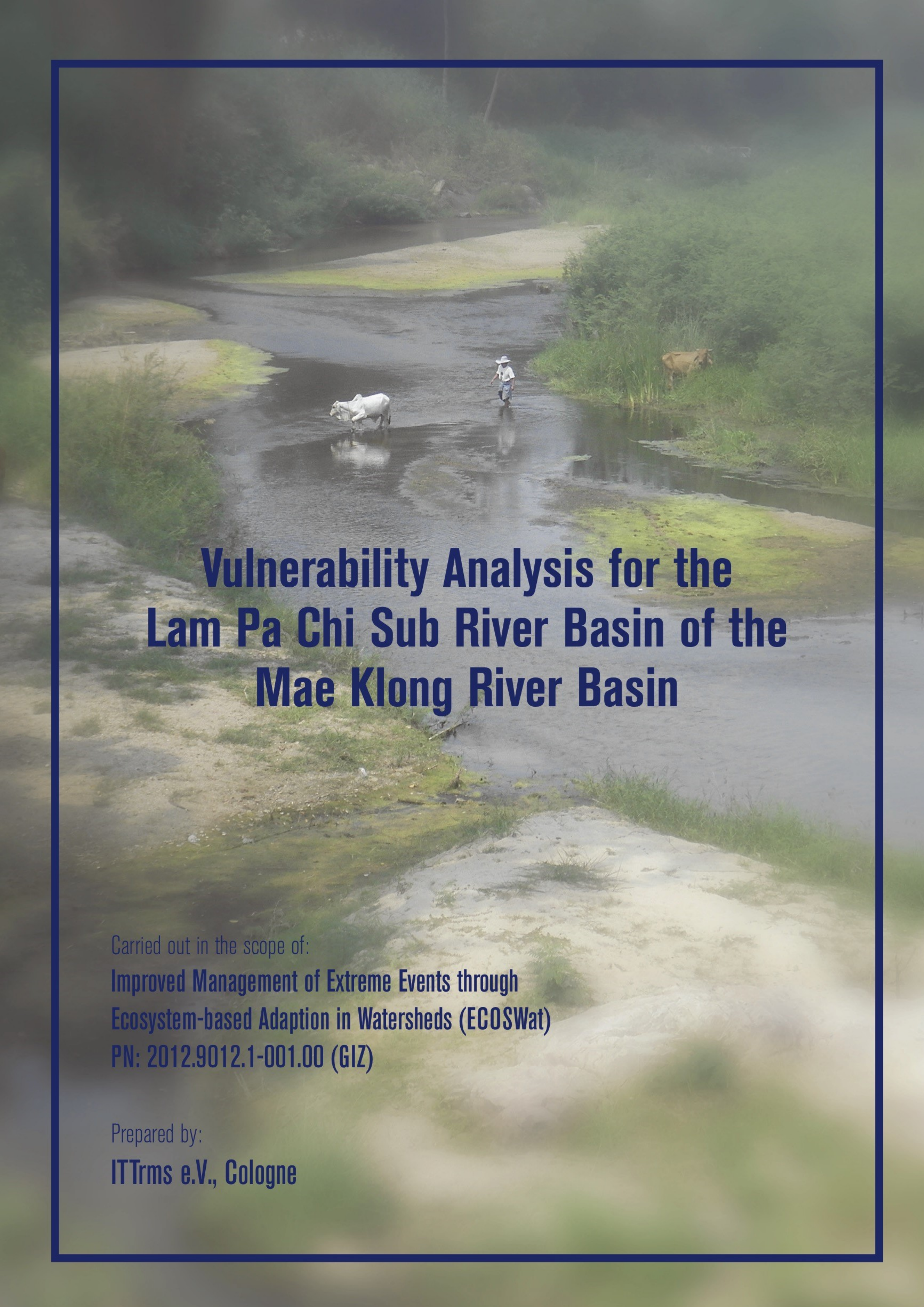

Vulnerability Analysis for the Lam Pa Chi Sub River Basin of the Mae Klong River Basin

Carried out in the scope of:

Improved Management of Extreme Events through Ecosystem-based Adaption in Watersheds (ECOSWat)
PN: 2012.9012.1-001.00 (GIZ)

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Photos: Lam Pa Chi River, by Georg Meier

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Summary

Lam Pa Chi, a sub-basin of Mae Klong river basin in western Central Thailand covers an area of around 2700 km² and is home to about 150.000 people. Due to the natural setting in combination with the land and water use patterns it is vulnerable to climate extremes leading to recurrent floods and droughts as well as to significant erosion.

The aim of this study is to compile available data about the basin in order to conduct a comprehensive basin inventory and to provide the information through an online data base (RBIS) accessible to stakeholders. Besides, the study has created packed *.kmz files and uploaded them to Google Earth providing an alternative for analyzing spatial attributes of studied river basins. Information on the climatic conditions – the key driver for natural hazards in the region- is analyzed in detail and, where available, climate change scenarios are described.

The risks related to floods, droughts and erosion were assessed based on field observations, observed hydro-meteorological historical data and satellite products. The study has determined causes of risks and identified vulnerable regions.

The results from risk analyses provide information to propose ecosystem based adaptation (EbA) measures to mitigate or cope with these challenges. After a screening process of alternative EbA measures applying several criteria, four EbA measures were proposed and described. Suggested locations for applying these measures are sampled as results of spatial analysis, field surveys and literature review; benefits and the technical specifications of each mentioned measure are also discussed.

The suggested measures can be considered as a first attempt to identify appropriate strategies to cope with natural hazards in the Lam Pa Chi river basin. It should be noted that for a reliable and targeted selection of adequate measures more local knowledge and expertise needs to be considered.

1 Introduction

Extremes of atmospheric weather and climate variables like temperature, precipitation or wind are the reason for natural hazards (like floods, storm surges and droughts or related events like erosion, forest fires or landslides) causing those natural disasters which by far are associated with the highest number of deaths and economic losses (World Bank 2010). Following the definition of IPCC, the term Climate Extremes refers to extreme weather and climate events and depicts the occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable (IPCC 2012). Climate extremes are a result of natural variability. IPCC (2012), however, concludes that “A changing climate…leads to changes in the frequency, intensity, spatial extent, duration, and timing of weather and climate extremes, and can result in unprecedented extremes” (IPCC 2012, p 111). It should be noted that so far the level of certainty of such a statement is still low as it is more difficult to predict changes of extremes as compared to changes of means. In addition, there are significant regional differences regarding climate change predictions with spatial variability below the resolution of common GCMs (for a detailed discussion compare also IPCC (2012, chapter 3.2).

However, overuse and geomorphological modification of (water) resources and bodies often play a larger role regarding the extent of disasters related to droughts, floods and erosion.

To assess the vulnerability of water resources in the Lam Pa Chi Sub River Basin against climate change impacts and socioeconomic development, a river basin assessment considering bio-physical and socioeconomic aspects has been carried out. The characterization of the water resources system, its pressures and vulnerability included the following steps:

- Data Acquisition and Data Management: available basic data about the watershed like land use, topography as well as hydro-meteorological and socio-economic data were collected and have been made available through the web based Lam Pa Chi River Basin Information System data system: http://rbis.itt.fh-koeln.de/LamPaChiRBIS
- River Basin description: the natural (climate, hydrology, land use, etc.) and socio-economic environment has been described based on the above mentioned data and thematic maps have been elaborated. The description has been made available on http://www.basin-info.net/river-basins/lam-pa-chi-river-basin-br-thailand and on the above mentioned RBIS.
- Literature Review about expected climatic changes for South East Asia and Western Thailand: an overview on climate change scenarios for the region is given in order to estimate the likely impact of climatic changes and increasing hydro-meteorological extremes on water availability.
- Water Resources Modeling, statistical data analysis and scenario development: assessment of historical trends in climate patterns and water availability, intra-annual shifts and increasing abstractions and consequent vulnerability. These analyses have been carried for monthly water availability and droughts (low flows) and expected annual soil loss. Water availability scenarios might be developed considering temperature increase and increasing abstractions.

Key constraint of any of the above described activities is the lack of hydro-meteorological data of higher temporal resolution and of general information, especially in English. Analyses of hydro-meteorological extremes require at least data of daily resolution and for floods even hourly. Therefore the hazard vulnerability could not be assessed sufficiently to obtain reliable risk scenarios and management tools (models). Also spatial data on socioeconomic activities are weak, so vulnerability of population and agricultural land use lack of accuracy.

2 Data acquisition and data management

2.1 Lam Pa Chi River Basin Information System

2.1.1 Introduction

The Lam Pa Chi Information System is a platform to store and manage relevant data and information of Lam Pa Chi River Basin, Central Thailand. The basin information system is developed based on open-source software as well as open standards. The system offers full read and write access to various types of environmentally related information such as time series data, spatial data, map, monitoring stations, documents, etc. The system can be accessed at http://rbis.itt.fh-koeln.de/LamPaChiRBIS/metadata/overview.php?view=observ_location. Please register (top page right side) and access will be provided.

2.1.2 Structure

The Lam Pa Chi Information System is built up in a modular way with five major modules as shown in Figure 2-1:

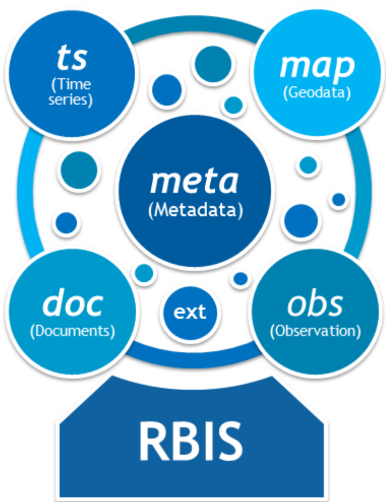


Figure 2-1. Structure of Lam Pa Chi River Information System, Source: Zander et al., 2011

Each module has different functions in managing uploaded data. Table 2-1 describes attributes and functionalities of the aforementioned module.

Table 2-1. Attributes and functionalities of modules in Lam Pa Chi Information System

Modules	Storage data	Functionalities	Notes
Metadata	• Metadata of all stored data	• Description of all stored datasets by meta-information	• Based on ISO 19115-1 Metadata Standard for Geodata • Extensions for other data types (time series, documents, …)
Time series data	• Measured time series • Simulated time series	• Gap detection • Rule based gap filling toolbox • Visualization and Analyze • Import and Export • Statistical processing	• Metadata: based on ISO19115
Documents/Files	• Text documents and pictures	• Raw/binary files	• Metadata: based on ISO19115
Geodata	• Vector & raster data •	• Storage, visualization and processing of geodata • Easy map editing	• Based on MapServer, PostGIS, OpenLayers
Observation	• Study site (area or point) • Observation (sampling, …)	• Indicate the location with linked data of the measuring stations	• Linked data of the measuring stations can be extracted here

2.1.3 Access and sharing data

While all meta-information can be accessed using a guest login, a validated user account is required for full access to the Information System. There is a registration form to apply for a new account. The registration form should be sent to the administrator of the system at http://rbis.itt.fh-koeln.de/LamPaChiRBIS/metadata/overview.php?view=observ_location. After logging in, the user can access and download the stored data. Figure 2-2 shows the interface of the module of time series data. The user can also interactively plot the data.

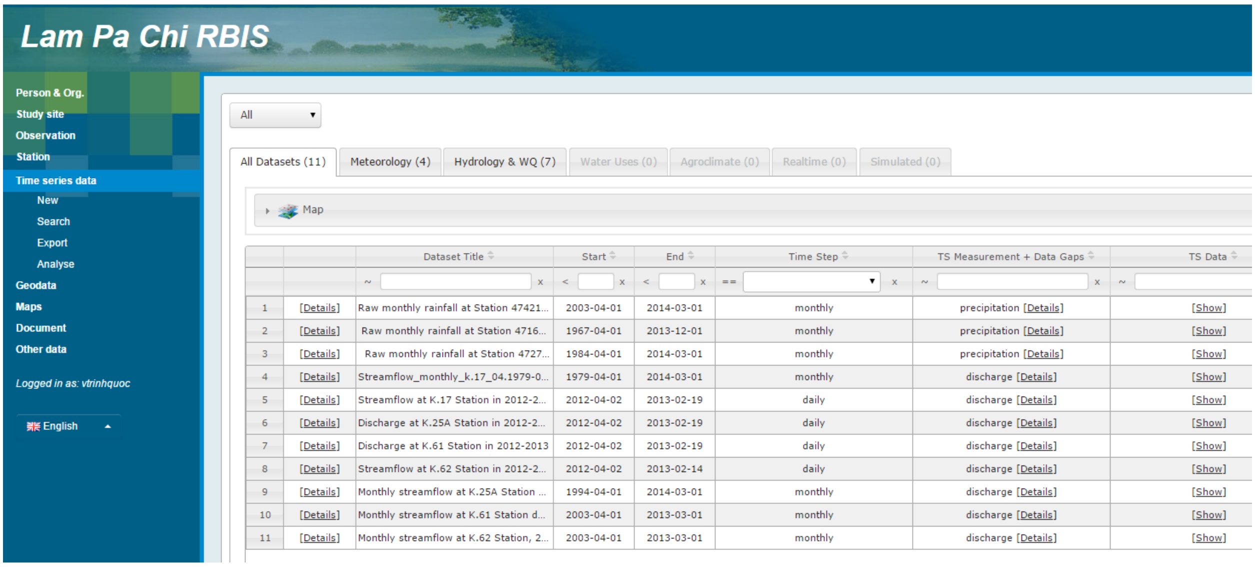


Figure 2-2. Interface of time series data module

2.1.4 Additional important functions

The system supports text and spatial search (bounding box, study site). The flexible, user-oriented design provides an easy access and sharing data. The system also automatically notify new or changed events or stored datasets, upcoming events, permission request / grant. Contact: Trinh Quoc Viet, ITT, FH Köln, Germany

2.2 Data availability, data stored on Lam Pa Chi RBIS

The Information System of Lam Pa Chi River Basin has been built and first-step data and information as well as study results being uploaded to RBIS. Table 2-2 shows relevant data, information uploaded to RBIS:

Table 2-2. Uploaded data and information of Lam Pa Chi RBIS

Modules	Storage data	Notes
Study site	• Shapefiles showing the location of the Lam Pa Chi	• Further spatial information: load attached file LPC_GoogleEarth_kmz to Google Earth
Observation	• Empty	• Metadata: based on ISO19115
Stations	• Location of 23 observing stations, classified to 8 River discharge stations, 14 climatic stations and 1 water quality/surface/ ground station , is loaded to map	• The measuring data of each station is organized in the form of time series and can be extracted. • The measuring data of each station will be continuously updated
Time series	• Four monthly rainfall time series of Station 47421 (2003-2013), 47161 (1967-2013), 47271 (1984-2013)and K.62 (2006-2013) were uploaded • Seven monthly or daily streamflow time series of Station K.17, K.25A, K.61, K.62 were uploaded	• The time series can be downloaded or be plotted for visualization
Geodata	• There are 28 datasets being imported to RBIS. There are water & environment (17), Land use and ecology (3), boundary (4), monitoring stations (3), infrastructure (1), LANDSAT-8	• Dataset is projected to WGS84/UTM 47N
Maps	• Including created maps (9) and collected maps (23). The created maps consist of water uses, forest, soil, overview, administrative, aquifers, land use, topographic and Lam Pa Chi in Thailand maps.	• Mapped by ITT based on the data provided by WRD, MONRE
Documents	• Approximately 30 reports, articles related to study topics in the Lam Pa Chi Basin are uploaded	
Other data	• Cross sections, temperature and other relevant data	

3 Lam Pa Chi River Basin description

This chapter describes the most relevant features of the Lam Pa Chi (LPC) including administrative issues, topography, soils, climate, land use and hydrology. Maps, tables and figures are based on shapefiles obtained by MONRE or as indicated in the metadata on Lam Pa Chi RBIS.

3.1 Location

The Lam Pa Chi basin is located in the western part of Thailand bordering in the mountain range with Myanmar. It is a sub-basin of the Mae nam Mea Klong Basin and has a drainage area of 2,664 km² (representing approximately 8.6% of the Mae Nam Mae Klong) ranging from 99° 9' 54.0" – 99° 35' 31.2" E and 13° 8' 52.8" – 13° 56' 20.4" N. The terrain in the basin is characterized by high mountains and steep river valleys. The elevation varies from 36 m.a.s.l. at the outlet until 1,156 m.a.s.l. at the mountain range bordering with Myanmar (Figure 3-1). The major stream runs north and joins the Tha Khoei River at the outlet of the sub-basin.

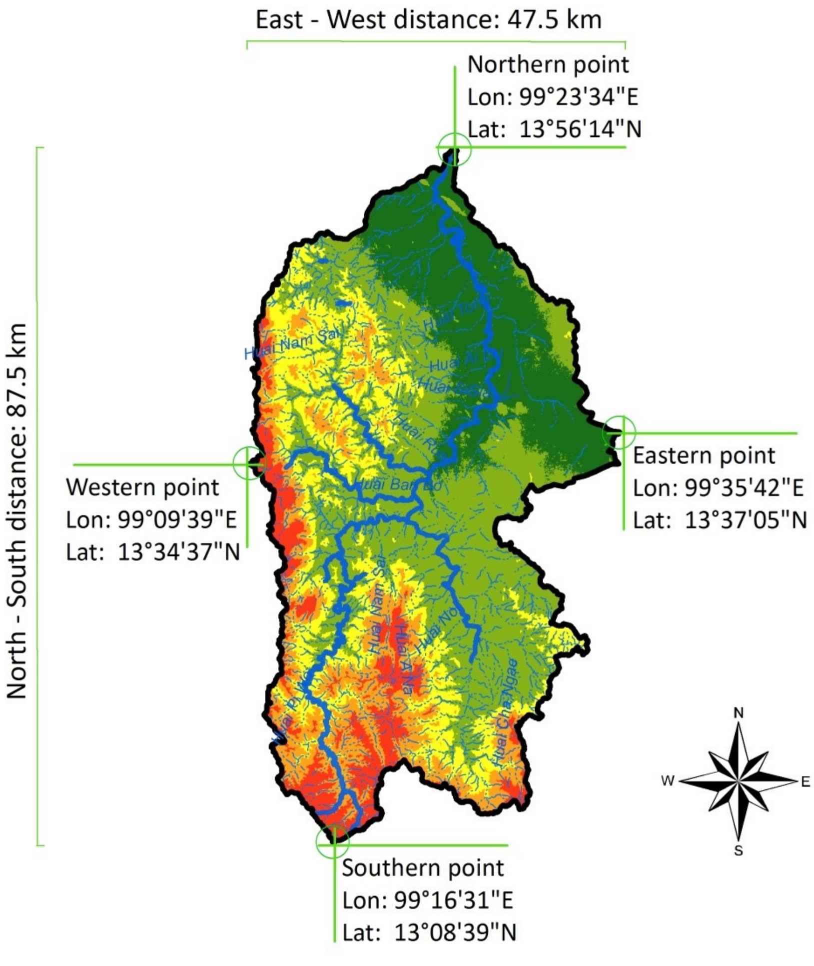


Figure 3-1. Geographic location of Lam Pa Chi River Basin

3.2 Lam Pa Chi as part of Mae Klong River Basin

The Lam Pa Chi is located entirely within the territory of Thailand and being a part of the Khwae Noi, it is one of two major sub-basins forming Mae Klong River Basin (Figure 3-2). Naturally, the basin is bordering the Mae Nam Phetchaburi River Basin in the South, the Mae Nam Tha Chin in the East and small catchments in the Tanintharyi Region, Myanmar in the West.

The Mae Klong Basin is subdivided into five sub-basins consisting of Khwae Yai Upper (KHY), Khwae Noi Upper (KHN_U), Khwae Noi Middle (KHN-M), Lam Taphoen (LTP), Lam Pa Chi (LPC), and Mae Klong Plain Upper (MK_PU) (See Figure A- 1 in Annex). The Mea Klong is located in the western part of Central Thailand, in the major areas of Tak, Kanchanaburi, Ratchaburi provinces and smaller parts of Kamphaeng Phet, Nakhon Sawan, Tak, Uthai Thani, Suphan Buri, and Phetchaburi provinces. With 30,836 km^2, Mae Klong is the fifth largest river basins in Thailand, after Thailand's Mekong, Chi, Mun, Ping and Nan basins (Office of the National Water Resources Committee, 2000).

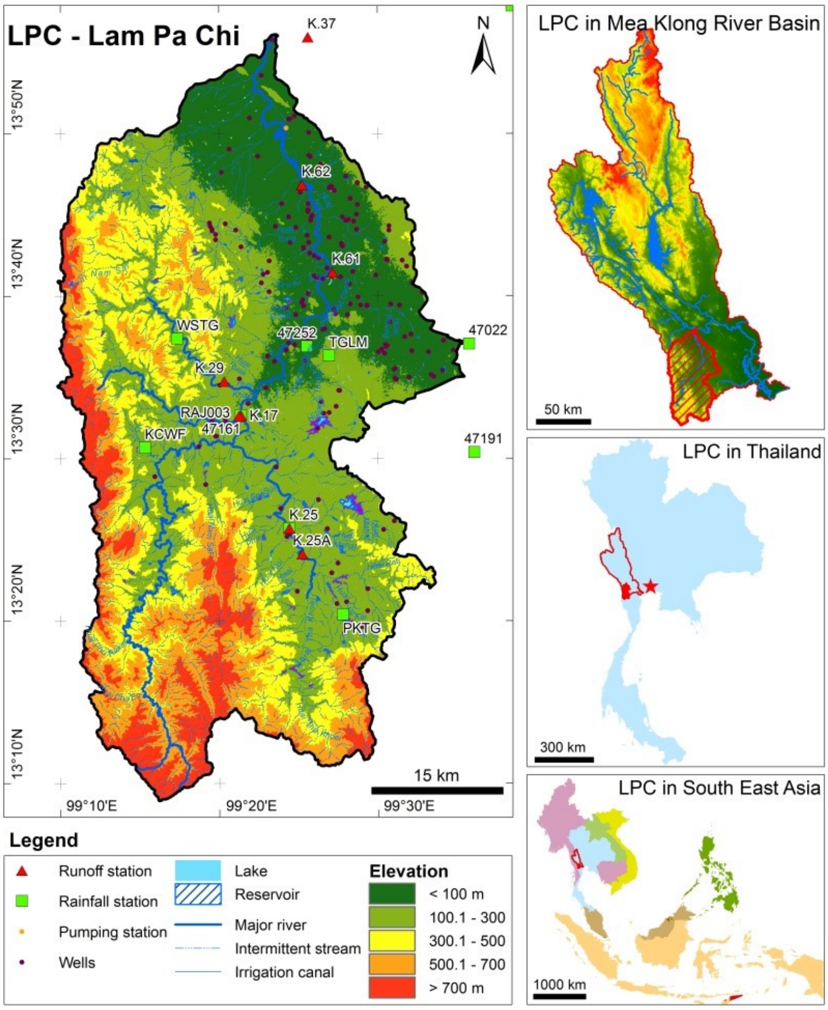


Figure 3-2. Lam Pa Chi in Mae Klong River Basin

Annually, approximately 12,943 × 10^6 m^3 of surface runoff generated from 30,836 km^2 of the basin. The annual specific runoff reaches 419,359 m^3/km^2, standing 11 out of 25 basins in Thailand. However, compared to other large river basins, the Mae Klong has a relatively low annual specific runoff (see Table A- 1 in Annex).

3.3 Administrative boundaries and governance

The administration system of Thailand is organized into 76 provinces (Changwat). District (Amphoe) → sub-districts (Tambon) → villages (Moo baan) are the next administration levels (http://web.nso.go.th/). The Lam Pa Chi River Basin covers 2,664 km^2 of Ratchaburi and Kanchanaburi provinces. There are 132 villages in the basin (Table 3-1).

Table 3-1. Administrative organization in the Lam Pa Chi Basin

Province	District	Sub-district	Number of villages
Kanchanaburi	*Dan Makham Tia*	Chorakhe Phueak	4
		Dan Makham Tia	6
		Klondo	1
		Nong Phai	12
Ratchaburi	*Chom Bung*	Boek Phrai	2
		Chom Bueng	1
		Dan Thap Tako	19
		Kaem On	13
		Rang Bua	11
	Ban Kha	Ban Kha	31
	Suan Phung	Pa Wai	7
		Suan Phueng	13
		Tha Khoei	12
Lam Pa Chi			**132**

The Lam Pa Chi River originates in the Tenasserim Hills in the Ban Kha District (amphoe) and passes through the Suan Phueng and Chom Bueng districts, Ratchaburi Province (changwat). The river joins the Mae Klong River in Mueang Kanchanaburi District, Kanchanaburi Province. Major upstream parts of Lam Pa Chi belong to Ratchaburi and a small downstream part of the basin belongs to Kanchanaburi. Figure 3-3 shows the administrative organization as well as transportation system, meteo-hydrological stations in the basin.

Figure 3-3. Administrative map of the LPC, provinces, districts and roads

Several government institutions are in charge of water management. For instance, the Royal Irrigation Department (RID) is in charge of the irrigation infrastructure, including dams and weirs, as well as of monitoring discharge. Moreover, the Department of Water Resources (DWR) has the responsibility of formulating policies and plans on integrated water resources management in the river basin. The DWR is leading the process of establishing a river basin committee where all stakeholders should be represented to jointly develop policies and plan for the LPC. The Provincial Waterworks Authority (PWA) provides drinking water to urban settlements within the basin. It manages a dam to store water for the treatment and distribution of drinking water.

3.4 Climate

Little is known about the particular climate in Lam Pa Chi Basin (Manton et al., 2001). It is influenced by the southwest monsoon during the period from May to October and also the tropical cyclonic storms from the South China Sea at the end of the rainy season from September to October (Biltonen et al. 2003). According to the Köppen classification, the LPC belongs to the Tropical wet and dry or savanna climate (Aw) group, with hot tropical climate (with average temperatures of all months above 18°C) including wet summers and relatively dry winters.

Temperatures in the hottest month, April, reach an average temperature of 32 °C while December is the coldest with an average of 25 °C (Figure 3-4).

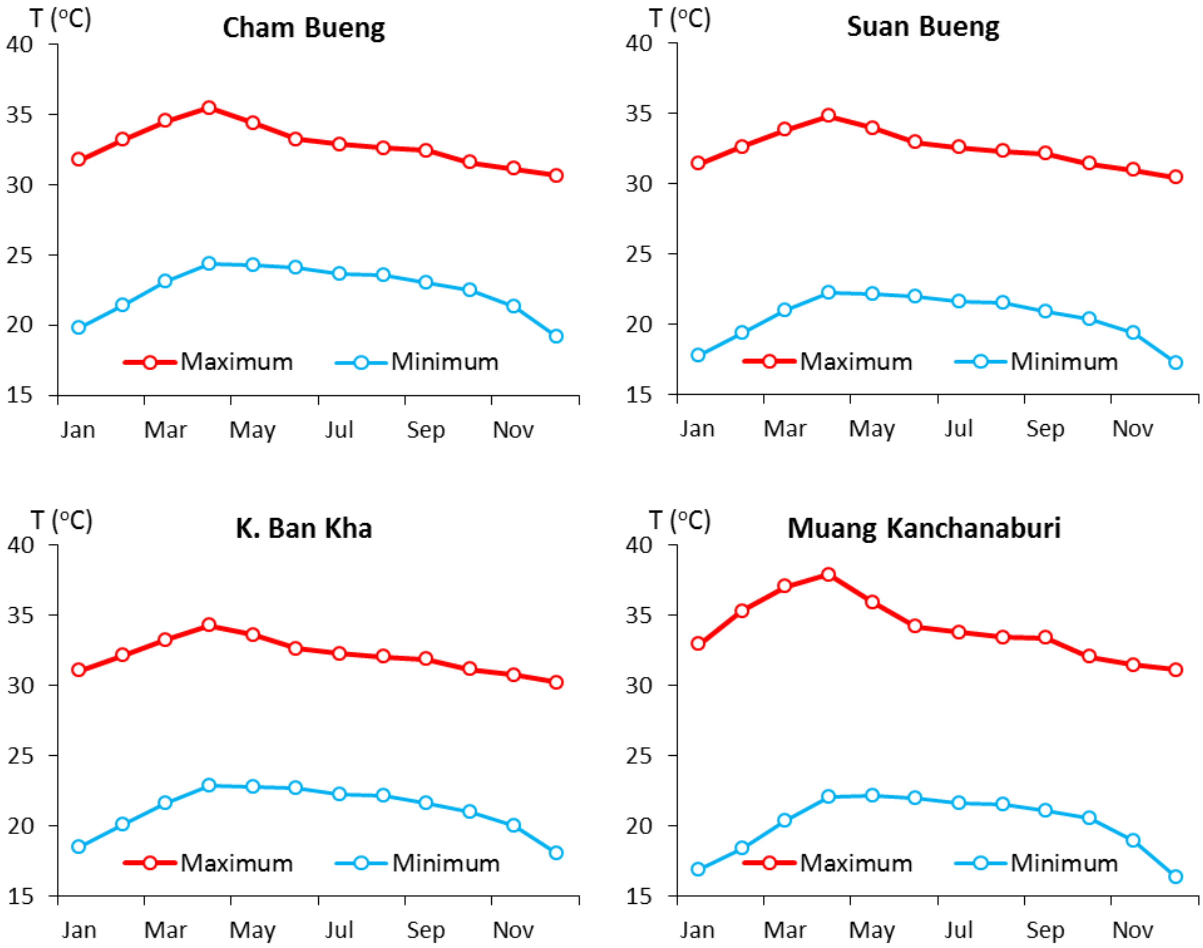


Figure 3-4. Averaged maximum and minimum temperatures (°C) in 1981-2001 of districts in the basin. Source: Marc Souris; IRD at http://www.savgis.org/thailand.htm#THAIMETEO

According to the precipitation data available (3 stations) the annual precipitation ranges from 990 to 1,180 mm. Almost 85% of the total precipitation falls during the wet season from May until November. During the rainy season heavy rain events occur causing one of the main environmental problems in the region: soil erosion. Figure 3-5 shows the inter-annual variation of monthly precipitation and discharge for the period 1967-2013 at the three stations. For instance at the station 47161 located in the center of the basin at 110 m.a.s.l., it can be seen that May, September and October are the months with the highest precipitation with average values of 160, 203 and 261 mm, respectively, while December until February are the driest months with average values under 15 mm.

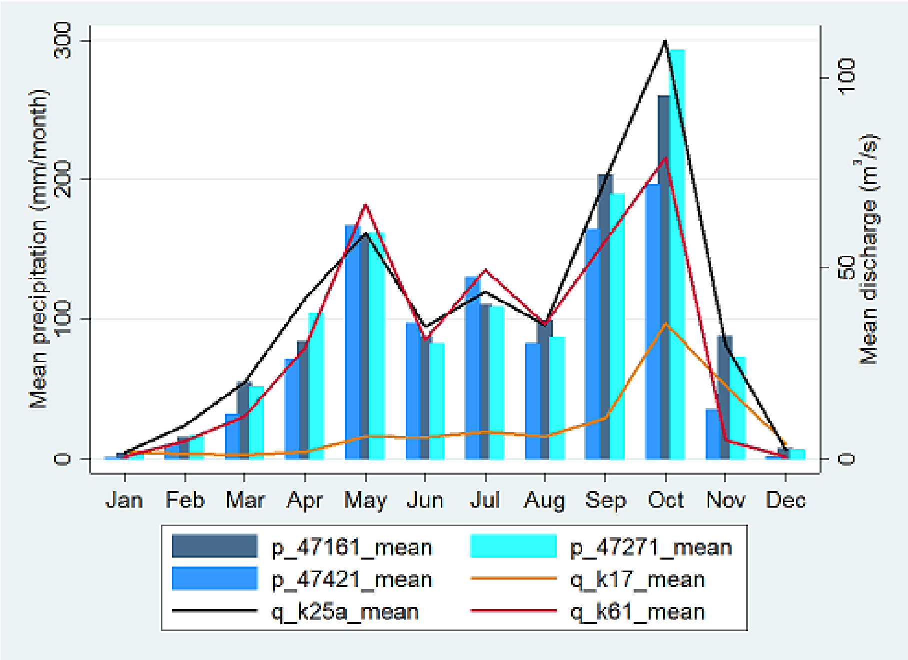


Figure 3-5. Inter-annual variation of monthly precipitation and discharge for the period 1967-2013

For comparison, the average values for precipitation and discharge for Thailand are shown in Figure 3-6:

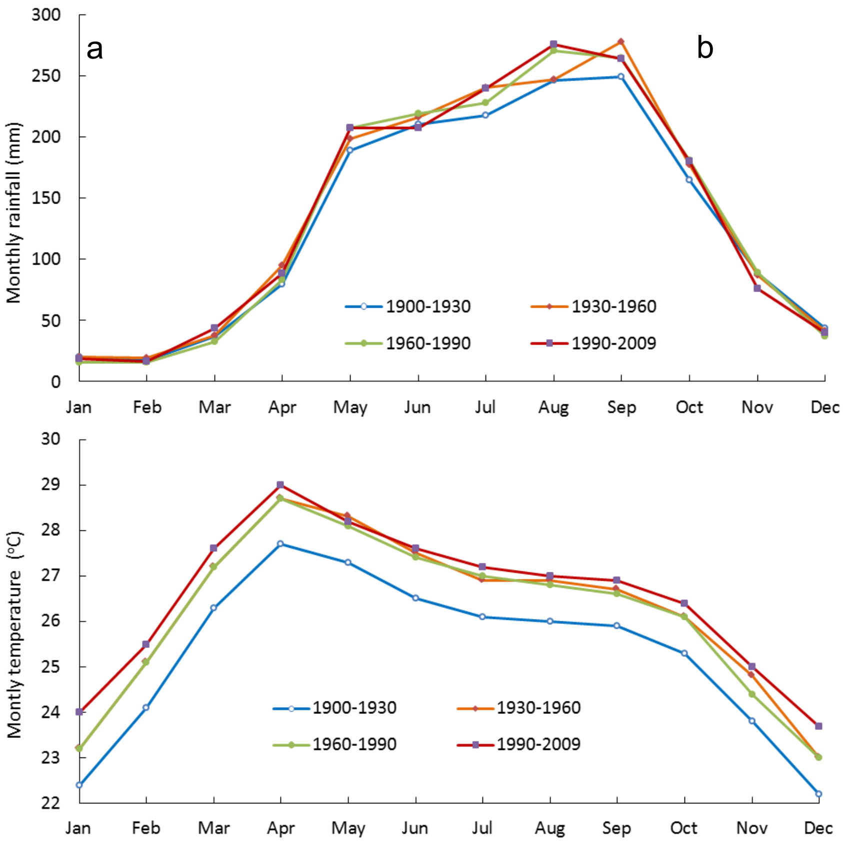


Figure 3-6. Mean historical monthly rainfall (a); and mean historical monthly temperature(b) for Thailand during the time period 1900-2009
Data: Climatic Research Unit (CRU) of University of East Anglia (UEA)

The figure indicates that the Lam Pa Chi is exposed to two monsoon peaks, one in May and one in October. Annual rainfall in Thailand as a whole is higher than annual rainfall of Lam Pa Chi, except in October when rainfall in this month of LPC far exceeds the mean rainfall in October of the country. Consequently, discharge also differs with two peak flow seasons in May and October. The spatial distribution of annual rainfall in LPC is shown in Figure 3-7.

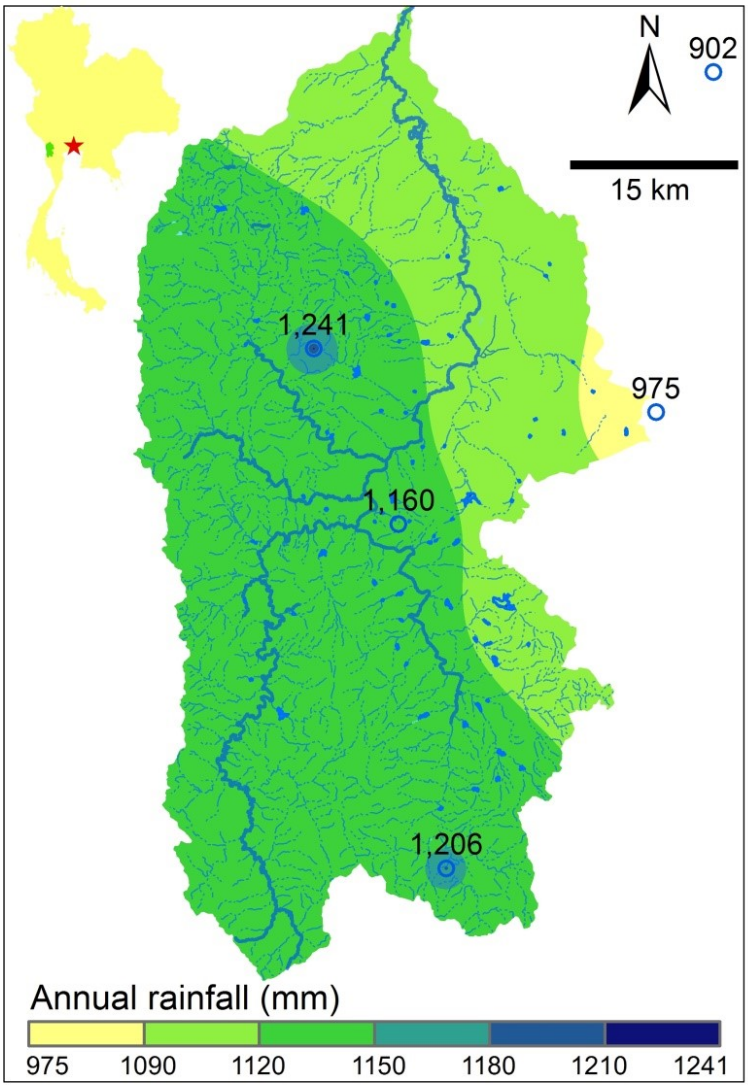


Figure 3-7. Areal rainfall in LPC

It is obvious to see that the uplands and midlands in western and southern parts of the basin receive more rainfall than the lowlands. The highest annual rainfall in the basin is 1,206 mm occurring in the upstream parts and the lowest annual rainfall is 975 mm occurring in the eastern plains.

3.5 Hydrology and hydrological network

The main channel is 130 km long and it has its headwaters in the western and southern mountain range draining the basin in a South-North orientation before meeting the Khoei River. Streamflow responds accordingly to the precipitation pattern showing two main seasons: a wet and a dry season (*Figure* 3-8).

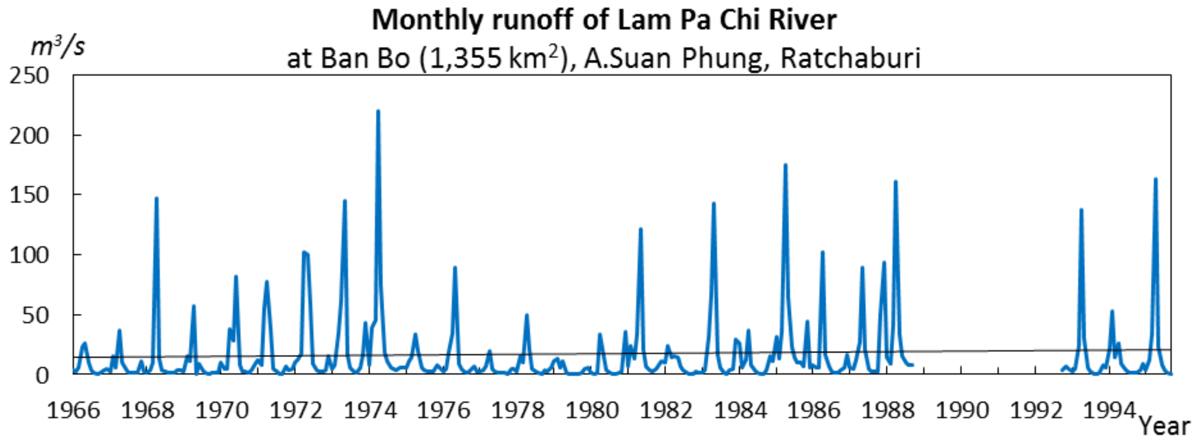
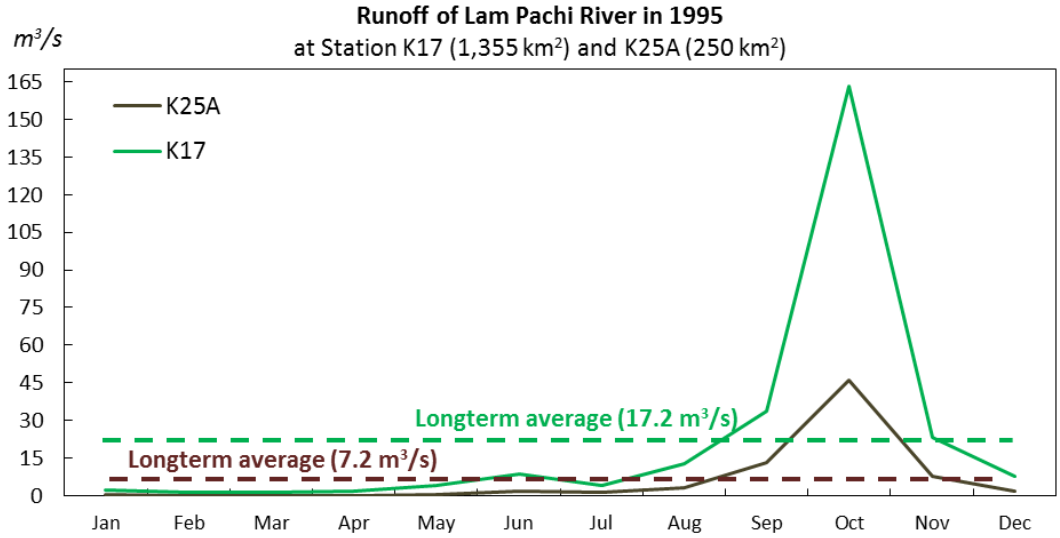


Figure 3-8. Long term monthly runoffs of Lam Pa Chi River (at Ban Bo, Suan Phung, Ratchaburi). *Data: http://irre.ku.ac.th/MIIS/miis(hydro)/rainfall_station.html*

According to monthly data available at the most downstream discharge station (k.62) the highest discharge occurs in October with an average value of 56 m^3/s while the driest months are from January until March with less than 3 m^3/s of streamflow in average. The ratio between the highest and the lowest streamflow is 25:1 showing a high intra-annual variability. Furthermore, two of the most relevant environmental problems in the basins are related with the response of the streamflow during the two abovementioned seasons: (i) flooding during the wet season and (ii) water scarcity during the dry period (Figure 3-9).



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
K25A	0.2	0.1	0.0	0.1	0.2	1.5	1.5	3.2	13.1	46.0	7.9	1.8
K17	2.2	1.5	1.3	1.6	3.9	8.6	4.2	12.7	33.5	163.4	23.3	7.4

Figure 3-9. Seasonal distribution of Lam Pa Chi's runoff
Data: *http://irre.ku.ac.th/MIIS/miis(hydro)/rainfall_station.html*

Although the second peaks of rainfall usually occur in May or June but those small rain events are not likely to substantially increase the river flow. The majorities of rainfall in these months are evaporated or infiltrated to the soil after drought in several consecutive dry months.

3.6 Geology and groundwater aquifers

According to Maita et al. (2004) igneous rocks from the Mesozoic and sedimentary rocks from the Paleozoic underlie the headwaters and the mountain range bordering Myanmar. Downstream, the lowlands of the watershed are formed from sedimentary rocks from the Quaternary Period. Geologically, Lam Pa Chi is formed with rock ranging in ages from Cambrian to Quaternary periods (Figure 3-10).

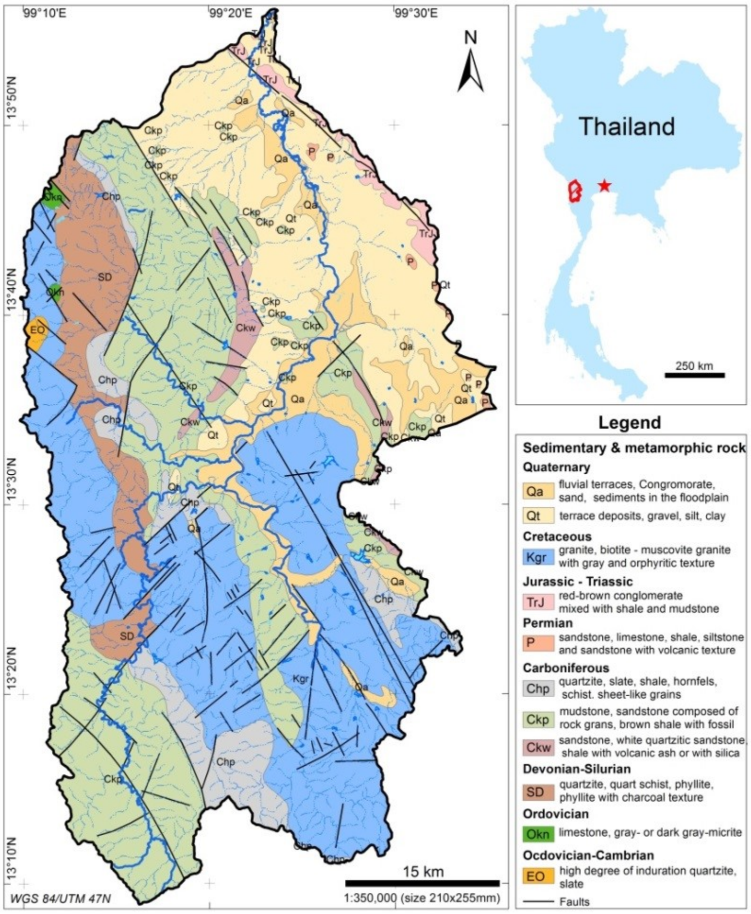


Figure 3-10. Sedimentary and metamorphic rocks in the basin

- Quaternary sediments in the Lam Pa Chi are subdivided into two sub-groups. The fluvial terraces, with coarse-grained sedimentary rock are distributed along the Pa Chi River in the middle and lower parts. The terrace deposits with gravel, silt, clay are formed in large areas in the lower part.
- Cretaceous sediments forming on the in the granite, biotite - muscovite granite with gray and orphyritic texture occurred in the areas, along the Thailand-Myanmar border and in the southeastern parts. The rock formed in this period ranks the second largest area (751 km^2), after Carboniferous periods (897 km^2).
- Rocks formed during Jurassic and Triassic periods are characterized by red-brown conglomerate mixed with shale and mudstone. The rocks in this period exist in small areas (30 km^2) along the fault in the northeast.
- A small area (5 km^2) of sandstone, limestone, shale, siltstone and sandstone with volcanic texture were formed during Permian period.

- Rocks with Carboniferous ages are subdivided into three sub-groups: quartzite, slate, shale, hornfels, schist -like grains in a preferred orientation (Chp); mudstone, sandstone composed of rock grans, brown shale with fossil (Ckp); and sandstone and white quartzitic sandstone, shale with volcanic ash, shale with silica content (Ckw). They are distributed in the northwestern parts.
- Quartzite, quart schist, phyllite, phyllite with charcoal texture formed in Silurian - Devonian periods are distributed in a strip (191 km^2) from northwest to southeast between rocks dating Cretaceous and Carboniferous periods.
- High-degree-induration quartzite, slate in Cambriam-Ordovician period and limestone, gray- or dark gray-micrite in Ordovician period distribute in small areas. Total areas of these rocks are 11 km^2.

Regarded to ground water, aquifers in the basin were dated from Cambrian to Quaternary periods. The Metasediment aquifers in Permian to Carboniferous periods share the largest areas and the aquifers formed in Ordovician period are smallest (Table 3-2). The granitic aquifers and colluvial aquifers have good quality while the water quality of Carbonate aquifers is moderate and the water quality of metamorphic aquifers is suitable for domestic use (Thailand Department of Water Resources).

Table 3-2. Aquifers in the basin

Code	Name	Age	Area (km^2)
D-Emm	Metamorphic aquifer	Cambrian to Devonian	133.9
Gr	Granitic aquifers	Cretaceous	810.2
Oc	Carbonate aquifer	Ordovician	3.7
Pc	Carbonate aquifer	Permian	28.7
PCms	Metasediment aquifer	Permian to Carboniferous	978.6
pEmm	Metamorphic aquifer	unknown	233.8
Qcl	Colluvial aquifer	upper Tertiary to Quaternary	384.3

The following map shows the spatial distribution of groundwater aquifers in the region (Figure 3-11).

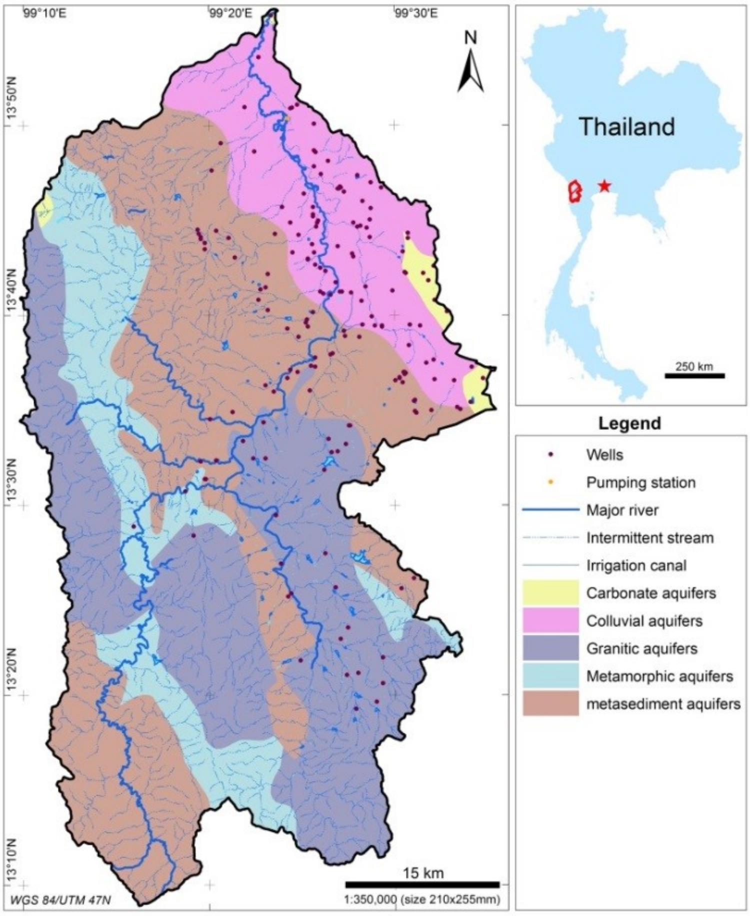


Figure 3-11. Groundwater aquifers

Groundwater aquifers formed in the Cretaceous and Permian to Carboniferous era share the largest areas and the younger aquifers in upper Tertiary to Quaternary eras share the small areas in the basin.

3.7 Land Use

Land use changes (e.g. deforestation, agricultural expansion, urbanization) can be regarded as important driving forces enhancing the current hydrological and water quality degradation trend in the world. Changes in land cover and in land use have become recognized over the last decades as important global environmental changes (Turner II 2002). Land use changes are also interrelated with other important environmental issues, such as climate change and carbon cycle, loss of biodiversity, and sustainability of agriculture (Lepers et al. 2005). The existing landuse pattern in the LPC is shown in Figure 3-12.

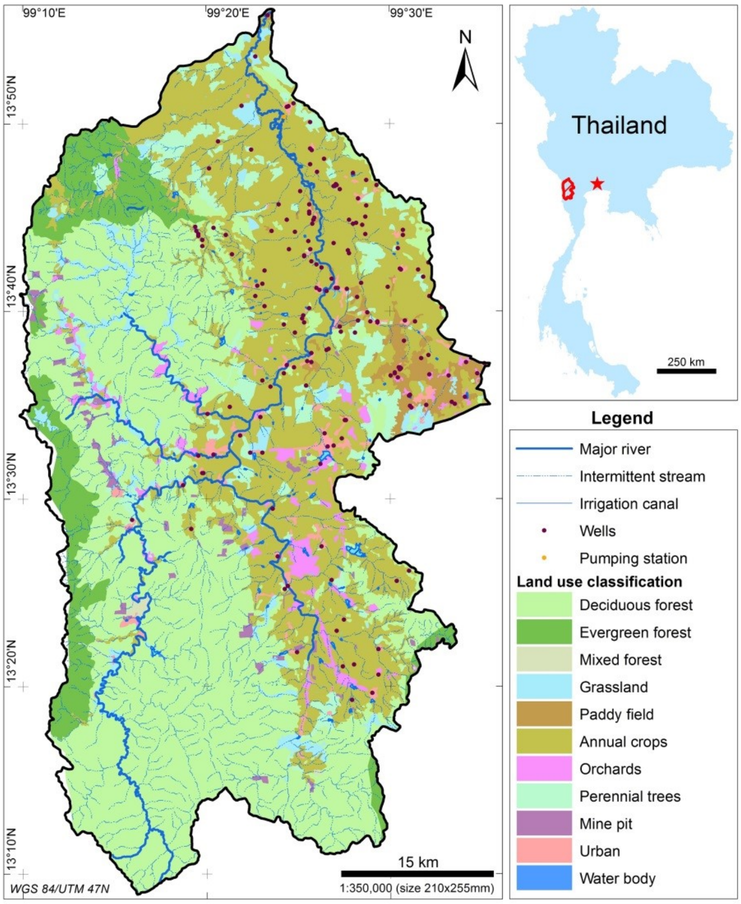


Figure 3-12. Main land uses within the basin

The region has faced rapid land use changes in the last decades including deforestation processes to gain the land for agricultural production. The impacts of deforestation on water resources are well documented including soil erosion, flooding, biodiversity and impairment of water quality through sediments (Foley et al. 2005), among others. Based on data from the Royal Forest Department (RFD) from 2002 Thangtham (2002) found out that in the provinces of Ratchaburi and Kanchanaburi (main provinces for the Lam Pa Chi) the forest cover drastically decreased during the period 1961-2000 going from 64.8% to 25.1% and from 91.3% to 60.5%, respectively. Forest clearance has the main purpose of increasing the area for crop production.

Table 3-3. Land use classes and their respective area within the LPC

Land use types	Area (km^2)
Deciduous forest	1,116.6 (44.1%)
Evergreen forest	187.0 (7.4%)
Mixed forest	3.9 (0.2%)
Grassland	80.7 (3.2%)
Paddy field	47.6 (1.9%)
Annual crops	917.5 (36.2%)
Perennial trees	136.2 (5.4%)
Urban	37.6 (1.5%)
Water body	6.4 (0.3%)

Table 3-3 shows the main land uses in the LPC. The different types of forest (including evergreen, deciduous and mixed) and field crops account for almost 85% of the total surface of the basin. Forest land use is found mainly in the mountain range in the western and southern part of the catchment. Moreover, crops are mainly produced in the lower and flatter parts such as the floodplains as well as in the hilly areas, in the case of pineapple.

3.8 Crop pattern

Classifying land use types provides first impression about water uses in the basin. However, in order to estimate more accurate water uses for agricultural production, spatial distribution of major crops is crucial important. Forest occupies half of the basin area and distributes mainly in the western upper parts of the basin. Forest ecosystem of the basin belongs to the Tenasserim Hills ecosystem. The degraded deciduous forests account for the largest forest areas. The evergreen forests expand in an area of approx. 1,000 ha. Teak, a valuable timber of deciduous forest, grows in 33.5 ha near the Thailand-Myanmar border. Eucalyptus is recently planted in large scale (over 10,000 ha) in the lower parts of the basin (Figure 3-13).

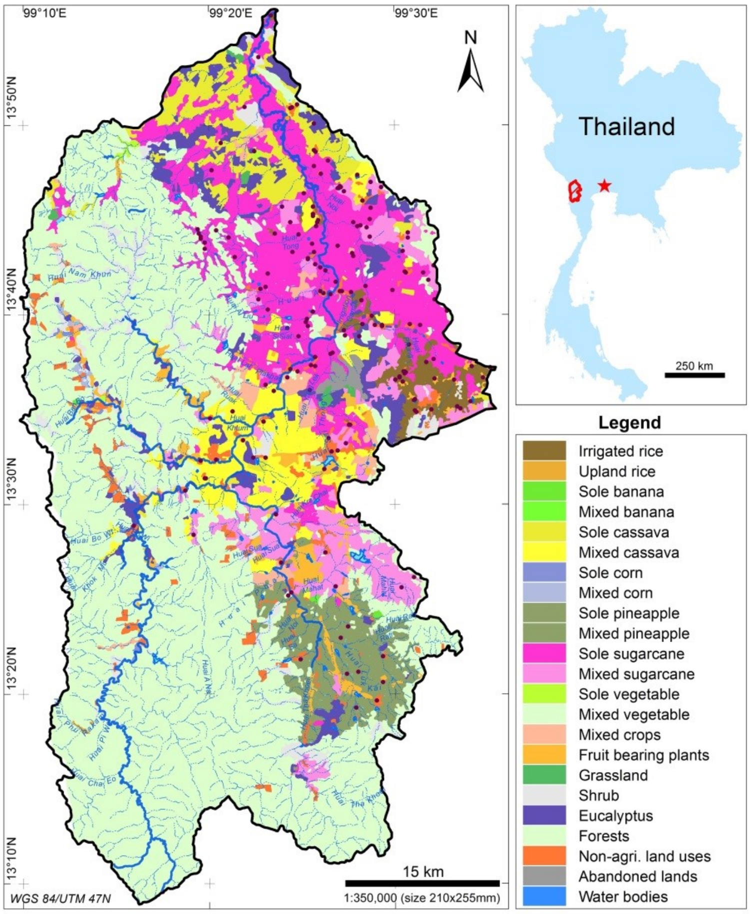


Figure 3-13. Agricultural land use in the LPC river basin

Non-agricultural production land uses accounts only 2.5% total area and mainly are lands for mining, rural settlement, transportation. Land use for urban activities is insignificant as the fact of low urbanization in the region (Figure 3-14).

Lands for agricultural production distribute in the eastern lower parts and along the large streams. 38% area of basin serves for agricultural production. Sugarcane is planted in the largest areas, approx. 50,000 ha (20% total area). The other major cultivated plants are cassava, pineapple and paddies. Paddy rice is plated in 4,760 ha and mainly is irrigated. In smaller proportion other crops such as corn, tamarind and mango are also cultivated (Figure 3-14).

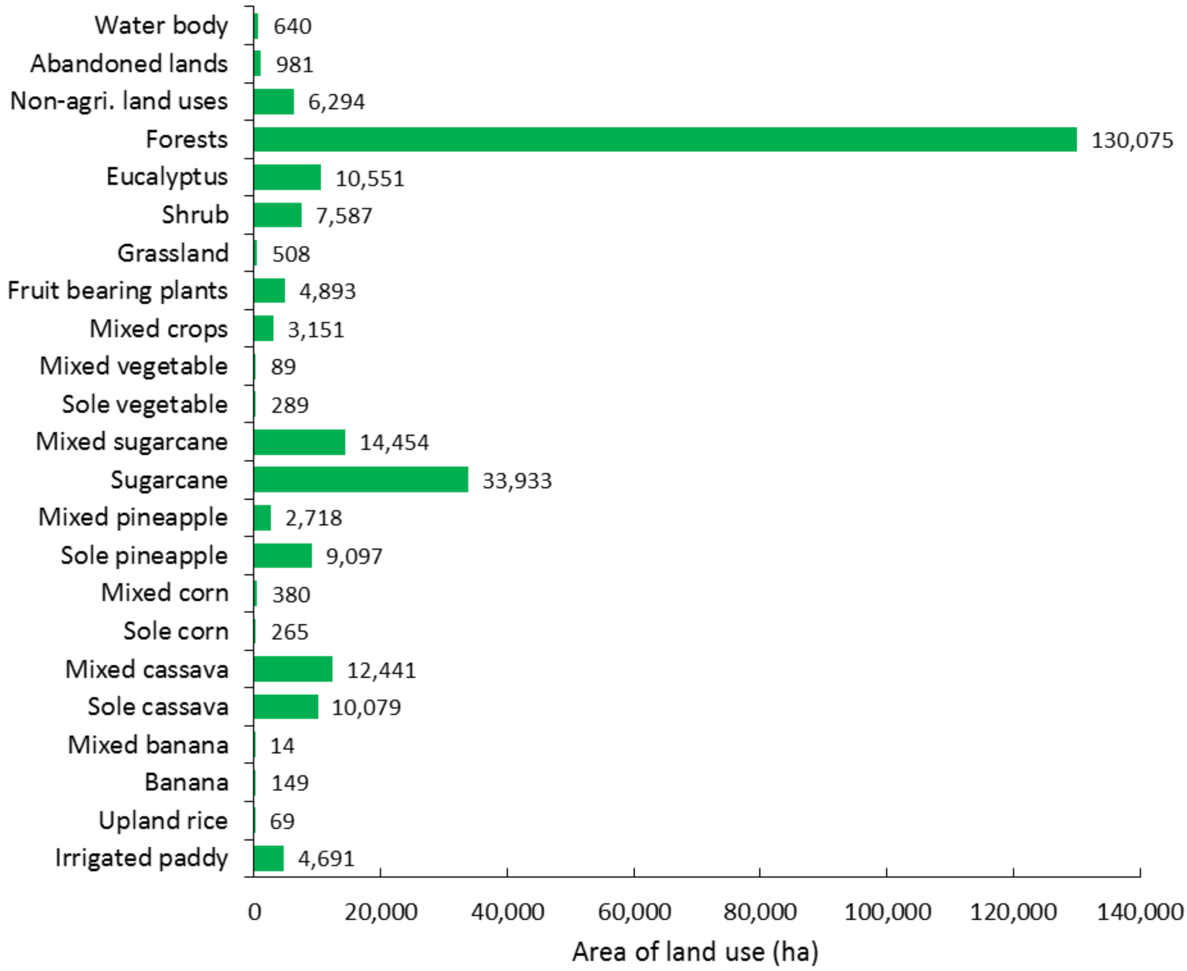


Figure 3-14. Area of major land uses types

In conclusion, half of the basin is covered by forest with deciduous forest accounting for the largest parts. Agricultural production land uses share about 38% of the area with sugarcane, pineapple, cassava, paddy being the major annual crops. Non-agricultural land uses are very limited (2.5%). Thus, the largest water abstraction in the basin is for irrigation purposes.

3.9 Soil types

A major part of the basin is sub-categorized as slope complexes, on which the forests are growing (Figure 3-14 and Figure 3-15). The well drained soils consisting of clay, loam and sandy soils distribute along the major branches in the lowlands and used mainly for agricultural purposes.

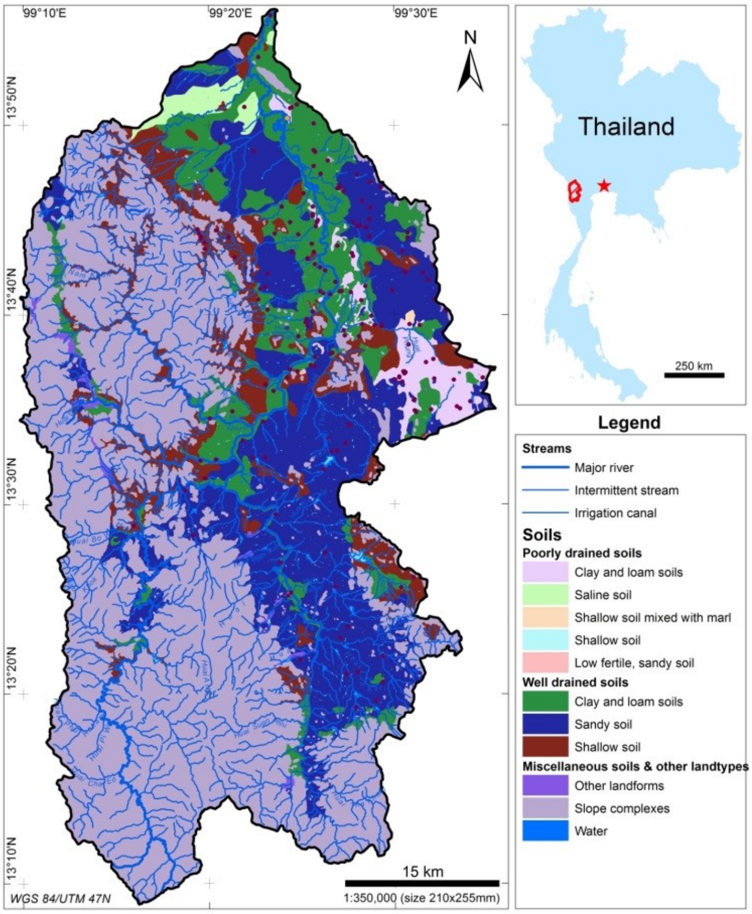


Figure 3-15. Soil map of the basin (Source: Shapes obtained by Department of Water Resources, Thai MONRE)

The major soils types in the basin is summarised in Table 3-4.

Table 3-4. Area of soil types (Source: Shapes obtained by Department of Water Resources, Thai MONRE)

Soil types	Area (km^2)
Poorly drained soils	
Clay and loam soils	62.8
Saline soils	0.3
Shallow soil mixed with marl	1.1
Low fertile, sandy soils	27.4
Well drained soils	
Clay and loam soils	339.2
Sandy soil	593.4
Shallow soil	242.9
Miscellaneous soils and other landforms	
Slope complexes	1,287.6
Other landforms	16.6
Water	2.8

3.10 Demography and Water Use

The total population of the basin adding the number of inhabitants of the four main sub-districts (Dan Makham Tia, Chom Bung, Ban Kha, Suan Phung) is 143,375 and according to Biltonen et al. (2003) over 80% of the population can be considered as rural. The rural population is mainly dependent on agricultural production and its related activities.

As mentioned before, the main crops cultivated in the region include pineapple, sugar cane, cassava and others. The production is mainly exported to other regions within the country and only two small factories transform the raw material into a food industry product: canned pineapple.

Surface and groundwater in the basin have three main uses:

1. Irrigation
2. Drinking water
3. Tourism / Industry

Irrigation infrastructure is under the responsibility of the Royal Irrigation Department (RID). For this purpose, 5 small dams and several weirs were constructed in the basin to store water, especially during the dry season. Water is pumped into channels to irrigate the individual crop fields. Detailed data about these water abstractions are not available. Only some rough values were obtained during a field visit to one of the pumping stations.

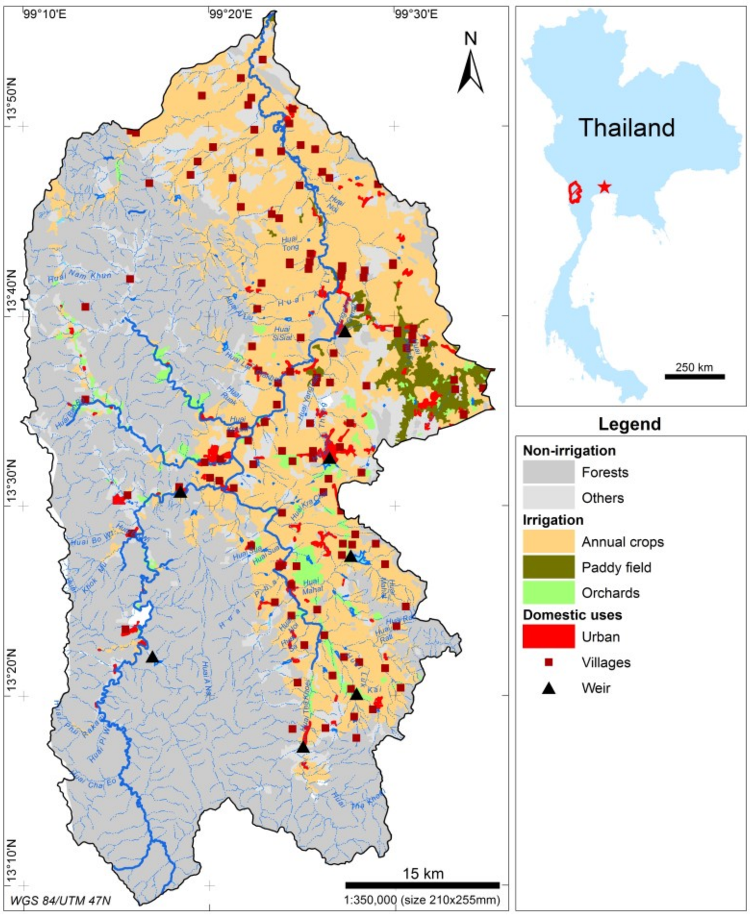


Figure 3-16. Relevant information to estimate water demand in the LPC basin: crop water demand

Figure 3-16 shows the settlements and agricultural area types to calculate crop water demand.

There is no law or regulation for groundwater abstractions. In the floodplains many wells have been constructed to extract groundwater and irrigate during the dry season. No reliable data about these abstractions is available.

The RID is also in charge of conducting hydrological and meteorological monitoring in the basin. A network of 4 discharge and 3 precipitation stations with monthly values was available. In the last decade, the Department of Water Resources (DWR) was founded. They also are in charge of monitoring water resources in the basin. In some cases, both departments run parallel monitoring activities.

Drinking water treatment and distribution is the responsibility of the Provincial Waterworks Authority (PWA). The PWA manages a dam to store water and divert it to a treatment plant. After the proper physical and chemical treatments water is distributed through pipelines into the main urban settlements. In the case of rural areas, water is pumped directly from streams or from the ground.

According to interviews conducted during our field visit to the basin, the tourism industry is growing rapidly in the region and is expected to continue growing in the future. Several hotel complexes are being currently developed in the floodplains impacting the morphology of the river but also increasing water consumption.

4 Climatic trends and predictions

4.1 Identification of climate change in the region

Climate change has been recognized as a relevant risk factor worldwide. IPCC (2012, 2013) summarizes recent research results on projections of GCMs regarding extreme temperature, precipitation, climate phenomena and drought and flood hazards. Key findings of the study are:

- According to model predictions it is virtually certain that substantial warming in temperature extremes (frequency and magnitude of warm days) will occur by the end of the 21st century. It is very likely that the length, frequency, and/or intensity of dry spells or heat waves will increase over land masses at a global level.
- Projected changes indicate that it is likely that the frequency of heavy precipitation or the proportion of heavy rainfalls from total rainfall will increase in the 21st century over many areas on the globe, especially in the high latitudes and tropical regions, and northern mid-latitudes in winter. For most parts of South East Asia projections suggest that in June-August intensity of rainfall will increase while for the period December-February it will slightly decrease.
- Regarding climate phenomena like monsoon, El Nino, Tropical cyclones there is not yet enough evidence to state that intensities will increase or decrease towards the end of the 21st century.
- Due to inconsistencies of projections and definitional issues there is low confidence regarding increasing drought probability for the region of South East Asia, even though there is medium confidence that in December-February the number of consecutive dry days will increase.

- Also for the issue of flood hazard there is low confidence that future climate change will lead to significant increases. This is due to the complexity of the relationship between precipitation patterns and flood peaks. There is medium confidence (based on physical reasoning) that projected increases in heavy rainfall would contribute to increases in rain-generated local flooding, in some catchments or regions.

Thus, regarding temperature and precipitation extremes the projections are providing a high degree of certainty while for the resulting impact on hazards no clear conclusion can be drawn yet. Observing and predicting the intensity of floods the SREX report (IPCC, 2012) emphasizes that it is problematic to separate climate change from other human impacts; many rivers, for example, are not in their natural status any more leading to huge alteration of flood patterns, independent of climate factors (IPCC, 2012).

However, the impacts of climate change are region dependent. Several studies appoint Thailand as a vulnerable country to the impacts of climate change: droughts, tropical storms, large scale floods and flash flooding. Being Thailand the major rice producer in the world, such impacts pose a threat to the livelihood of almost half of the country's population.

Eastham et al. (2008) for instance predict that in 2030 the Nakhon Phanom, Mukdahan, Yasothon and Ubon Ratchathani catchments of northeast Thailand will continue to face high levels of water stress during the dry seasons, despite higher annual precipitation. Driving forces are rising temperatures and decreased dry season precipitation as well as higher water withdrawals than availability. The Khorat Plateau area may also experience a significant shift in season. Rainfall during the early months of the wet season will increase, especially in July. The dry spell between the early season rain peak and late season rain peak will be reduced from three months (July–September) to two months (July–August). The areas which will be particularly wetter in June and July will be the southern provinces. The late season rain peak will be longer and wetter, especially in September when the monthly rainfall will be increased from 15 bcm per month to 26 bcm per month. The overall rainfall in the area of the Khorat Plateau will be increased from 124 bcm per year to 137 bcm per year, i.e. a 10% increase (Eastham et al., 2008).

Lacombe et al. (2012) characterize projected fine-scale changes in precipitation and temperature in Southeast Asia over the period 1960–2049. He uses grid-based daily precipitation and temperature time series produced by the PRECIS regional climate model under A2 and B2 scenarios. Trend analysis and detection was carried out by applying the modified Mann-Kendall test. The results indicate that temperature increases over the whole region with steeper trends in higher latitudes (Lacombe et al. 2012). Changes in precipitation rates are minor over continental areas in contrast to other climate studies that suggested significant precipitation changes over Southeast Asia. TKK & SEA START RC (2009) carried out dynamical downscaling of the PRECIS regional climate model based on ECHAM4 GCM data. In their study they considered two climate scenarios based on two different CO_2 rising schemes, SRES A2 and B2 (IPCC, 2000). The regional climate scenarios were simulated at high resolution of approximately 25km x 25km, and rescaled to resolution of 20x20km. Their results from both GCMs for maximum and minimum temperatures also indicate that the region will become slightly warmer in the future. Concerning precipitation, model simulations indicate that precipitation will fluctuate in the first half of the century, but show an increasing trend during the latter half of the century. The simulations according to the B2 scenario show fewer changes in precipitation than the A1 scenario. No detailed analyses of these downscaling results were included in the cited publication (Keksinen et al., 2010; TKK & SEA START RC, 2009).

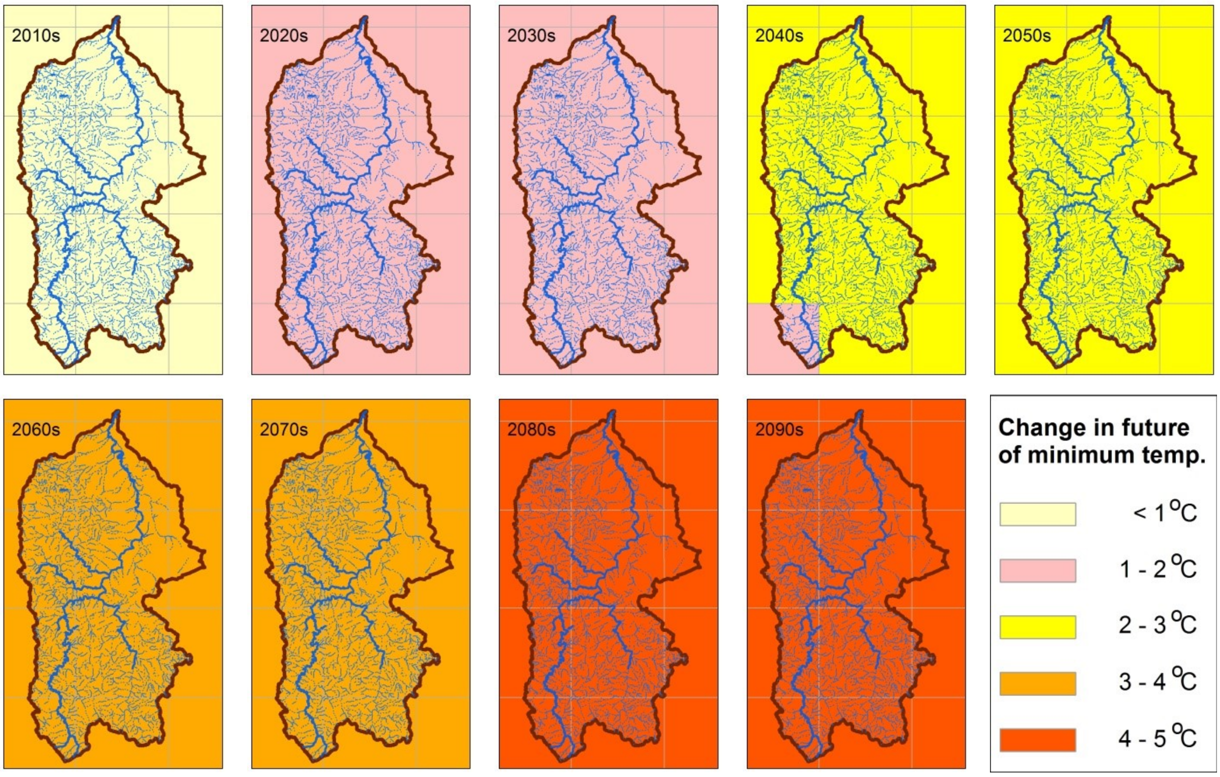
Johnston et al. (2010) for IWMI carried out a climate change and water resources analysis for South East Asia and the Greater Mekong region. They used observed (1953-2004) and projected (1960-2049, using PRECIS climate model) rainfall and temperature data in the region, to identify climate trends. Based on the results of this study and others, Johnston et al. (2010) summarized the projected climate changes in the GMS to 2050 as follows:

- Increase in temperature of 0.02–0.03 °C per year across the entire region in both warm and cold seasons, with higher rates of warming at higher latitudes
- Higher temperatures will increase evapotranspiration and hence increase irrigation demand
- No significant change in annual rainfall across most of the region (projected changes in rainfall vary from decreases of a few per year to increases of up to 30 mm, with a high degree of uncertainty).

In conclusion, based on these projections, climatic extremes in the Lam Pa Chi basin may become more intense. However, exact future intra-annual precipitation patterns are not predictable and even lower rainfall rates are not consistently predicted. However, all simulations and trends agree that temperatures will increase during night and day time as well as in both warm and cold seasons and expose negatively impacts on evapotranspiration during dry periods. This might lead to increasing evaporation rates as well as to increasing irrigation demand in especially dry periods, putting a secure and constant water supply at risk.

4.2 Change in future of minimum temperature

In the next two decades, the minimum temperature is projected to increase 1 – 2°C in whole basin. The minimum temperature will continue increasing with higher rate in the next two decades (2040-2060s), especially in the lowlands and midlands. In comparison to the temperature pattern in 1960s, the minimum temperature in the end of 21st century will increase 4-5 °C, the average rate is projected at 0.5 degree Celsius for each decade (Figure 4-1).



Source: Developed from http://gis.gms-eoc.org/ClimateChange/start2/index.html

Figure 4-1. Future change of minimum temperature based on outputs of ECHAM4-A2-PRECIS RCM scenario

The climate outputs of ECHAM4-A2-PRECIS RCM and ECHAM4-B2-PRECIS RCM scenarios developed by SEA START Regional Center indicate the significantly increase of minimum temperature, especially in the A2 Scenario. The annual minimum temperature will surpass 25°C in both A2 and B2 scenarios at end of 21st century. The annual minimum temperature at that time is projected in the range of 25.1 to 26.8 °C (Figure 4-2).

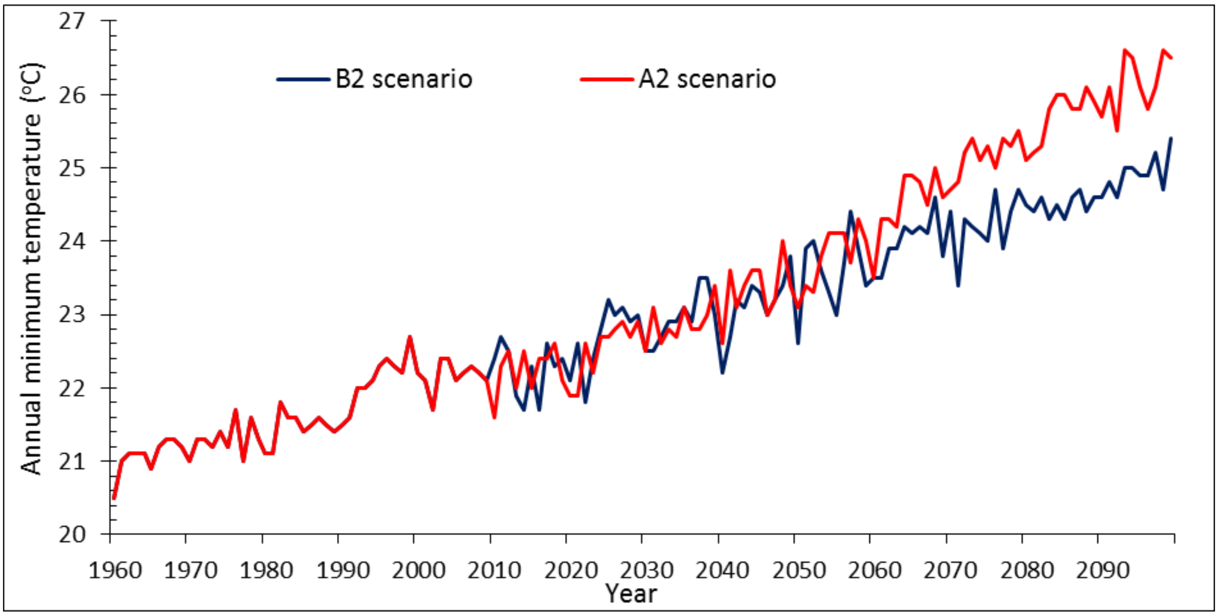


Figure 4-2. Projected trend of annual minimum temperature
Data: Southeast Asia START Regional Center

Together the upward moving of annual minimum temperature, the amounts of cold days in a year is projected to significantly decrease. Amount of the days with temperature being under 15°C will decrease from aprrox. 13 days per year in 1960s to lower than 5 days per year after 2050s. At the end of the 21st century, the Lam Pa Chi, except the high mountainous areas will not have temperature lower than 15°C (Figure 4-3).

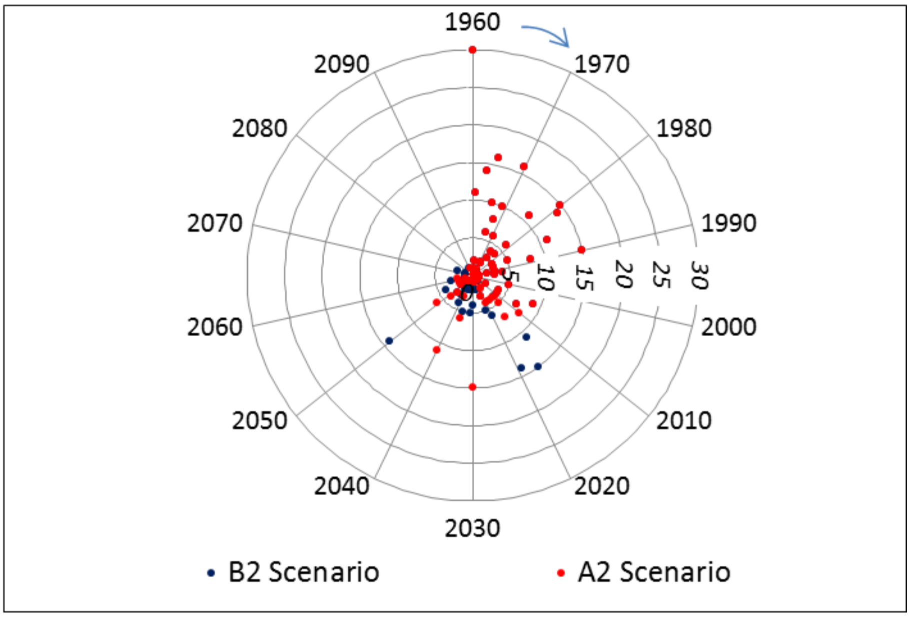


Figure 4-3. Amount of cold days (15°C) in a year in 1960 – 2099 period
Data: Southeast Asia START Regional Center

Months from October to February in Central Thailand are usually regarded as „cool season“ but with the upward rising of temperature, the „cool season“ is likely to disappear in the future.

4.3 Change in future of maximum temperature

In the next three decades, the maximum temperature is projected to increase 1 – 2°C in whole basin. The maximum temperature will continue increasing with higher rate in the next two decades (2060-2070s), especially in the lowlands, where it is projected to increase 3 – 4 °C while in the highlands and midlands, the maximum temperature is projected to increase 2 – 3 °C (Figure 4-4).

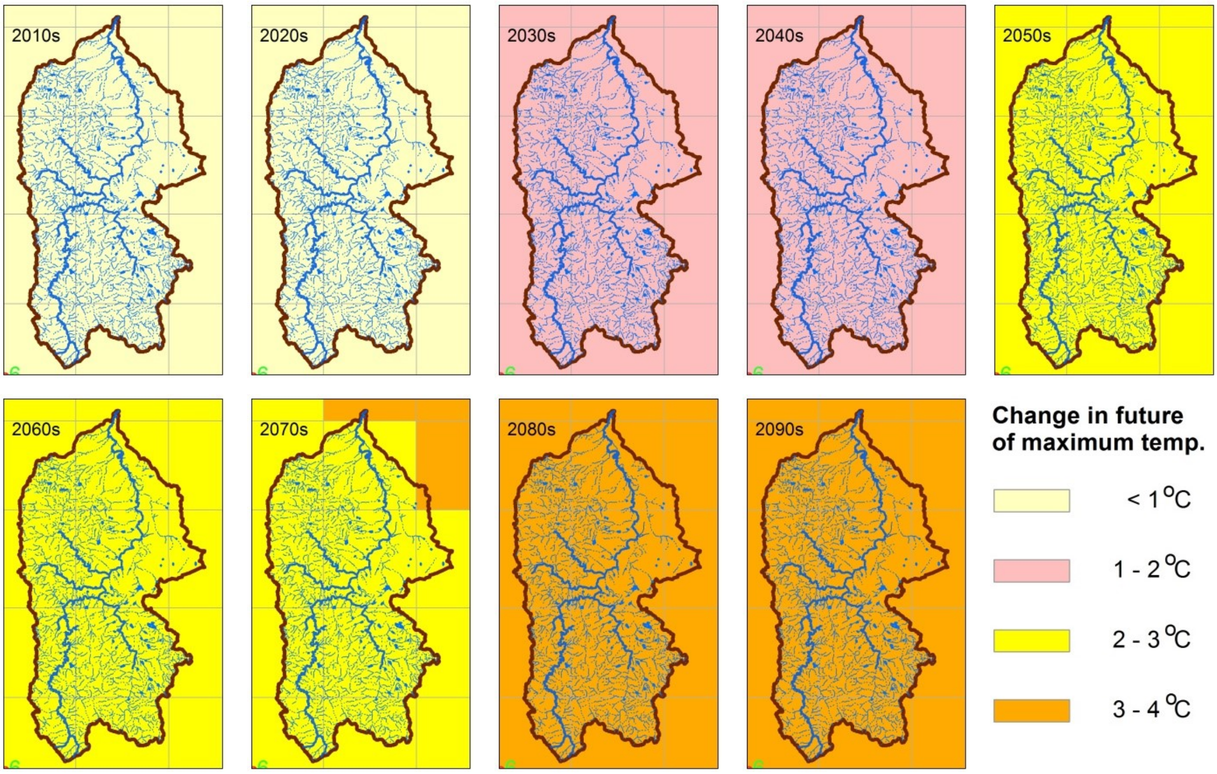


Figure 4-4. Future change of maximum temperature based on outputs of ECHAM4-A2-PRECIS RCM scenario. Source: Developed from http://gis.gmseoc.org/ClimateChange/start2/index.html

Climbing up of annual maximum temperature occurs in both A2 and B2 scenarios. In comparison to the temperature pattern in 1960s, the maximum temperature in the end of 21st century in the region will increase 3-4 °C, the average rate is projected at 0.3 – 0.4 degree Celsius for each decade (Figure 4-5).

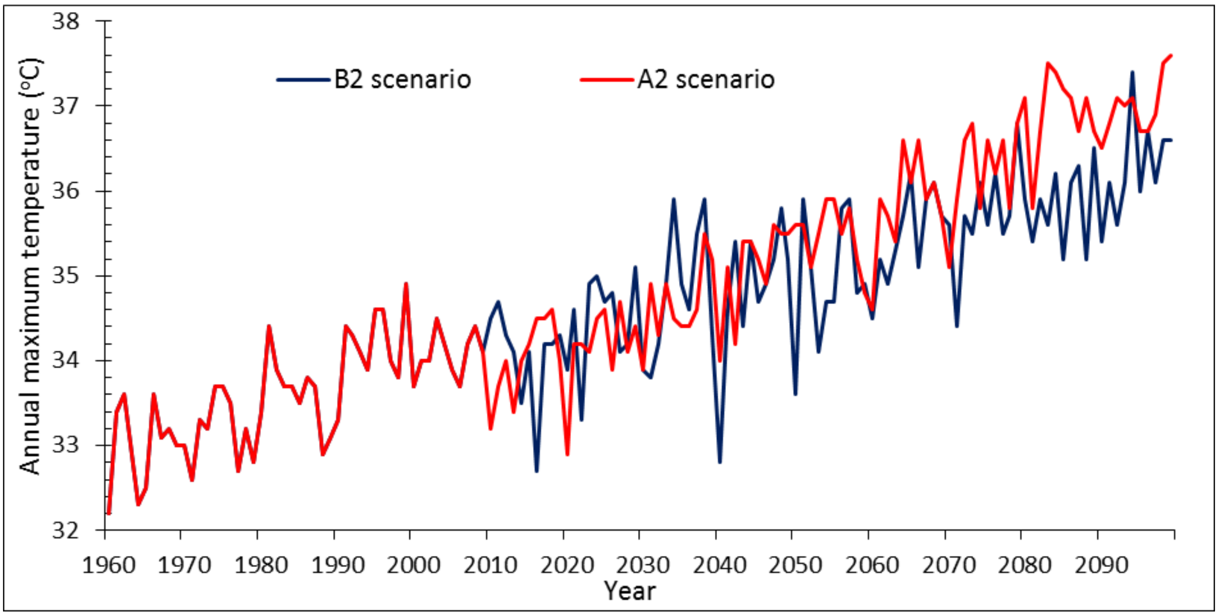


Figure 4-5. Projected trend of annual maximum temperature,
Data: Southeast Asia START Regional Center

The days with excessive temperature (≥ 35°C) will increase as consequences of global warming. The climate change outputs of recent researches show the frequent appearance of days with excessive temperature. In average, there were less than 100 days with excessive temperate during 1960- 2000. The situation changes significantly in the next decades. At the end of 21st century, in a course of a year, more than 250 days being projected to have excessive temperature (Figure 4-6).

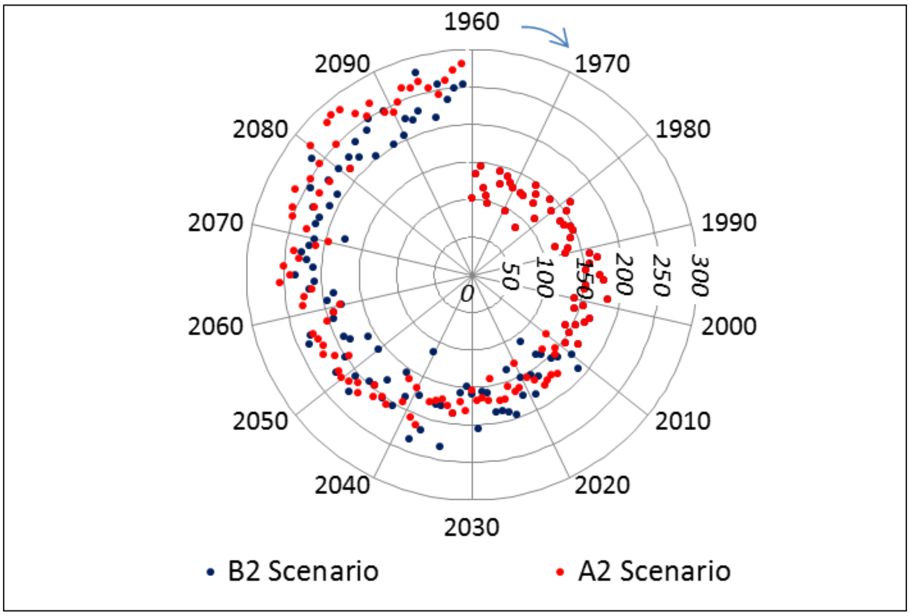


Figure 4-6. Amount of hot days (35°C) in a year in 1960 – 2099 period
Data: Southeast Asia START Regional Center

Analysing the climate outputs of ECHAM4-A2-PRECIS RCM scenario indicates that the increase rate of minimum temperature is higher than the increase rate of maximum temperature. The high increase rate of both minimum and maximum temperature in the pattern of high temperature will result unfavorable temperatures for the region.

4.4 Change in future of precipitation

Precipitation is an important indicator to assess water resources of a given region. The spatial changes of precipitation over time provide key information to manage water resources of a basin. Based on the output of ECHAM4-A2-PRECIS RCM scenario developed by SEA START Regional Center, the spatial changes in precipitation in Lam Pa Chi Basin in the future is mapped as shown in Figure 4-7. Changes in precipitation in the mountainous areas are much larger than in the lowlands. Precipitation is projected to decrease in the next three decades till 2050s before increasing afterward. Large tolerance of changed precipitation (from < -200 mm to > 500mm) poses several difficulties in managing water resources in the region.

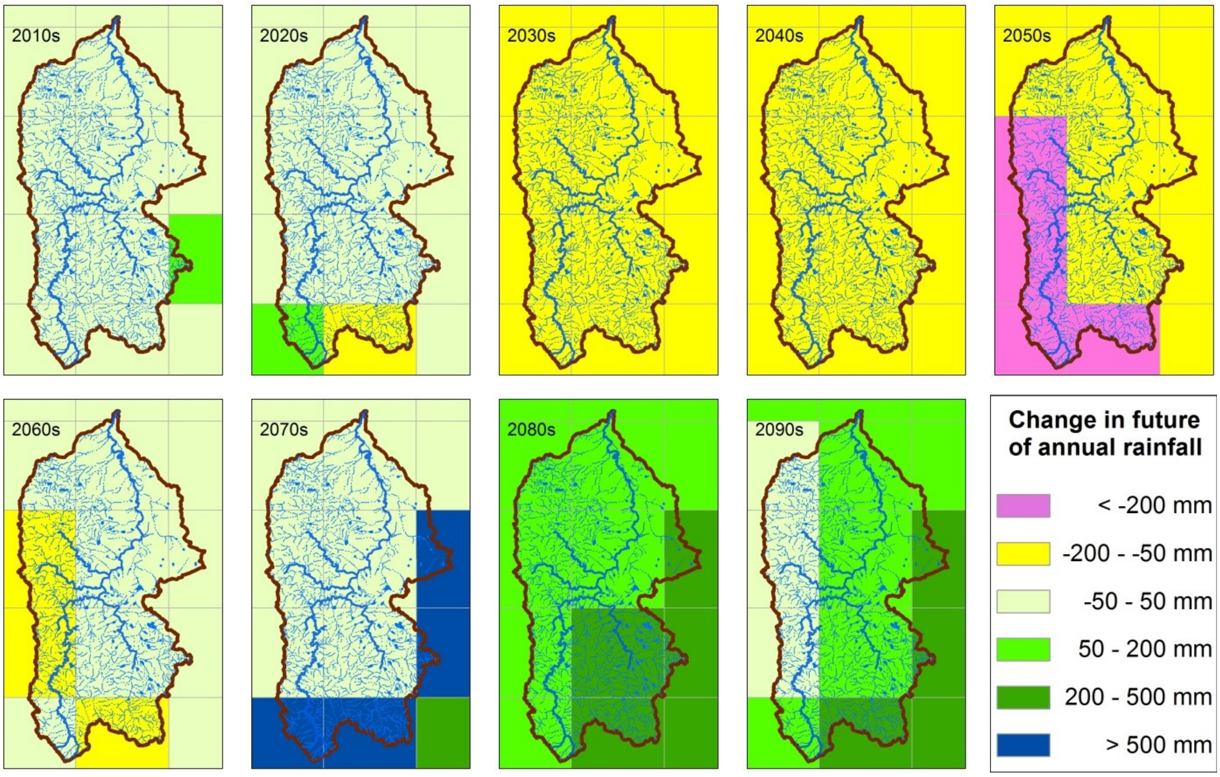


Figure 4-7. Future change of annual precipitation based on outputs of ECHAM4-A2-PRECIS RCM scenario,
Source: Developed from http://gis.gms-eoc.org/ClimateChange/start2/index.html

In long term, the precipitation of the region is projected to slightly increase in both A2 and B2 scenarios as shown in Figure 4-8.

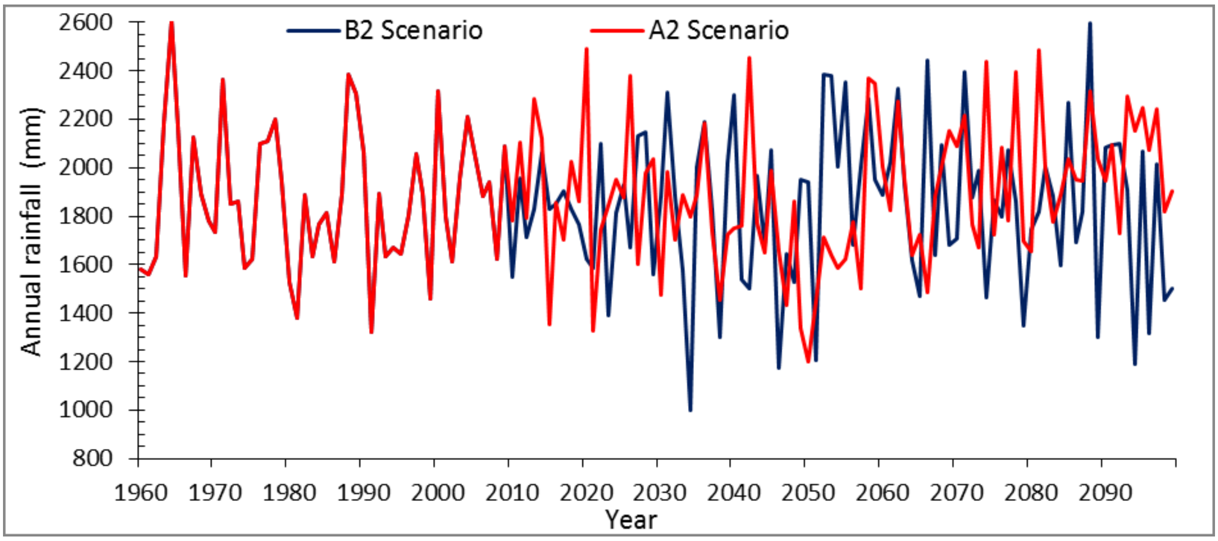


Figure 4-8. Projected trend of annual precipitation
Data: Southeast Asia START Regional Center

Amount of rainy days in a year is rather constant in coming decades with approximately 150 – 200 having rain (> 0.1 mm/ day) in a year (Figure 4-9).

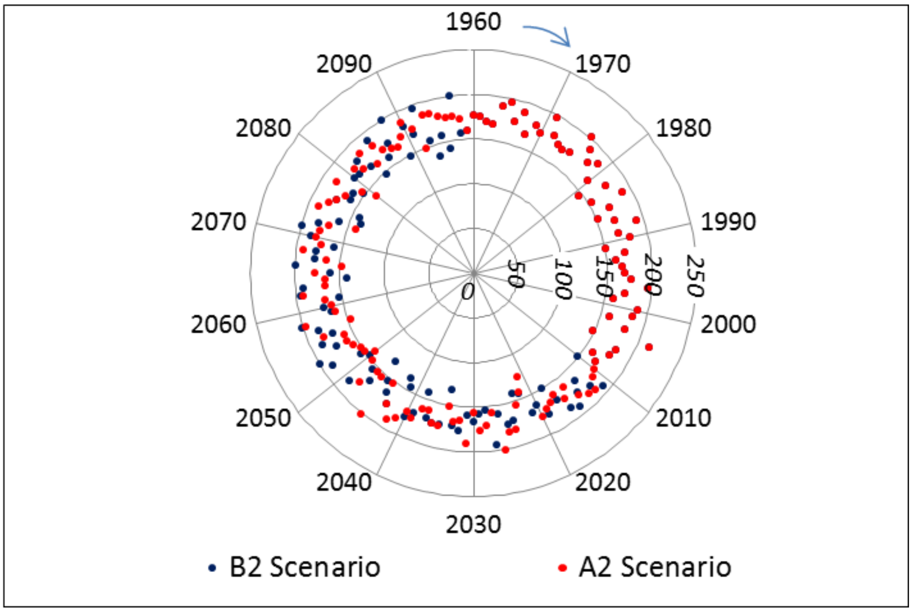


Figure 4-9. Amount of rainy days (> 0.1 mm/day) in a year in 1960 – 2099 period

Amount of rainy days, rainfall volume, and daily highest rainfall provide useful information for water resources management in a given river basin. These data of the Lam Pa Chi would be uploaded in the RBIS for further investigation.

4.5 Comments on climate change in the region

By analysing climate change outputs of different developed scenarios, some conclusions on climate change in the Lam Pa Chi can be discussed:

- The minimum temperature of the whole basin will increase approximately by 4 – 5 °C in the end of 21st century, the "cool" seasons in the region will no longer appear. The days with temperature under 15 °C will also significantly decrease, particularly after 2050s.

- The effects of global warming to temperature pattern in the basin are also shown in the increase of the amount of days with excessive temperature (≥ 35 °C). At the end of the 21st century, over the course of a year, excessive temperature is projected to occur in around 200 – 300 days.

Precipitation is projected to vary in the next decades with upward and downward changes in different periods. The climate change scenarios also indicate the spatial and seasonal changes of precipitation. The rainfall patterns in uplands and midlands will be more sensitive to change than the rainfall patterns in the lowlands. Higher rainfall in rainy seasons and lower rainfall in dry seasons will lead to long lasting droughts, water shortages in dry periods while likely cause large flood in wetted periods.

5 Water Balancing

In order to account for the water balance of the basin and to provide the basis for developing future scenarios the WEAP (Water Evaluation and Planning) model is an adequate tool. The following chapters describe the basic functionality of WEAP and apply it to evaluate and plan water uses in the LPC basin as far as the data basis permits. It should be emphasized that the following is based on the available data and rather shows the potential application of the WEAP model for the basin water balance model than directly useable input for decision making.

5.1 Introduction to WEAP (Water Evaluation and Planning)

WEAP is a model used for evaluating and planning of water resources on a local to national level. The evaluating and planning processes encompass estimating water supply and water demand. The scope and accuracy of the resulting simulations depends on the system which is intended to be described and its available data. Urban districts exhibit distinctively other water demanding parties, such as energy producers; as do more rural areas with the predominant one being agriculture.

Due to the fact that the stakeholders change from area to area, the accuracy of available data varies and influences directly to the reliability of the simulation. After recreating the prevalent system, developed scenarios are run. Whenever modelled scenarios being run (environmentally or economically), there are questions should be answered qualitatively or quantitatively (such as trends and assumptions). In some specific cases, such questions might entail what the impacts of industrial growth, population growth, accelerated urban migration on water demand or what are probably the most concerns that the scientific community tries to answer, or how future climate change will affect our everybody's lives in terms of water supply and demand.

To be confident that a model is able to answer such questions sufficiently it is imperative to look at certain quantifiable indicators such as the number of publications which used that particular model and how widely it is used in terms of countries and institutes all over the world. WEAP is used in at least 5 continents and 22 countries and served for research purposes in over 300 publications which is therefore an important and sufficiently tested tool to assess and plan the world's water resources.

WEAP's greatest advantage is its flexibility, as can be displayed by the work of e.g. the World Bank in 2015 where the possibilities of enhancing Africa´s infrastructure resilience to climate change were tested by B.J.M. Goes, et al. (2015) who looked on the integrated water resource management of a river in Afghanistan or in a research conducted in 1995 by Paul Kirschen, et al. where WEAP was used for transboundary water management. Other reasons might be that files produced with GIS-programs can be used easily with no compatibility problems and the straight-forward operation of the model enables beginners to have a steep learning-curve.

5.2 Hydrological Inputs

Basic hydrological inputs for the River Basin contain climate data such as precipitation and evapotranspiration. The remainder of rainfall not consumed by evapotranspiration is simulated as runoff to a river, or can be proportioned among runoff to a river and flow to groundwater via catchment links.

The input data for the simulation was obtained in monthly values. They are:

Precipitation

Three stations were used to obtain the mean precipitation for each sub–watershed using the Thiessen Polygon Method in ArcMap. Time series data was available from year 2000 until 2013. The average monthly precipitation for the sub–watersheds varies between 89 – 104.2 mm, with the lowest values exhibited by the eastern part and highest values by the western parts of the basin (see Figure 3-7).

Evapotranspiration

Due to lack of information on important data such as wind speed, radiation or humidity, which is needed to use the more accurate Penman-Monteith equation, the Blaney-Criddle Method was used for evapotranspiration estimations (Equation 1).

$$ET_0 = p * (0.46 * T_{mean} + 8) \quad (1)$$

Where:

ET_0 = Reference crop evapotranspiration in mm day^{-1} as an monthly average
T_{mean} = Mean daily temperature in °C
p = Mean daily percentage of annual daytime hours to maximum daytime hours

Groundwater

In most watersheds surface water systems and groundwater aquifers are hydraulically connected. Streams can contribute to groundwater recharge or can gain water from the aquifer depending on the groundwater level. The levels of the groundwater table respond to natural recharge from precipitation, but can also be influenced by irrigation in the watershed, where a portion of this water may recharge the aquifer rather than be utilized by the crop.

Unfortunately, no studies with the aim of sufficiently quantifying those resources were conducted in the basin so far. The available data suggests a groundwater recharge and use of ca. 80 000 m^3 km^{-2}. The initial storage capacity was assumed to be three times this value in order to ensure that the aquifer will never be drained completely.

Runoff

Time series data from four streamflow gauging stations in the basin was available with monthly averaged values for the river discharge. Data was available from year 2003 until 2013 (See *Figure* 3-8 and Figure 3-9).

5.3 Agricultural demand

To calculate the water demand of the agricultural area the software CROPWAT developed by the FAO was used. Input data for CROPWAT, such as Kc values, growth stage values, was obtained from www.fao.org. The demand of fruit trees had to be assumed to be the same as of citrus trees. Further information of crop specific water demands can be found in Annex A.

5.4 Domestic demand

The Domestic Sector in Thailand consumes 5% of total water resources (Thai Water Partnership, 2013). The domestic water demand differs among rural and urban population whereby the rural population has a significantly lower water consumption of 50 l day^{-1} cap^{-1} compared to 250 l day^{-1} cap^{-1} for the urban areas (Thai Water Partnership, 2013). The Lam Pa Chi however consists of 80% rural and only 20% urban population divided in 132 villages among the 5 sub-basins (ITT, 2015).

In order to calculate the population distribution, the total number of inhabitants in the basin was divided by the area of each sub-watershed. The population density was assumed to be around 70 persons per square kilometer.

5.5 Scenarios

Scenarios created by WEAP are a simplified form to explore the effects of future changes in hydrological patterns. Implemented supply and demand sites can be interlinked and adjusted according to observed trends in order to create assumptions for future situations. Four following scenarios have been developed:

- Scenario – Increase in domestic water demand
- Scenario – Agricultural expansion
- Scenario – Improvement of irrigation efficiency
- Scenario – Climate Change

Scenario – Increase in domestic water demand

According to the Thai Water Partnership Report from 2013 an increase in the per capita consumption of water is likely to happen. Within the next 20 years researches expect an increase of 35% per person. However, several evidences of developed countries state that domestic consume does not increase infinitely but rather become stable or even decrease due to technical developments and environmental awareness. Since no sufficient data was found for trends in rural areas in Thailand after 2035, a cap was set from this point on.
The expected 35% were distributed equally among 20 years resulting in an annual growth of 1.75%. Additionally the seasonality of domestic water withdrawal was taken into account using 120% of the average during the dry season and 80% during the wet season (Walker, 2002).

Scenario – Agricultural expansion

The area of land used for agricultural production in the Lam Pa Chi is expected to grow in the upcoming years. Currently the growth factor of agricultural land is 2% (Leturque et al. 2010). Mainly due to geographical reasons this expansion will not continue indefinitely, since the watershed at some point runs out of arable land (see Figure 3-13). Therefore a cap was set after 10 years resulting in a total expansion of 20%.

Scenario – Improvement of irrigation efficiency

Innovations and developments in irrigation technology show a distinctive potential to improve efficiency in agricultural water use. Studies show irrigation efficiency in large state-run schemes in Thailand as low as 30% (Molle, 2003). Replacing traditional irrigation methods by advanced technologies such as drip-irrigation will improve efficiency rates. And agricultural water consumption can be reduced by at least 25%. This was implemented in WEAP as an annual change in water demand of -0.7%.

Scenario – Climate Change

In contrast to the previous scenarios Climate change will have an impact mostly on the supply site. In Thailand, the major expected impacts come in terms of temperature increase of 3 degree Celsius and an increase of rainfall of 20% until 2100. Until now, there are no results available for this scenario. It will be implemented at a later time, if required.

5.6 Results

Scenario 1 - Increase in domestic water demand

As seen in Figure 5-1, the domestic water demand shows a steep increase until 2035. The annual water consumption increases from 32 m^3 cap^{-1} to 58 m^3 cap-^{1} which is an increase of daily consumption values from 88 l day^{-1} cap^{-1} to 124 l day^{-1} cap^{-1}.

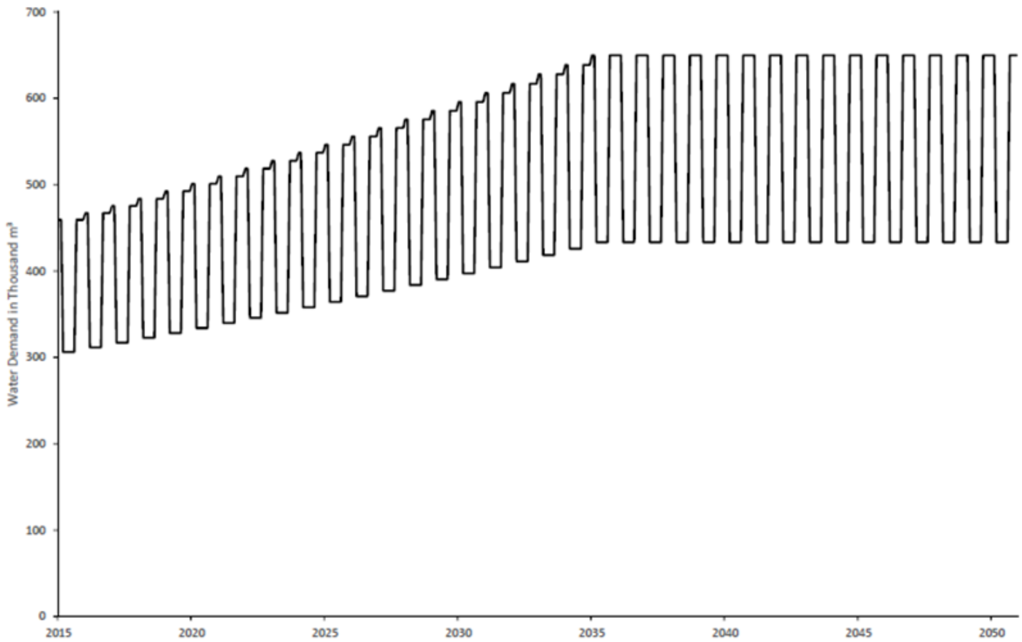


Figure 5-1. Scenario result of water demand considering increase in domestic water demand

Scenario 2 - Agricultural expansion

An increase in agricultural land usually results in higher water demand due to an increase in irrigated area, this impact was tested in Scenario 2 and the results are shown in Figure 5-2.

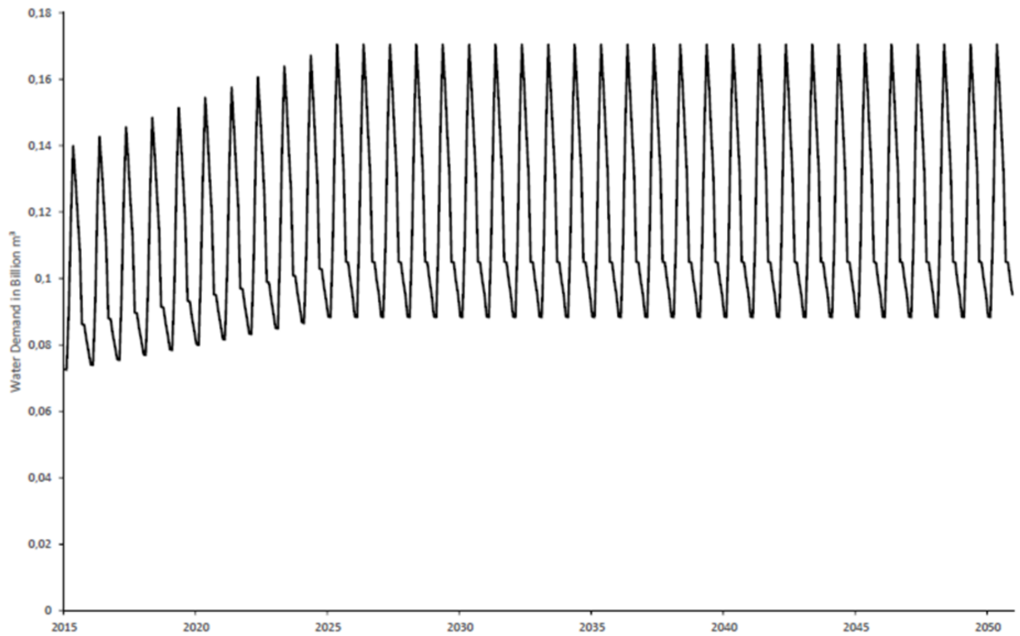


Figure 5-2. Scenario development of water demand considering agricultural expansion

Scenario 3 - Improvement of irrigation efficiency

The impacts of increased efficiency of irrigation schemes used in the Lam Pa Chi River Basin are displayed in Figure 5-3 and show a significant decrease in water demand from agricultural practices

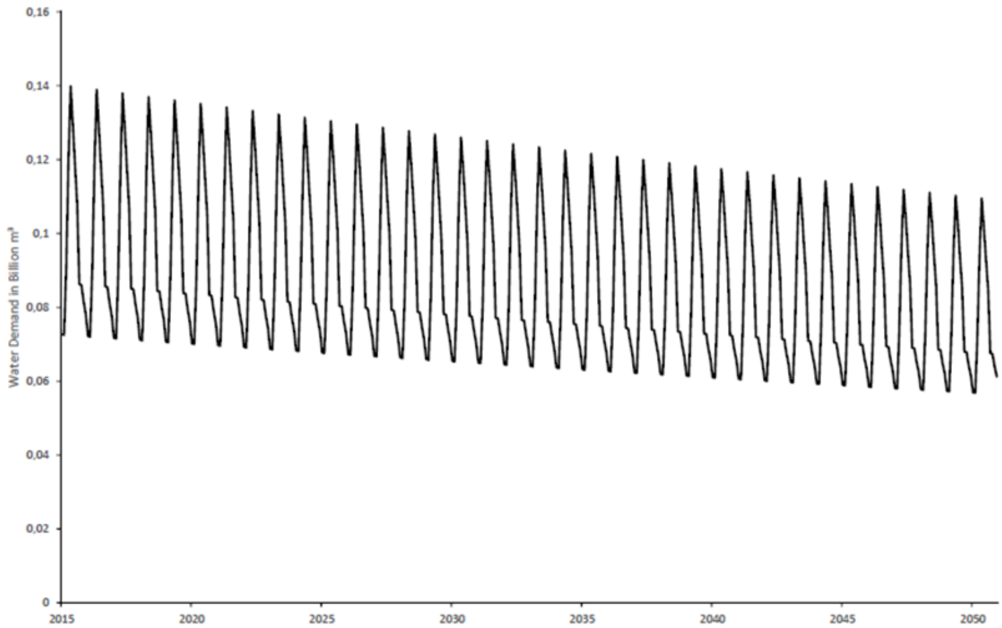


Figure 5-3. Scenario result of water demand considering irrigation efficiency

Combined scenarios

In order to gain a holistic picture, the individual outcomes of the listed scenarios are compiled and presented in two forecasts: the worst case scenario and a trend including counter measures.

Worst case scenarios describe exclusively negative impacts as in this case increasing water demands (Figure 5-4). In this specific situation it includes increases in domestic consumption and expansion in agricultural area. The trend line shows the constant rise of water consumption of the both considered sectors.

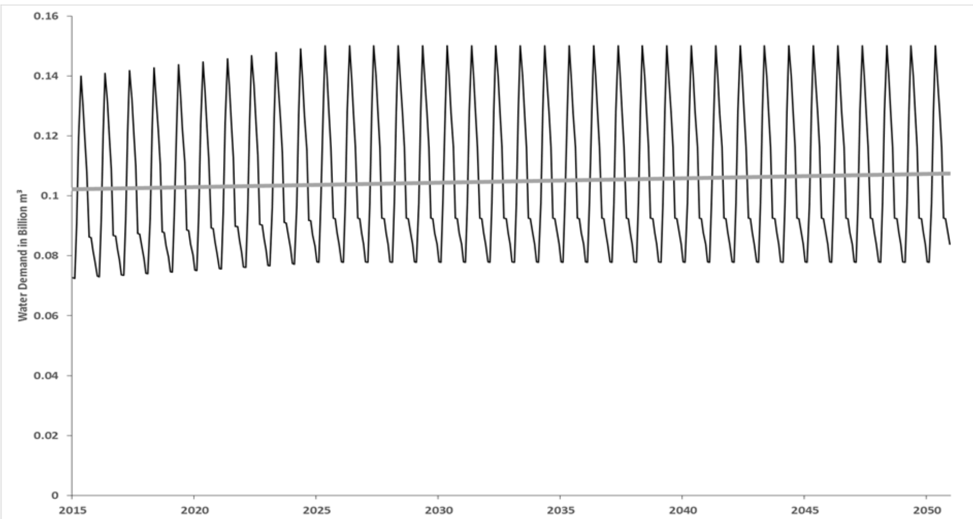


Figure 5-4. Scenario result of water demand in the worst case (scenario 1&2 combined)

The annual total water demand for the worst case increases from 1.18 billion m³ to 1.27 billion m³ (Figure 5-5). This is an increase of 7.3% from 2015 to 2025 and a much smaller increase from 2015 to 2050 of less than 7.33%.

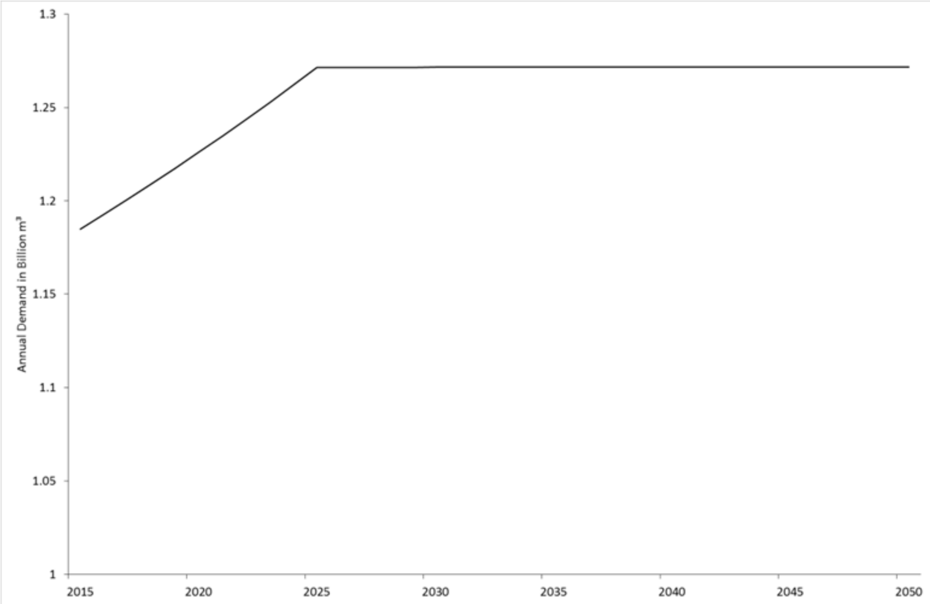


Figure 5-5. Annual-total water demand of the worst case scenario (scenario 1&2 combined)

Especially the total annual value gives evidence that the agricultural sector is the main reason for the steep growth.

Since the percentage of domestic water withdrawal compared to the overall extraction of water in the Lam Pa Chi Basin is rather small, it does not have a major impact on the expected developments of the water demand until 2050. This assumption also corresponds to the results for the whole Thailand, where domestic demand varies between 2-5% from the overall demand. However it is worth mentioning that the per capita use of water is likely to increase. There are expectations of a per capita increase of 35% in the next 20 years.

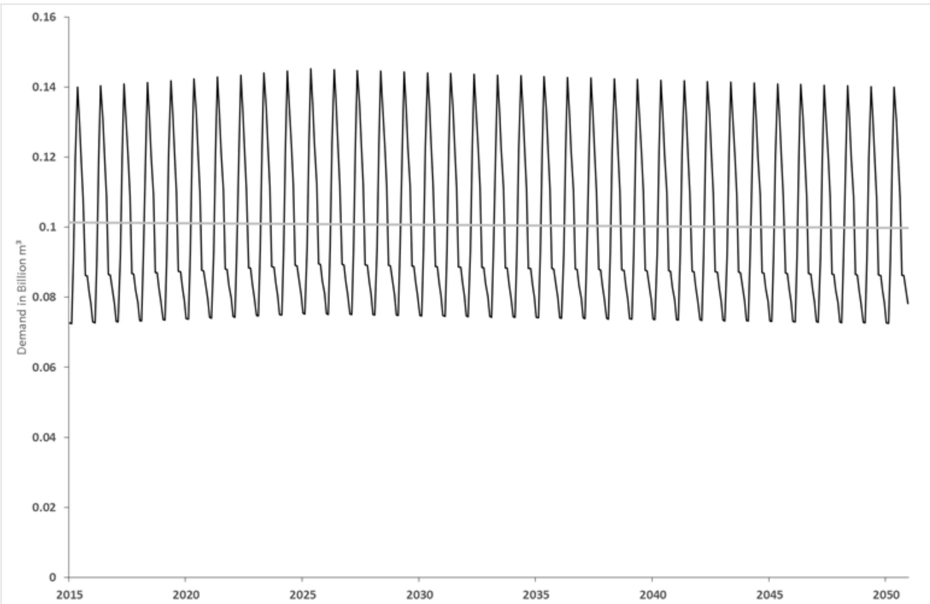


Figure 5-6. Total water demand for scenarios 1, 2 and 3 combined

Therefore water saving initiatives are mostly reasonable in the agricultural sector and show the greatest impacts. In the specific case of Lam Pa Chi the implementation of the improvement of irrigation efficiency scenario achieves a compensation of the increasing water demand until 2050 (Figure 5-7). The water demand for scenario 1&2 increases by 21%

from 2015 to 2025 and is 0% afterwards. For scenario 3 the water demand decreases by 7% until 2025 and by 22% until 2050.

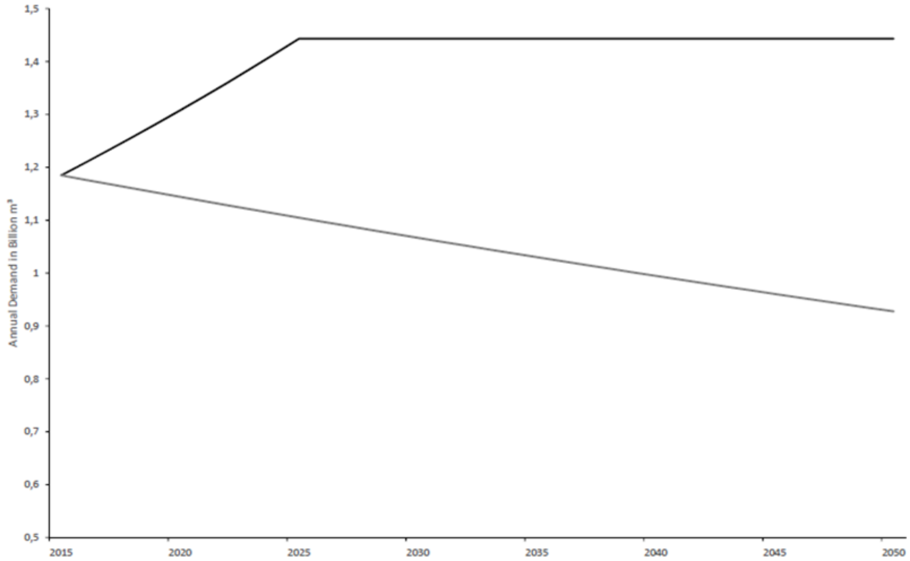


Figure 5-7. Annual-total water demand of scenario 1 and 2 (black line) and scenario 3 (grey line)

As the black line describes the expantion of agricultural land mentioned above and the grey lower line represents the savings by improved irrigation technology, the longterm compensating effect becomes visible. Moreover, the water demand can not only be compensated by savings but reduce in the long run. In order to formulate sufficient and holistic statements in terms of recommendations however, the supply side and their according scenarios must be taken into account.

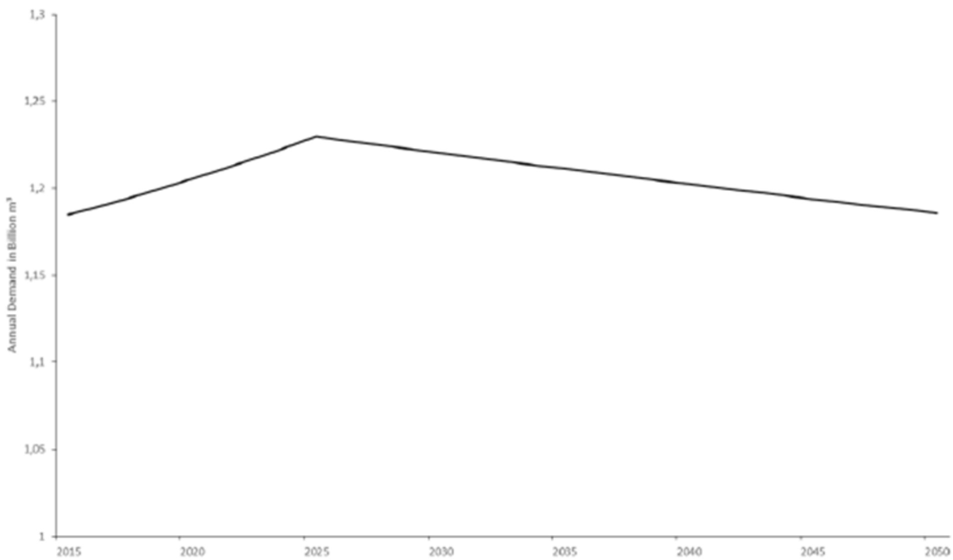


Figure 5-8. Annual-total water demand of all scenarios combined (1, 2 and 3)

The effect of the increased irrigation efficiency is displayed in Figure 5-8. Although there is an apparent increase until year 2025, the water demand decreases subsequently. The water demand of 2025 is 4% higher than in 2015 but then drops to a level that is just 0.1% higher than in 2015.

6 Vulnerability Assessment

6.1 Introduction to risk and vulnerability assessment

A risk is typically defined as a combination of vulnerability and hazard. While hazard describes the level of threat, vulnerability describes the extent to which people, infrastructure or the natural environment can be impacted by such hazard. The larger the number of people, the more expensive the infrastructure and the higher the value of crops, for instance, the higher the expected impact on the system and the higher the vulnerability. The ability to withstand a certain hazard resulting in negative impacts is defined as resilience.

6.1.1 Risks and Disaster Risk Definition

In order to understand disaster risks two main issues are crucial: a) the nature of the hazard potentially leading to a disaster and b) the condition of the society (level of exposure and vulnerability, resilience or coping capacity). Disaster risk is a combination of exposure, vulnerability and hazard (climate extremes) as depicted in (IPCC, 2012, SREX). It should be noted here that exposure can be seen as an intrinsic property of a specific location and resilience as the ability of the local population and infrastructure to withstand the risk. However, in this study the focus will be on vulnerability.

The probability of hazard occurrence is determined by the prevailing climate variability which is likely to be altered in the coming decades due to climate change. Exposure and vulnerability are dynamic; varying across temporal and spatial scales, and depending on economic, social, geographic, demographic, cultural, institutional, governance, and environmental factors. Settlement patterns, urbanization, and changes in socioeconomic conditions have all influenced observed trends in exposure and vulnerability to climate extremes. It is thus not surprising that fatality rates and economic losses expressed as a proportion of gross domestic product (GDP) are higher in developing countries. Here increasing exposure of people and economic assets have been the major cause of long-term increases in economic losses from weather- and climate-related disasters (IPCC 2012)

Regarding flood and drought risk, the conceptual model used for this study is that proposed by IPCC (2012) depicted in Figure 6-1:

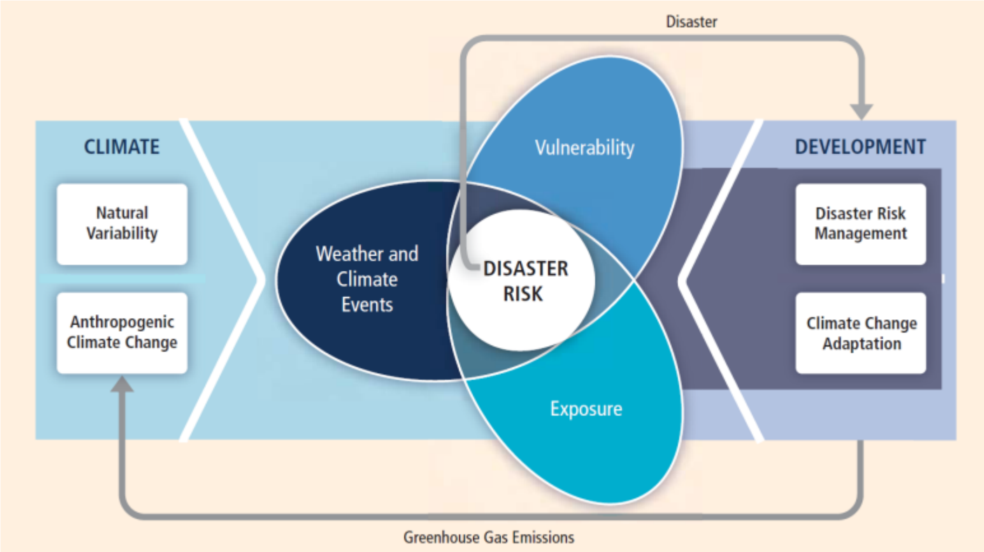


Figure 6-1. The concept of disaster risk cycle, Source: IPCC 2012 (SREX)

The hazard (weather and climate events) in combination with vulnerability and exposure determines the impacts and likelihood of disasters (disaster risk). This model emphasizes the close link between climate and society. In the context of the present study a weakness of this model is that it does not refer to the multiple causes of climate related hazards. A flood usually has causes beyond the climate system, for example in land use changes, hydropower development or other infrastructural interventions as the building of levees or roads.

In particular in developing countries, data on disasters (hazards and vulnerabilities) are lacking at the local level, which often constrain improvements in local disaster risk reduction. Understanding causes of disasters, efforts of forecasting and risk assessment and all depend on a profound data base. The analysis involves the identification of drivers and pressures, which influence the vulnerability component of the disaster risk in certain areas as well as the vulnerability and exposure of societies, infrastructure and (agro)ecosystems exposed to these disasters. Vulnerability, on the other hand, can be understood as a composite of sensitivity and resilience. In a first approximation it can be stated that poorer people tend to be more vulnerable. People prepared for a certain particular disaster are more resilient. This is the fact case in areas that recurrently experience a certain hazard. The following figure illustrates the components of vulnerability and hazards in the Lam Pa Chi basin (Figure 6-2).

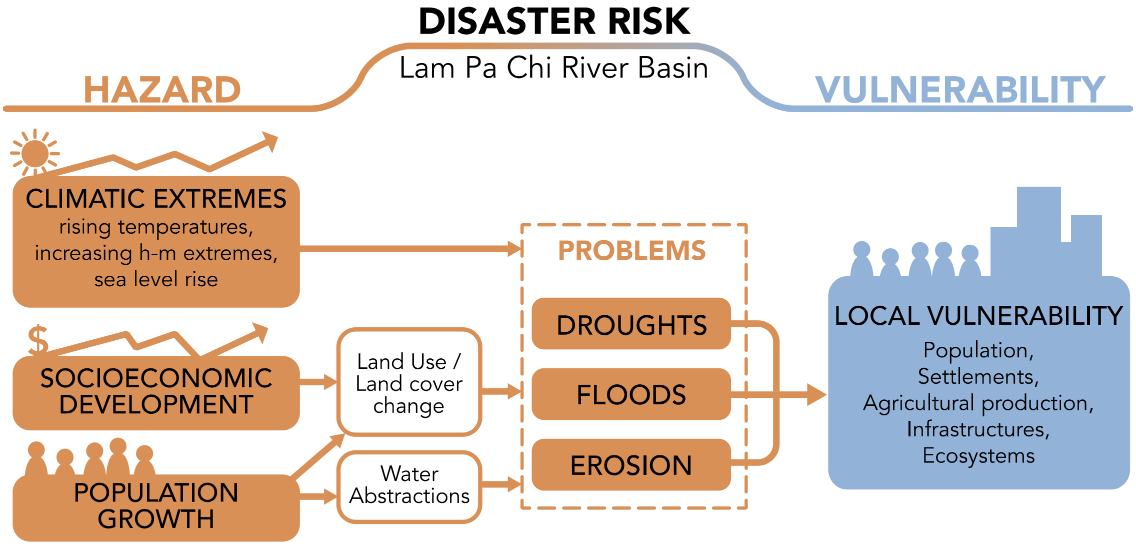


Figure 6-2. Overview on risk and vulnerability components for the Lam Pa Chi Basin

6.2 Justification: why floods, droughts and erosion

The first step before conducting the vulnerability analysis consisted in identifying the main problems affecting the river basin. The two mains sources of information to complete this step were available literature (Pattrawutichai 2003; Kimura et al. 2004; Maita et al. 2004; Sakuma, Ogawa, et al. 2002; Sakuma, Toyomitsu, et al. 2002) and the field visit undertaken in February 2015. Based on this the three main environmental problems identified were:

1. Soil erosion/sedimentation
2. Flash-floods during the rainy season
3. Water scarcity during the dry season

These problems were mentioned by the different stakeholders in the river basin including farmers as well as sub-district chiefs and staff from the DWR in the region. Their impacts and their severity are dependent of the location (i.e. up-, middle- or downstream) will be assessed separately in this study. Government agencies and civil society have been implementing measures to cope with these challenges but are eager to receive support to improve their response to these environmental challenges.

To complete this study a general methodology was designed and consisted of the following steps:

1. Identification of main problems based on literature and interviews with experts and stakeholders
2. Determination of the causes for the identified problems
3. Identification of vulnerable regions
4. Recommendation of ecosystem based adaptation (EbA) measures to mitigate or cope with these challenges

Figure 6-3. General methodological approach to assess vulnerability in the Lam Pa Chi river basin

Table 6-1. Main problems in the basin and their respective causes as well as main impacts

Problems	Possible causes	Impact
Floods	Deforestation	Less flow regulation, increase of flood events and their intensity
	Inappropriate land use (e.g. urban in steep slopes)	Increase of surface runoff enhancing the risk of flash floods
	Lack of riparian forest/vegetation	Less regulation flow
	Channel and floodplain alteration	Change of channel flow increasing the risk of flash floods
Erosion/ Sedimentation	Land use change	Less canopy coverage leading to soil exposure and erosion
	Lack of riparian vegetation	Enhances river bank erosion
	Flow alteration	Weirs and dams reduce flow and enhance sedimentation
Water scarcity	Increased withdrawals	More withdrawals lead to water overuse, especially relevant during the dry season
	Climate variability and change	Increase in temperatures lead to higher evapotranspiration rates and may intensify water scarcity during the dry season

6.3 Flood vulnerability

This chapter presents the background and main possible causes for the one of the main environmental problems faced by the population of the LPC: floods. According to the information from the chiefs of the sub-districts downstream flood events occur every year during the rainy season. People from villages in these sub-districts must be evacuated and floods impact their livelihood by inundating agricultural areas.

In this chapter a topographic methodology was used to identify the areas within the basin prone to be flooded. These areas were related to the villages in order to determine their vulnerability. In the next chapter, EbA measures are proposed to reduce the risk of flooding in the basin.

6.3.1 Background

Flooding is one of the most common and harmful hazards occurring worldwide. Although a natural event, the impacts of floods have increased in the last decades due to urbanization (increasing the number of affected people), deforestation (decreasing natural flow regulation), and climate change (increasing the intensity of weather events). Therefore, water management plans should aim at minimizing and coping with this problem.

For instance, Thailand suffered under the devastation of floods during the year 2011. 65 out of 77 provinces were affected by flood during this year. More than 884 people were killed and according to the World Bank (WB) economic losses added up to USD 45.7 billion (LLC 2012). This raised the awareness of governments and civil society in Thailand to research and design adequate plans and policies to adapt to impacts of floods.

According to the information gathered during the field trip in February 2015, floods were identified as one of the main environmental problems in the basin. Especially in the sub-districts located downstream, where they mentioned that flooding occur every year and some populations need to be evacuated. Therefore, a clear identification of flood-prone areas is necessary to reduce the vulnerability of the population living in them. Moreover, based on this identification EbA measures may be suggested to reduce the risk of flooding.

As mentioned before, the deforestation process taking place in the basin for the last decades has impacted on the number of flood events and their intensity. The ecosystem service of forest cover regulating flow has been widely documented. Moreover, climate change scenarios for the Mae Klong river basin suggest an increase of precipitation rates during the wet season (Shrestha 2014) which would also increase flood risk for the Lam Pa Chi river basin. Therefore, for a sustainable water resources management concept it is necessary to identify flood-prone areas where risk is at highest. With this information it will be possible to design specific strategies to minimize the social and economic risk.

6.3.2 Objectives

Due to the lack of high frequency meteorological and hydrological data a preliminary morphological analysis was conducted to identify the flood-prone areas within the LPC. This analysis is based solely on the DEM and is a first approach which needs to be validated with further analysis and hydraulic studies (only if the data is available). Based on this, the main objectives of this chapter are:

1. Determine the main causes leading of flooding
2. Identify the flood-prone areas using a topographic-based methodology
3. Relate these areas to the urban and rural settlements to determine their vulnerability

6.3.3 Methodology

The identification of flood-risk areas is primordial in the context of river basin management. However, making an accurate flood maps is neither simple nor inexpensive (Manfreda et al. 2011). Hydraulic and hydrological models are data-intensive and need high spatial and temporal resolution data. In developing countries, data acquisition is one of the main challenges while conducting risk assessments. However, remote sensing arises as a technology which can provide information for the whole world at an acceptable resolution. For this study, no data was available to apply a hydro-dynamic or a hydrological model. Therefore, the methodology developed by Manfreda et al. (2011) was applied to delineate flood-prone areas based only on the topography using a DEM. This is a first step in identifying flood-risk area but it has to be validated and analyzed further using data when available (Manfreda et al. 2014).

This method works with the a modified version of the Topographic Index (TI) developed by Kirby (1975). However, the modified version includes an exponent (n) which incorporates the cell-size of the DEM being used for this calculation. The Modified Topographic Index (MTI) is calculated using the following equation:

$$TI_m = log\left[\frac{a_d^n}{tan(\beta)}\right]$$

where a_d refers to the drained area per unit contour length (dependent on DEM cell-size); tan(β) is the local gradient. This method requires calibration which can be completed by comparing the resulting map with actual flood maps or results from hydraulic modeling. For the calibration an error function is introduced:

$$E_{total} = E_1 + E_2$$

being

$$E_1 = \frac{S_{mod} \cap NS_{MTI}}{S_{mod}} \cdot 100$$

and

$$E_2 = \frac{NS_{mod} \cap S_{MTI}}{NS_{mod}} \cdot 100$$

where S_{mod} and S_{MTI} are the sets of domain predicted by hydraulic models and the proposed fast procedure, while NS_{mod} and NS_{MTI} are the areas predicted as non-flooded by hydraulic models and the procedure, respectively. E1 and E2 represent the underestimation and overestimation of the method. Manfreda et al. (2011) found a method to minimize the error function using two unknown parameters:

$$n = 0.016(cellsize^{0.46})$$

And a threshold is defined which divides flooded from non-flooded areas.

$$\tau = 10.89n + 2.282$$

This algorithm was implemented in GRASS GIS 6.5 using Python by Di Leo et al. (2011) to develop a tool called r.hazard.flood[1]. This tool was downloaded and used to delineate the flood-prone areas in the LPC.

For the delineation of flood-prone areas two different Digital Elevation Models (DEMs) with different cell-sizes were used. The two different raster sets included:

1. Shuttle Radar Topography Mission (SRTM)[2] – 90 meters cell size
2. Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)[3] – 30 meters cell size

The rationale of using two different data sets and spatial resolutions was to compare the results and make the conclusions more robust. Since there is no flood map available for the region this methodology could not be validated and should be taken a preliminary result which needs further research in this area using hydrological and hydraulic data (if available).

The resultant maps only differentiate between flooded and non-flooded areas. The difference relies on the threshold, i.e. all areas below the threshold are considered as non-flooded while the areas above the threshold are considered as flooded.

[1] http://grass.osgeo.org/wiki/GRASS_AddOns#r.hazard.flood

[2] http://srtm.usgs.gov/index.php

[3] http://gdem.ersdac.jspacesystems.or.jp/

6.3.4 Results

Figure 6-4 shows the MTI calculated using the SRTM DEM with a cell-size of 90 m. The results show low MTI values in the mountainous area in the west while the highest values are found in the flood plain. The red cells show those regions with the highest values. The MTI raster was the base to determine the flood-prone areas. For this purpose, the threshold was calculated using the tool in GRASS GIS. The resultant threshold was 3.66, which means that cells with MTI values higher than 3.66 were considered as flooded while cells below this threshold were considered as non-flooded.

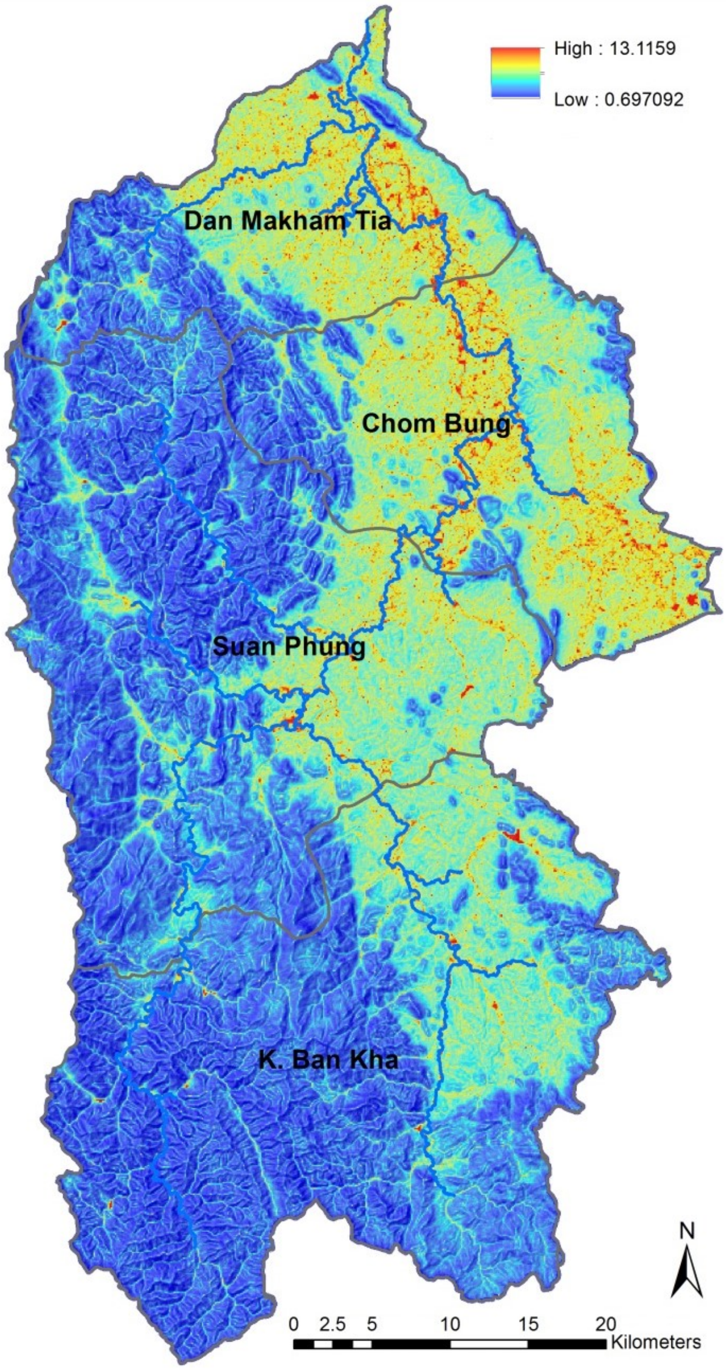


Figure 6-4. Modified Topographic Index (MTI) using SRTM data for the Lam Pa Chi River Basin

The resultant map (Figure 6-5) shows in red the flood-prone areas according to the four different sub-districts. Probably due to the coarse resolution of the DEM only some areas were identified as prone to be flooded. These areas can be seen mainly in the flood plains next to the main rivers as well as in the flatter areas of the basin.

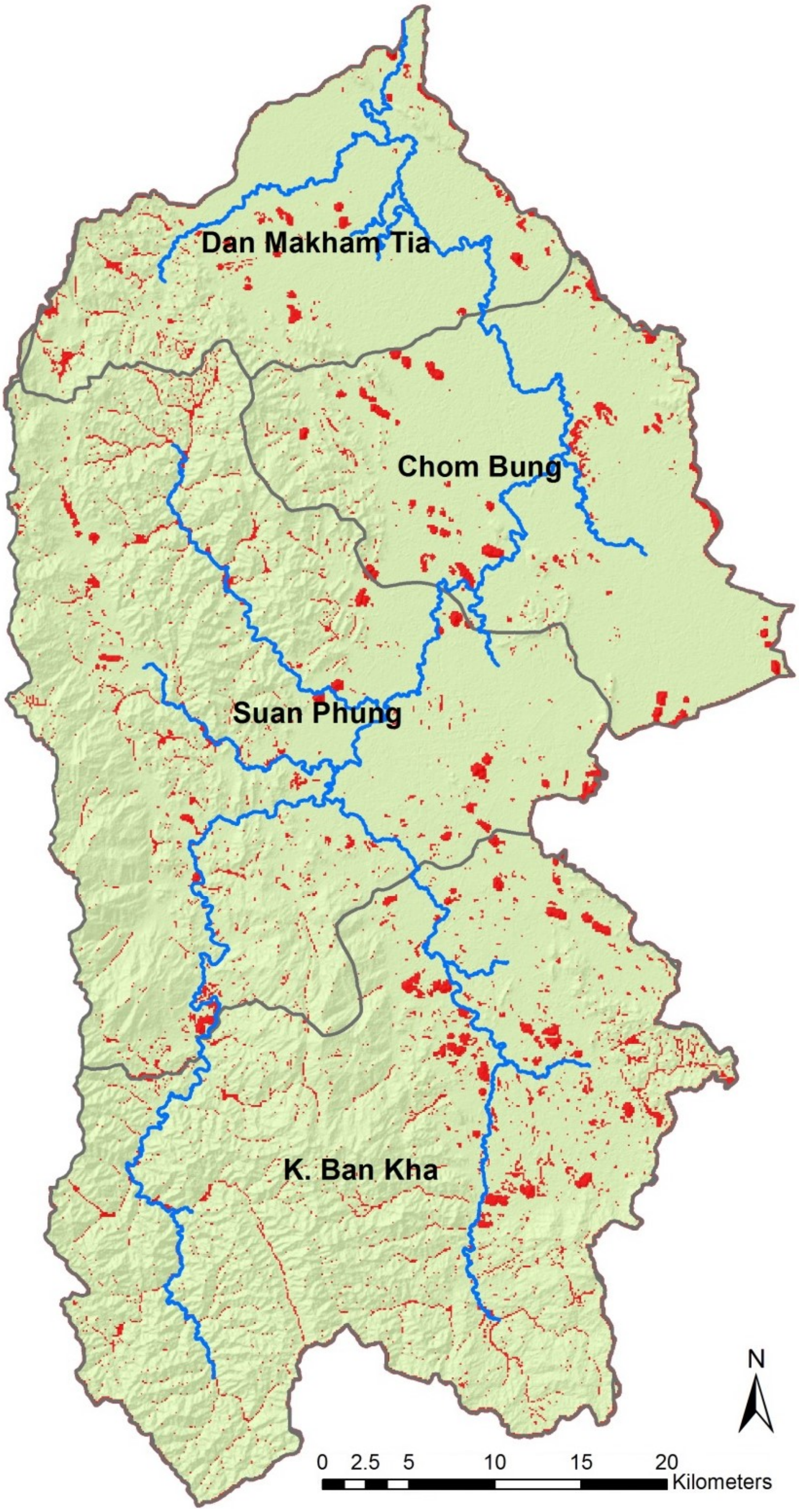


Figure 6-5. Flood-prone areas (in red) based on the SRTM for the whole Lam Pa Chi River Basin

The same procedure was followed using the ASTER DEM which has a higher resolution with a cell-size of 30 meters. The MTI raster map (Figure 6-6) presents lower total values of MTI. There is a clear border between the mountainous and the flatter area of the basin. Due to a different resolution the threshold had to be re-calculated. The result was 3.11, meaning also that all cells with MTI values higher than the threshold were considered as flooded.

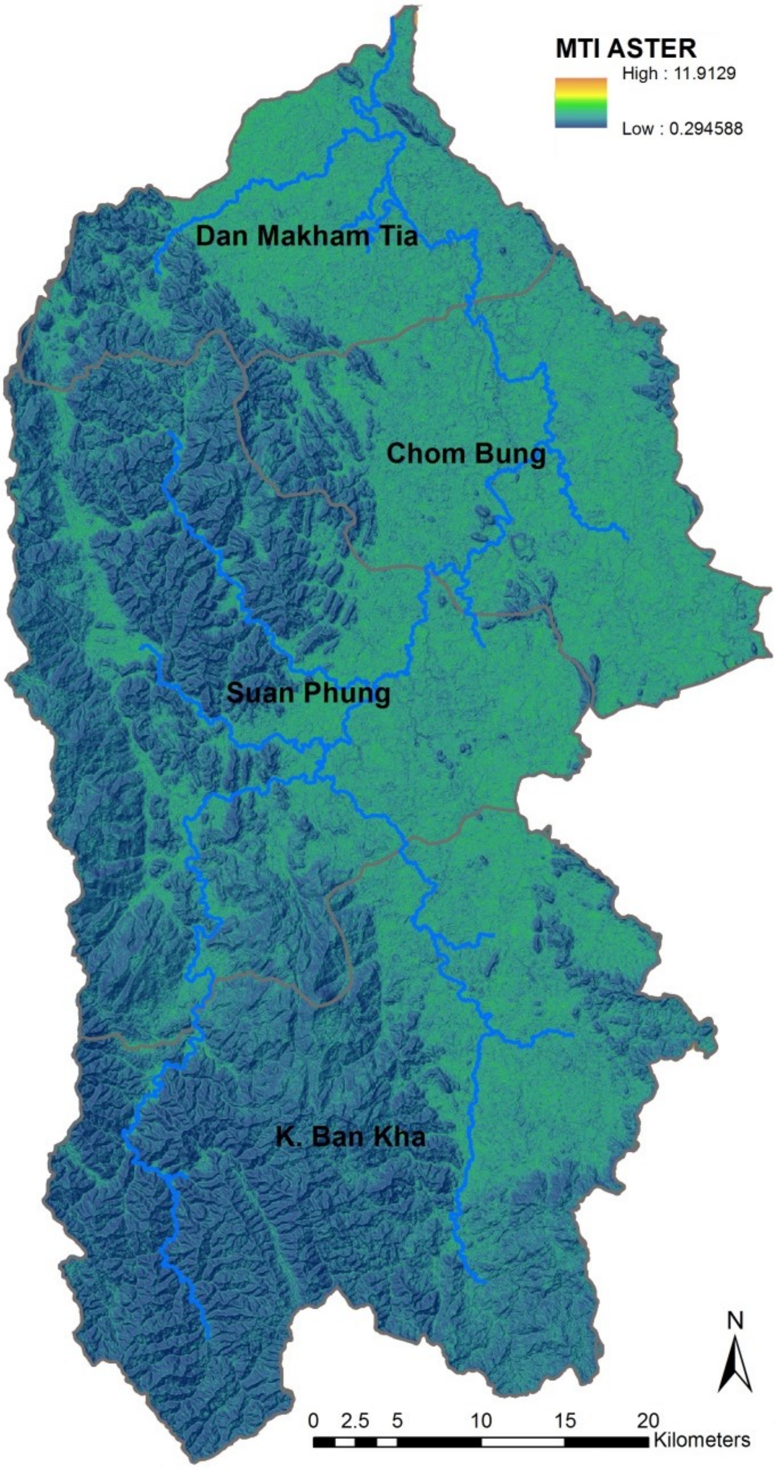


Figure 6-6. Modified Topographic Index (MTI) using ASTER data for the Lam Pa Chi River Basin

The results obtained using the higher resolution (30 m cell-size) ASTER DEM show larger areas prone to be flooded (in red in Figure 6-7). There is also some noise with many isolated red areas. However, the bigger areas downstream and in the flood plains coincide with the information collected from the stakeholders during the field visit to the region. Most of the flooded areas are located in the low parts of the basin coinciding with the two most populated provinces: Dan Makham Tia and Chom Bung, with 32,248 and 58,057 inhabitants respectively. This increases the vulnerability of the population to flood events. According to different stakeholders entire populations in these sub-districts are evacuated every year due to flood events.

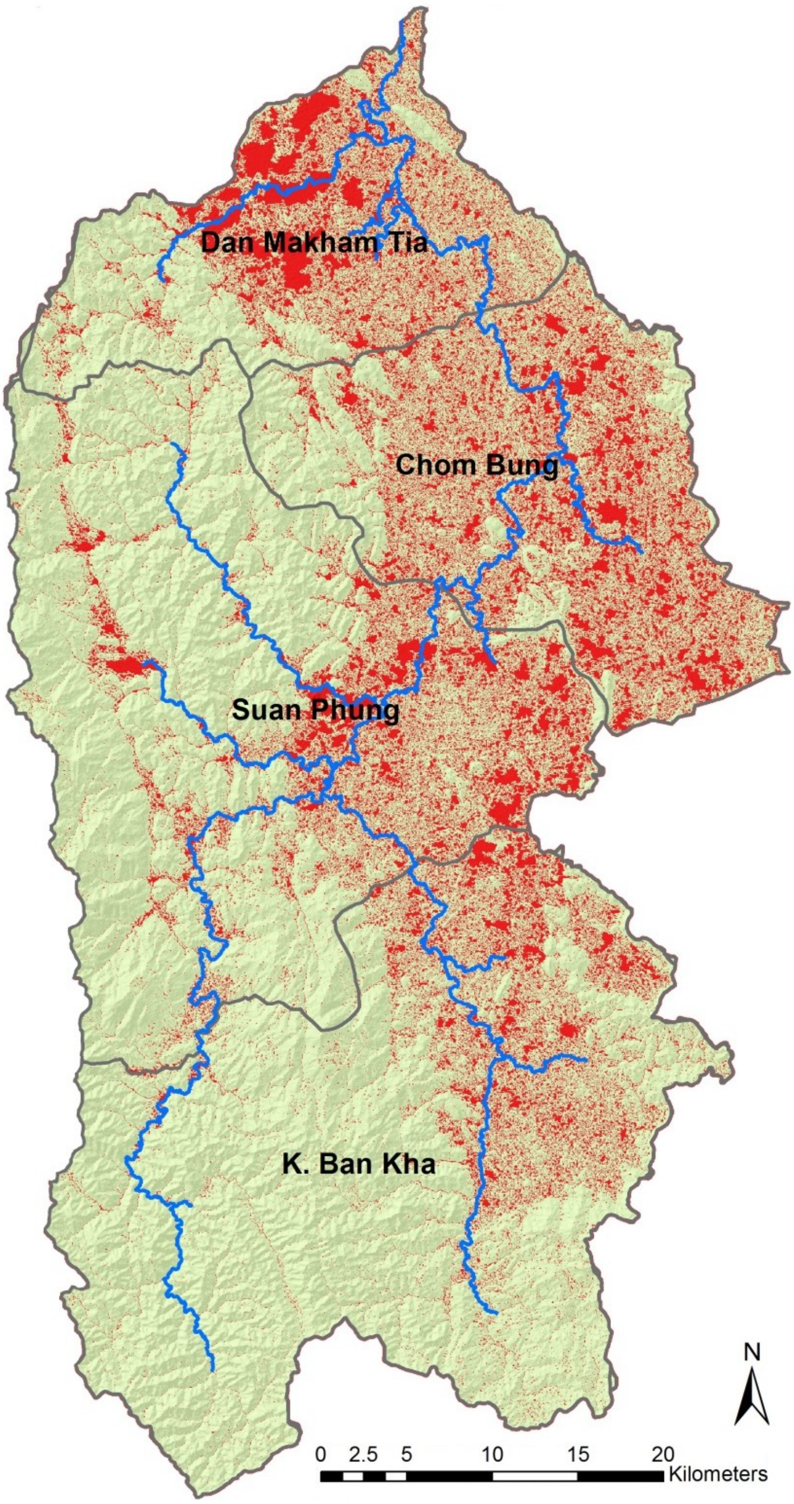


Figure 6-7. Flood-prone areas (in red) based on the ASTER for the whole Lam Pa Chi River Basin

Therefore, a zoom in shown in next figure presents closer the flood-prone areas related to the villages in lower parts of the basin. It can be seen that many villages lie within big red areas which means the live in risk of being flooded during the rainy season (Figure 6-8).

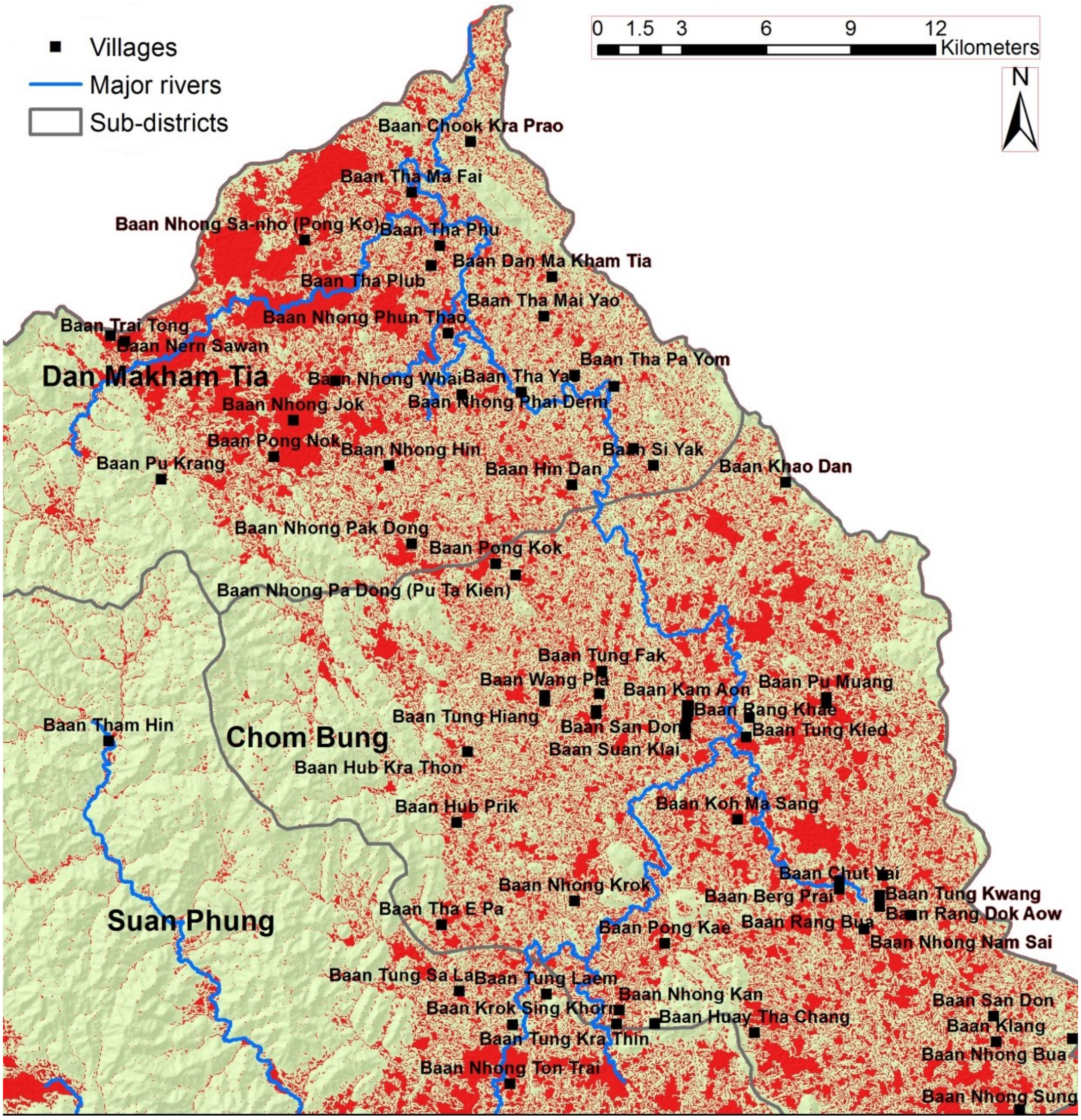


Figure 6-8. Downstream flood-prone areas (in red)

6.4 Drought vulnerability

6.4.1 Background

Significant research on drought assessment and characterization has been carried out for Europe since the late 90ies (Tallaksen et. al., 2004; Van Lanen et al., 2004; Van Loon and Van Lanen, 2012; Vogt et al., 2011) and drought hazard monitoring has been applied especially to arid and semiarid regions of the developed world (NDMC, 2012; UCL, 2011; Wilhite et al., 2000). Droughts in tropical South East Asia, however, so far have been neglected in scientific literature and in international disaster management strategies (UNDP, 2011). Consequently historical drought frequency, drought risk and types are still poorly investigated in South East Asian river basins. According to Adamson and Bird (2010), during the past two decades,

economic losses caused by droughts have by far exceeded losses caused by flood disasters in the region (Adamson and Bird, 2010; Terink et al 2013; Navuth et al, 2007).
Drought periods during the dry season severely impact on socio economic factors such as irrigated rice production, hydropower generation and urban water supply in Thailand. Besides the increasing frequency of heat waves and prolonged dry periods without rainfall, hydropower development and over-exploitation of water resources due to demographic and socioeconomic development are the main causes for drought-related disasters. According to Wuthiwongyothin (2007) agricultural droughts frequently occur in North Eastern Thailand and the Central Eastern part. Agricultural drought risk in the Western part and particularly in the Lam Pa Chi basin is low compared to other Thai regions. During the very dry early year 2015, when streamflow was very low in the LPC River, no significant drought impact was perceived by the local population. However, increasing abstractions through tourism and socioeconomic development, temperature increase and an expected increase of dry periods might increase the drought risk in the near future.
Therefore in the scope of this study, historical hydrological drought conditions are characterized and potential drought hazard and vulnerability of the catchment is assessed with different methods.

6.4.2 SPI/SRI Analyses

The Standardized Precipitation Index (McKee, 1993) is the most used index as it is simple to calculate and effective in analysing dry periods/cycles. At least 20-30 years of monthly values are required, the more the better. This record is fitted to a probability distribution, which is then transformed into a normal distribution so that the mean SPI for the location and desired period is zero. Positive SPI values indicate greater than median precipitation and negative values indicate less than median precipitation.

Table 6-2. SPI and SRI value classification

SPI values	SRI values	Condition
-0.25 to -0.49	-0.25 to -0.49	Mild drought
-0.5 to- 0.99	-0.5 to- 0.99	Moderate drought
-1.0 to -1.44	-1.0 to -1.44	Severe drought
-1.45 to -1.99	-1.45 to -1.99	Very severe drought
-2.0 and less	-2.0 and less	Extremely drought

Because the SPI is normalized, wetter and drier climates can be represented in the same way; thus, wet periods can also be monitored using the SPI.

The SPI and its runoff homologue SRI were calculated and compared. Monthly SPI values were determined using the available rainfall record from the precipitation gauging stations in the Lam Pa Chi Basin. The SRI values were determined similarly to the SPI and a gamma distribution is fitted to the monthly stream flow record. The cumulative probability of the time series for each month timescale is determined based on the two parameters α and β accounting for zero flow conditions. The cumulative probability is further standardized to have a mean of zero and variance of one. The following figure shows the SPI values for the largest available monthly precipitation time series at Station 47161 (1968-2014) and SRI values for the shorter neighbouring discharge station time series period (1979-2011). SPI values indicate major meteorological droughts in 1972 (-2.2), 1977 (-2.02).

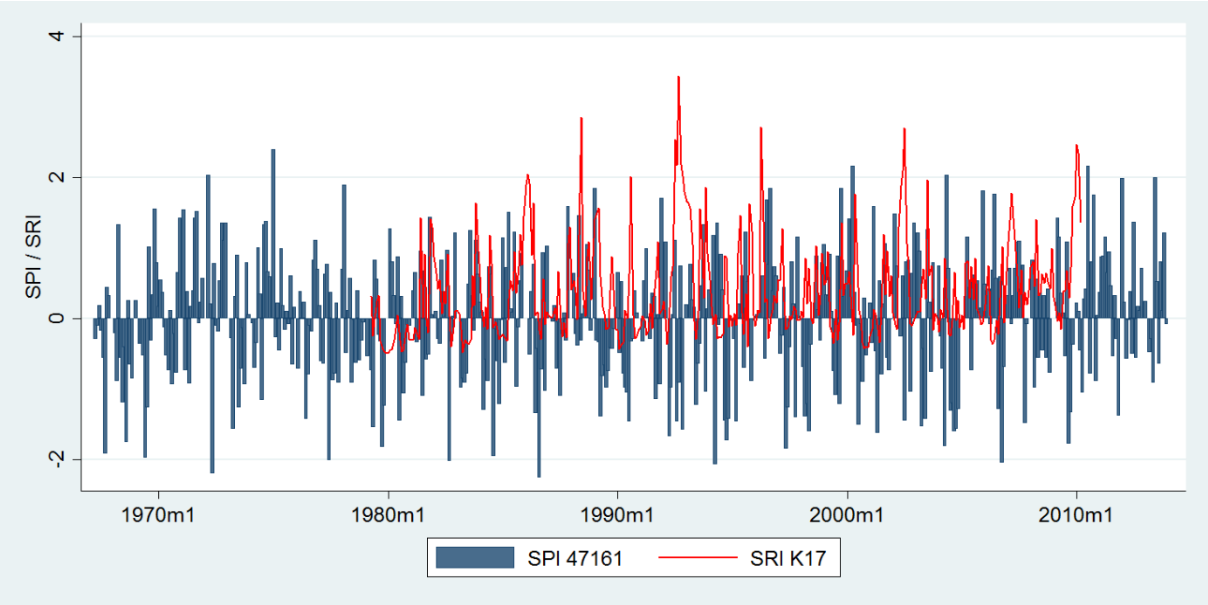


Figure 6-9. Monthly SPI at rainfall station 47161 and SRI at discharge station K17

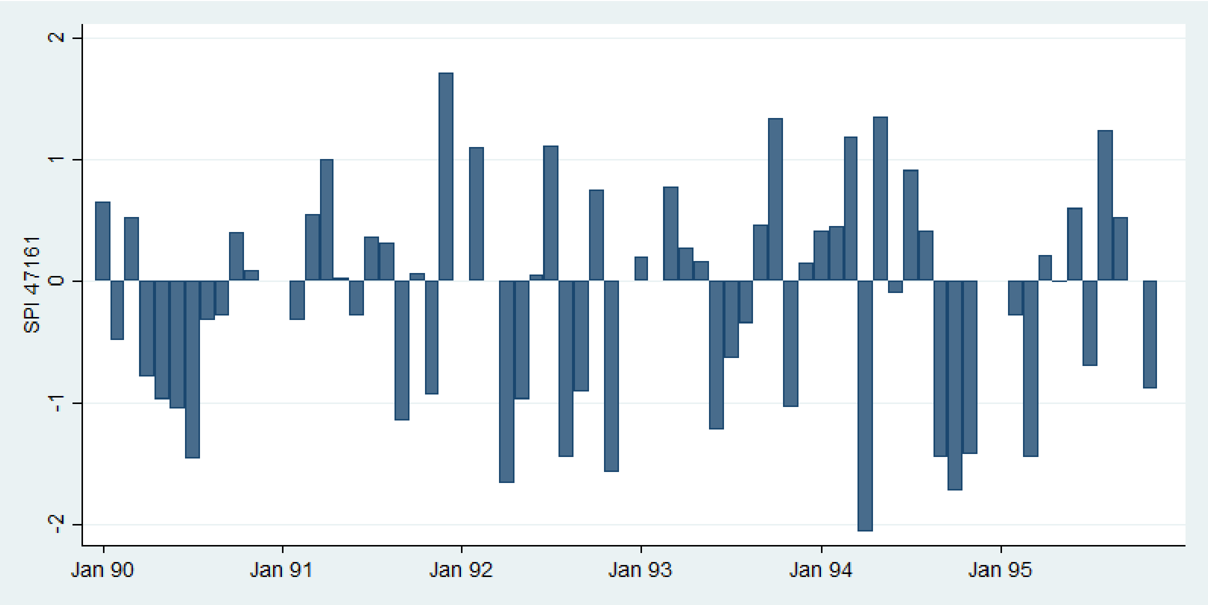


Figure 6-10. Monthly SPI at rainfall station 47161, 1990 – 1995

Figure 6-10 shows the monthly SPI of the rainfall station 47161 in the time frame between 1990 and 1995. During this timeframe a lot of very low SPI values can be observed. Especially interesting are the years 1990 and 1994, where the usual patterns of the dry and wet periods are interrupted. In the case of 1990, the reason is a comparable dry year, where all but two months show a maximum monthly precipitation of lower then 100mm. As pointed out in figure 3, the reason of the unusual pattern during the year of 1994 is a very high precipitation in the late

1993 (September and October), followed by four very dry months. Especially the April of 1994 is extremely dry, compared to other years, leading to a SPI value of -2.07 (extremely drought). Additionally one must take a look at the October of 1994 where the monthly precipitation reaches less than half of the expected rainfall for the month of October (109mm in 1994 compared to an average of 260mm). This leads to a SPI value of -1.73 (Very severe drought).

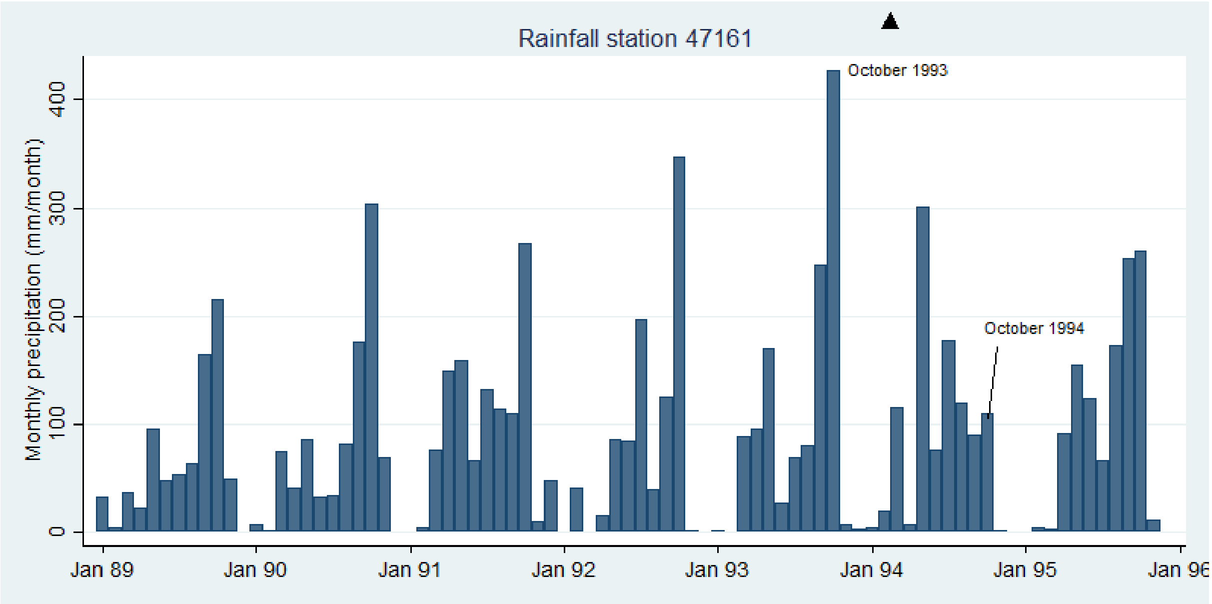
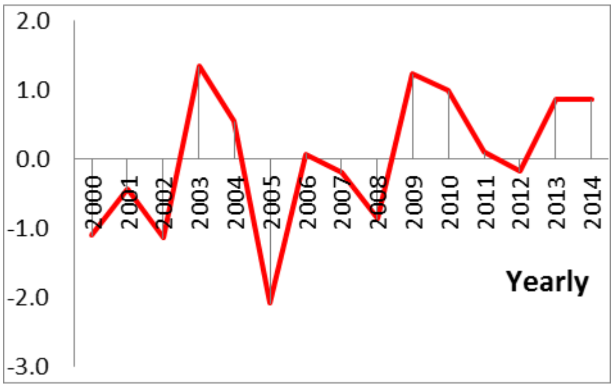


Figure 6-11. Monthly precipitation at rainfall station 47161, 1990 - 1995

FAPAR (Fraction of Absorbed Photosynthetically Active Radiation)

The annual temporal variability of the anomalies and mean values of FAPAR are shown in Figure 6-12, which are calculated for the period from 2000 to 2014. The presence of trends and anomalies provide information about the impacts of extreme climate events and disturbances on vegetation. The periods earlier 2003 with mean FAPAR value of 0.530 and from 2005 to 2008 have negative anomalies values, which imply a drought periods. After 2008, the Lam Pa Chi River Basin has a better condition, which has mean FAPAR value of the 0.565 on average.



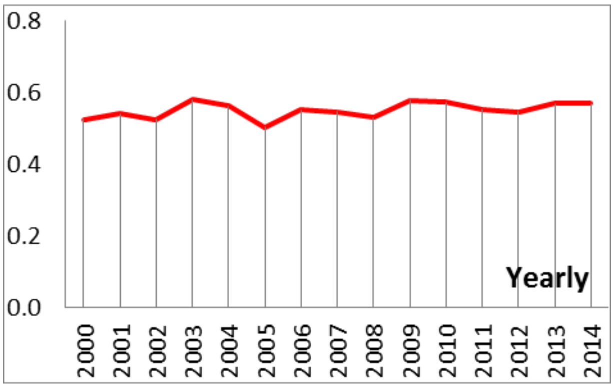


Figure 6-12. Yearly FAPAR anomaly (left) and average (right) for the time period (2000-2014)

To study FAPAR anomaly in more depth, the monthly analysis is also conducted. Figure 6-13 focuses on the time evolution for each month of FAPAR signals over Lam Pa Chi River Basin. In spite of the interannual variability, visually inspection reveals that in May and December there is an upward trend. The period from 2000 to 2005 exposes that the area has land dryness. It can be seen also that 2005 is considered as a transition year; it has FAPAR anomaly value below than zero (except in July and August). However, the highest FAPAR anomaly is observed in July 2010 as 2.11 and the lowest value equals -2.84 in Feb 2000. Since the MODIS data starts on 18th of Feb 2000, the lowest value could be attributed to the lack of data for this month. Therefore, the second lowest value is selected, which is for March 2005 (≈ -2.52).

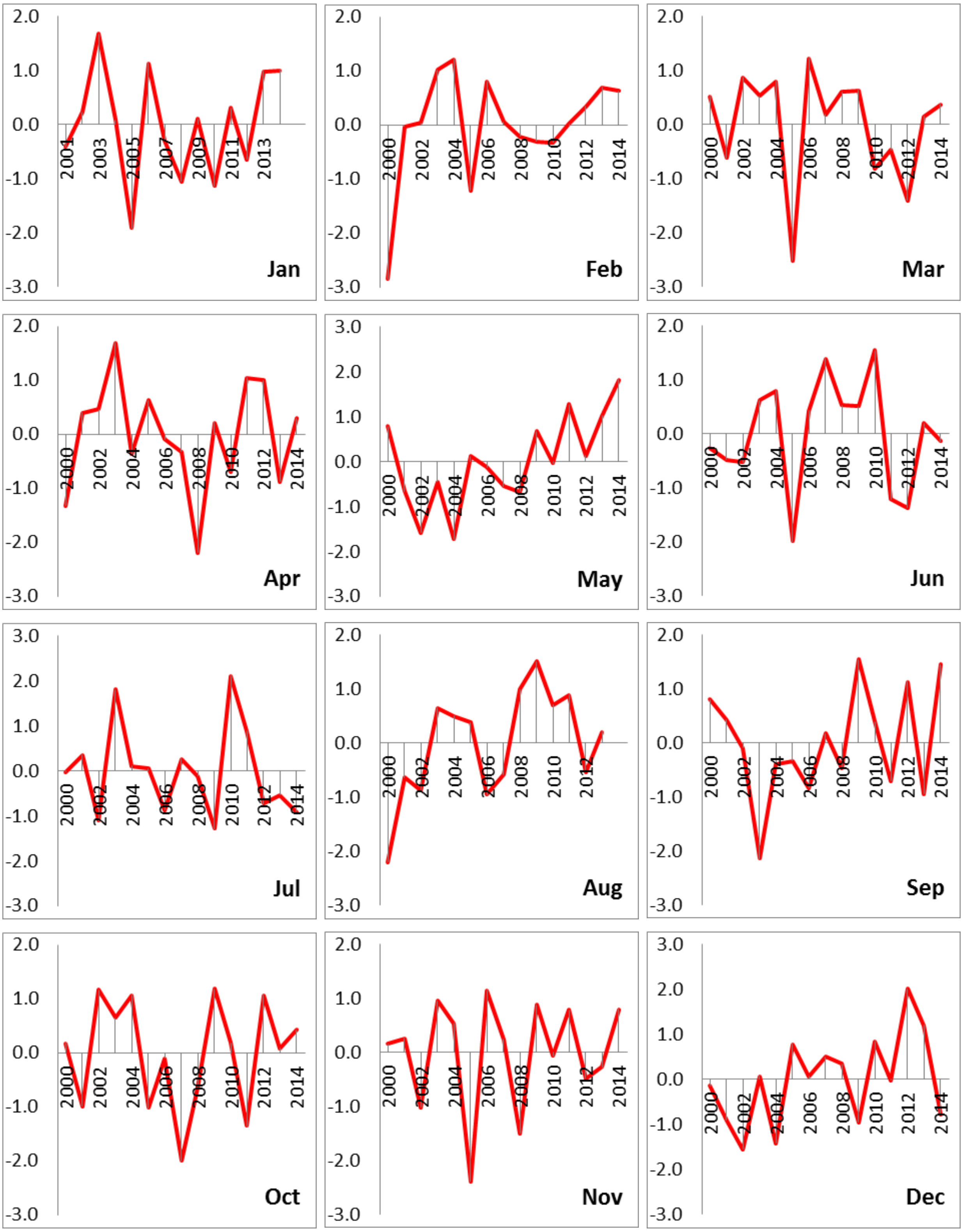


Figure 6-13. *Monthly FAPAR anomalies over Lam Pa Chi River Basin for the time period (2000-2014)*

Figure 6-14 illustrates the spatial distribution of the FAPAR over the Lam Pa Chi River Basin. As can be seen, the summation (bottom panels) and mean (top panels) spatial values are presented for the two extremes FAPAR anomalies for July 2010 (left) and March 2005 (right) as discussed earlier. The highest FAPAR values are always found at the south and south-east. This could be related to the fact that these areas have the highest elevation of the basin (around 700 above mean sea level (AMSL)). Also, the majority of the existing land-use of these areas is forest.

FAPAR in combination with SPI and possibly soil moisture analysis is typically used to characterize drought conditions in the region. It could be used to develop early warning products as well. However, there exists a real need for more in-situ measurements in this region in order to produce useful results with remote sensing data products.

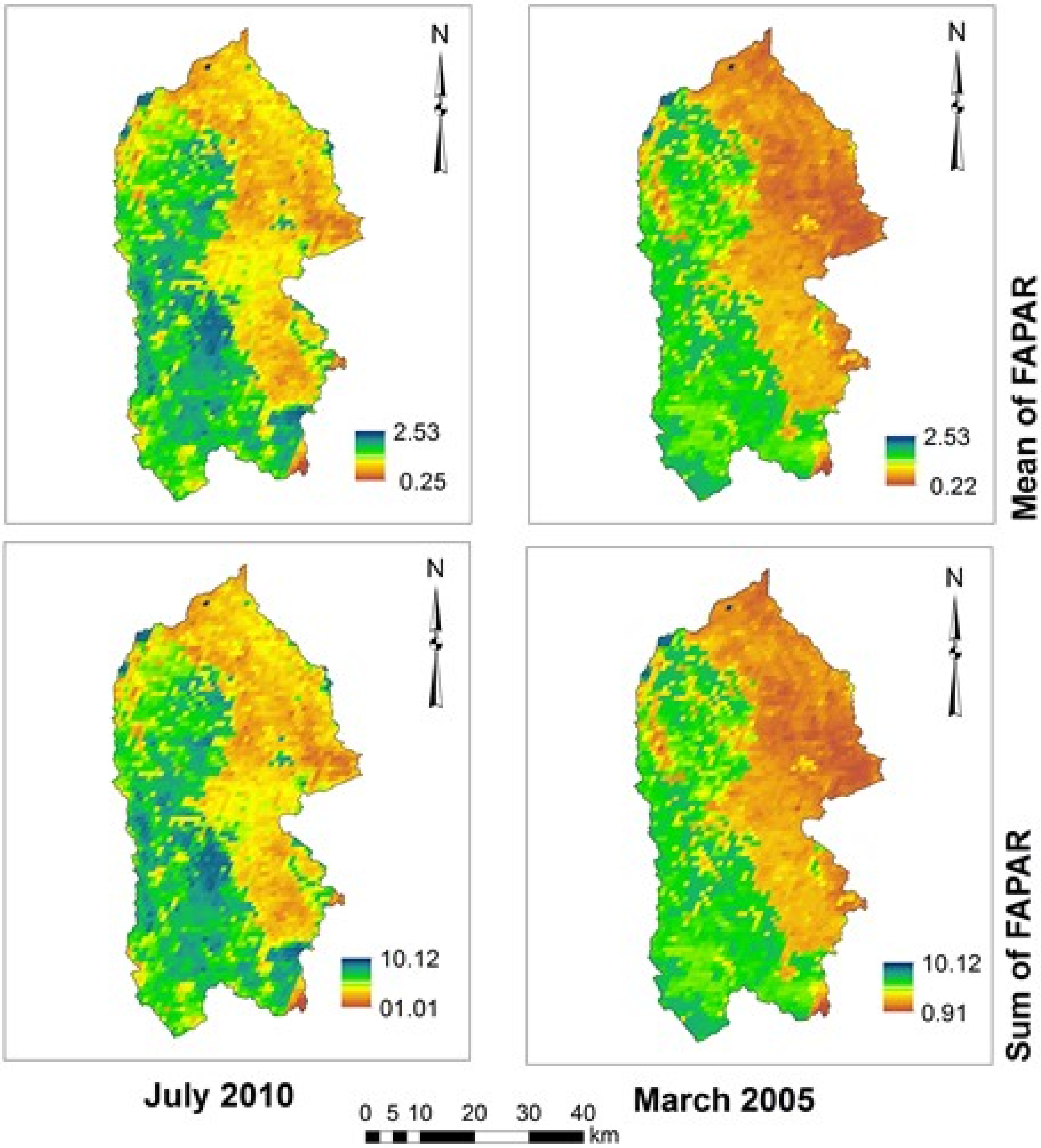


Figure 6-14. Spatial distribution of the summation and mean values of FAPAR

6.5 Vulnerability against soil erosion

6.5.1 Background

Soil loss caused by excessive erosion is one of the most serious land degradation problems all over the world and one of the most critical environmental hazards of modern times (LAL 2001; KRISHNA BAHADUR 2009). Especially in the tropics and subtropics with their intense rainfall events soil erosion is a hazard with long-term effects on soil quality, agricultural productivity, movement of pollutants, ecological diversity in streams and wetlands, river channel morphology and flooding (MORGAN, MORGAN *et al.* 1984).

Also in Thailand soil erosion is one of the major land degradation problems (PENSUK & SHRESTHA 2010). The Thai Land Development Department quantifies the annual damage of soil deterioration as 192 million Rai (1 Rai = 0.16 ha) affecting the income of about 30 million farmers countrywide (Source: Homepage of Land Development Department, accessed on 14.04.2015).

The planning and implementing of appropriate *Ecosystem-based-Adaptation (EbA)*-measures to counteract soil loss and its effects call for an erosion assessment to localize and quantify soil loss severity within the region of interest. For this purpose models like the *Revised Universal Soil Loss Equation – RUSLE* (WISCHMEIER & SMITH 1978; RENARD, FOSTER *et al.* 1997) are applied which provide useful information on erosion based upon a straightforward set of parameters.

Several studies use RUSLE to quantify soil loss rates in Thai river basins proofing the suitability of this method for application under Thai socio-ecological conditions (HENDERSON & ROUYSUNGNERN 1985; JANTAWAT 1985; TURKELBOOM, POESEN *et al.* 1997; ZIEGLER & GIAMBELLUCA 1997; TURKELBOOM, POESEN *et al.* 1999; ZIEGLER, GIAMBELLUCA *et al.* 2001; ZIEGLER, SUTHERLAND *et al.* 2001; SRIBOONLUE, TRELO-GES *et al.* 2004; PAIBOONSAK, CHANKET *et al.* 2005; ISHIKAWA, YAMANAKA *et al.* 2006; SANG-ARUN, MIHARA *et al.* 2006; STHIANNOPKAO, TAKIZAWA *et al.* 2007; TURKELBOOM, POESEN *et al.* 2008; CHANKET & MONGKOLSAWAT 2009; KRISHNA BAHADUR 2009; PAIBOONVORACHAT & OYANA 2011; WETERINGS 2011; NONTANANANDH & CHANGNOI 2012; WIJITKOSUM 2012; PLANGOEN, BABEL *et al.* 2013; SHRESTHA, SURIYAPRASIT *et al.* 2014).

6.5.2 Objectives

In this study, the *Revised Universal Soil Loss Equation – RUSLE* was used to quantify the amount of soil loss in the Lam Pa Chi river basin. The following research questions were answered to analyze the vulnerability against erosion within the research area:

- Localization: Which are the areas prone to erosion with the Lam Pa Chi river basin?
- Quantification: What is the soil loss amount in these areas?
- Cause analysis: Which are the topographic conditions and land use / land cover (LULC) types causing excessive soil loss rates?

6.5.3 Methodology – RUSLE

Apart from rainfall and runoff, the rate of soil erosion also strongly depends on soil, vegetation and topographic characteristics (KRISHNA BAHADUR 2009). Therefore the *Revised Universal Soil Loss Equation – RUSLE* (WISCHMEIER & SMITH 1978; RENARD, FOSTER *et al.* 1997) which incorporates all these factors is used in this study to assess soil loss rates in the Lam Pa Chi river basin.

The RUSLE is composed of six factors to predict the long-term average annual soil loss rate (A):

A = R * K * LS * C * P

where

A = estimated average soil loss rate [t/ha/h/a]
R = rainfall-runoff erosivity factor [MJ mm/ha/a]
K = soil erodibility factor [t mm/ha/h/a]
L = slope length factor [dimensionless]
S = slope steepness factor [dimensionless]
C = cover-management factor [dimensionless]
P = support practice factor [dimensionless]

From RUSLE's resulting raw pixel-based soil loss rate values [t/ha/a] were processed in the following manner:

- Mean and Standard Deviation, Maximum and Minimum of all soil loss rates predicted within the Lam Pa Chi river basin.
- Classification of individual soil loss rate values into five soil loss severity classes (*very slight, slight, moderate, severe* and *very severe*).
- Identification of areas with severe and very severe soil loss rates.
- Mean soil loss rate of land use and land cover types.
- Share of severity classes for each land use and land cover type.
- Calculation of absolute pixel based soil loss [t/a].
- Total soil loss [t/a] per land use and land cover type.
- Contribution [%] of each land use and land cover type to total soil loss within the Lam Pa Chi river basin.
- Calculation of area shares [%] of severely and very severely classified patches within the *Dan Ma Kham Tia, Suan Phung, Chom Bung and Bam Kha Districts* that take part of the Lam Pa Chi river basin.

Following up the six RUSLE factors are described in terms of soil loss relevance, data used and parametrization. For further detail about the calculation of the factors please see RENARD, FOSTER *et al.* (1997).

Rainfall Erosivity Factor (R)

<u>Description</u>

RUSLE assumes that when other factors are constant, soil losses from cultivated fields are directly proportional to a rainstorm parameter. The *Rainfall Erosivity Factor (R)* is calculated as a product of storm kinetic energy (E) and the maximum 30-minute storm intensity (I_{30}) summed for all storms in a year. This relationship quantifies the effect of raindrop impact and reflects the amount and rate of runoff likely to be associated with the rain. The R-Factor used to estimate average annual soil loss must include the cumulative effects of the many moderate-sized storms as well as the effects of the occasional severe ones. (RENARD, FOSTER *et al.* 1997)

However, data on rainfall intensity is difficult to get in many developing nations. Relational equations are commonly used to estimate R from annual rainfall amount (X) such as the one below for Thailand (see Parametrization).

Data source

Annual rainfall amount calculated as the mean of the annual rainfall amount of the years 1967-2013 based on monthly data of the rain gauge station No. 47161 located in the center of the Lam Pa Chi (x = 1175 mm/a).

We are well aware that this monthly data of one single station limits the regionalization of the soil loss assessment considerably. Extensive data mining efforts did not provide additional long-term precipitation data evenly distributed within the Lam Pa Chi.

Parametrization

The following equation was defined by the Land Development Department (LDD 2000) as suitable for the rainfall amount in Thailand and applied in numerous other studies concerning erosion in Thailand using USLE and RUSLE (PAIBOONSAK, CHANKET *et al.* 2005; NONTANANANDH & CHANGNOI 2012; WIJITKOSUM 2012):

$R = 0.4669*X - 12.141559$ [MJ mm/ha/h/a]

where

R = Rainfall Erosivity Factor
X = annual rainfall

According to the formula mentioned above one single R-factor value was calculated for the entire Lam Pa Chi (R = 536.466).

Soil Erodibility Factor (K)

Description

The *Soil Erodibility Factor (K)* is a quantitative description of the inherent erodibility of a particular soil; it is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff. The K-Factor is determined corresponding to the top soil property, land form and physical geography (WIJITKOSUM 2012).

Data source

Soil type information was taken from the delivered “Soil Shapefile” specifying the different soil groups in the Lam Pa Chi river basin. No information resp. metadata about year of classification, author and methodology was available.

Parametrization:

K-factors were assigned to the soil groups according to the following Table 6-3, which also provides a general description of soil group characteristics (LDD 2000; NONTANANANDH & CHANGNOI 2012). The K-Factor values for the different soil groups were developed by the Thai Land Development Department.

Table 6-3. K-Factor values for soil groups within the Lam Pa Chi (LDD 2000; NONTANANANDH & CHANGNOI 2012)

Soil Group	K-Factor	Short description
6	0.36	poorly drained, fine texture (clay loam, clay, silty clay)
7	0.36	poorly drained, fine texture (clay loam, silty clay loam, clay, silty clay)
16	0.34	poorly drained, medium texture (silt loan, silty clay loan)
17	0.30	poorly drained, coarse texture (sandy loam, sandy clay loam)
18	0.30	poorly drained, coarse texture (sandy loam, sandy clay loam)
19	0.30	somewhat poorly drained, medium-coarse texture
20	0.30	somewhat poorly drained, coarse texture
25	0.26	poorly drained, coarse texture
29	0.25	well drained, fine texture
31	0.25	well drained, fine texture
33	0.37	well to moderately well drained, medium texture (silt loam, silty clay loam)
35	0.24	well drained, medium texture
36	0.24	well drained, medium texture
38	0.24	well drained, coarse texture
40	0.24	well drained, coarse texture
41	0.04	well to moderately well drained, coarse texture (sandy)
44	0.04	well drained, coarse texture (sandy)
47	0.29	shallow, fine-grained bed rock
48	0.24	shallow, coarse-grained bed rock
52	0.25	shallow, calcareous layer
56	0.24	well drained, fine texture
62	0.25	soils of steep lands with more than 35% slopes

Slope length & slope steepness factor (LS)

Factor Description

The *L* is the slope length factor, representing the effect of slope length on erosion. It is the ratio of soil loss from the field slope length to that from a 22.1m length on the same soil type and gradient. Slope length is the distance from the origin of overland flow along its flow path to the location of either concentrated flow or deposition. *S* is the slope steepness factor representing the effect of slope steepness on erosion. Soil loss increases more rapidly with slope steepness than it does with slope length. It is the ratio of soil loss from the field gradient to that from a 9% slope under otherwise identical conditions. The relation of soil loss to gradient is influenced by density of vegetative cover and soil particle size. The *Slope Length Factor (L)* and the *Slope Steepness Factor (S)* are usually considered together (*LS-Factors*).

Data source

Topographical data, namely a Digital Elevation Model (DEM), was derived from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data. This raw ASTER-DEM with horizontal resolution of 30x30 m and vertical resolution of about 16 m was processed with ArcGIS tools to get a derive a depressionless DEM as the base data for calculating the *Slope Length Factor (L)* and the *Slope Steepness Factor (S).*

Parametrisation

The following procedures are taken in the calculation of the L and S factors (RENARD, FOSTER *et al.* 1997):

$$L = (\gamma/22.1)^m$$

Where

22.1m is the unit plot length
γ is the horizontal projection of slope length
m is a variable slope-length exponent

The slope steepness factor (S) is calculated (McCool et al., 1987) using the following two equations for the two steepness categories.

$$S = 0.065 + 0.045s + 0.0065s^2 \qquad when\ s\ (slope\ steepness) < 9\%)$$

$$S = 6.4\left\{\sin\left[\text{atan}(\frac{s}{100})\right]\right\}^{0.75} \left\{\cos\left[\text{atan}(\frac{s}{100})\right]\right\} \quad when\ s\ (slope\ steepness) \geq 9\%$$

Land Cover Management Factor (C) & Conservation Practice Factor (P)

Description

The *Land Cover Management Factor (C)* is considered to be the most important factor in RUSLE because it represents conditions that can relatively easily be managed to reduce erosion by changing land use types. The C-Factor reflects the effect of cropping and management practices on erosion rates. It indicates how conservation affects the average annual soil loss and how soil loss potential will be distributed during cropping and other management schemes (RENARD, FOSTER *et al.* 1997)

The *Conservation Practice Factor (P)* is a soil loss ratio for a specific support practice to the corresponding soil loss with up-and-down slope tillage. In Thailand, a value for the P-Factor has not been established for any agricultural cover types except for paddy (NONTANANANDH & CHANGNOI 2012). In all other cases the maximum value of 1 was assigned.

Data source

The land use / land cover (LULC) classification was adopted from the delivered “Landuse Shapefile” specifying the different land use types in the Lam Pa Chi river basin. No information resp. metadata about year of classification, author and methodology was available.

Parametrization

C-Factor and P-Factor values for the occurring land use / land cover types within the Lam Pa Chi were derived from the Land Development Department (LDD 2000). Both are listed in

Table 6-4.

Table 6-4. C-Factor and P-Factor values for land use types occurring in the Lam Pa Chi (LDD 2000).

LULC Class	LULC Code	C Value	P Value
Paddy field	A1	0.280	0.1
Field crops	A2	0.485	1
Perennial trees	A3	0.150	1
Orchards	A4	0.300	1
Horticulture crops	A5	0.600	1
Grassland	A7	0.100	1
Evergreen forest	F1	0.003	1
Deciduous forest	F2	0.048	1
Natural grassland	M	0.015	1
Mine pit	-	0.5	1
Water body	W	0	0
Urban	U	0	0

6.5.4 Results

Whole Lam Pa Chi River Basin

Within the Lam Pa Chi a mean annual soil loss rate of 12.5 t/ha/y (Standard Deviation: 15.0 t/ha/a) with a minimum of 0.0 t/ha/a and a maximum of 222.4 t/ha/a occurs according to the RUSLE equation. The total soil loss within the river basin during one year is 3.64 Mio. t/a. The original soil loss values were classified into five severity classes (Table 6-5) applying threshold values from literature (MORGAN 2009)

Table 6-5. Classification of annual soil loss rates in the Lam Pa Chi into severity classes.

Value Range [t/ha/a]	Description	Area [ha]	Share [%]
<5	very slight	79,677	31.0
5-10	slight	55,007	21.3
>10-25	moderate	79,715	31.0
>25-45	severe	33,214	12.9
>45	very severe	9,739	3.8

Considering the soil loss threshold of 10 t/ha/a above that soil loss reduction measures should be considered according to Morgan (2009), about half of the Lam Pa Chi exceeds this threshold (47.7%, namely the areas with *moderate*, *severe* and very *severe* classified soil loss). Areas of severe and very severe soil loss rates areas are mainly located in the Eastern floodplain part of the river basin (Figure 6-15).

Knowing these soil loss rating classes it is very important to know the kind of land uses that are most prone to soil loss (Table 6-6). Once the land use types and associated soil erosion severity are known, such information becomes extremely valuable as these can be used to formulate a plan focusing prevention and conservation measures in those areas. In this way not only the on-site effect but also the downstream effects of the sediment transport can be minimized.

Table 6-6. Mean soil loss rates and shares of soil loss classes per land use type

Land Use	Mean soil loss rate [t/ha/a]	Share of soil loss classes per LULC class [%]				
		very slight	slight	moderate	severe	very severe
Mine pit	54.03	4.7	4.6	13.1	36.9	40.7
Horticulture crops	35.23	5.0	7.6	19.0	47.7	20.7
Field crops	25.45	14.8	9.1	30.0	36.6	9.5
Orchards	15.10	28.9	8.8	50.3	8.2	3.8
Deciduous forest	8.54	23.8	34.5	41.5	0.1	0.1
Perennial trees	8.27	31.5	40.5	24.0	3.9	0.1
Natural grassland	5.49	65.5	16.1	18.1	0.2	0.1
Mixed forest	3.90	83.7	12.5	3.6	0.1	0.1
Paddy field	1.87	97.2	0.9	1.0	0.7	0.2
Grassland	0.93	98.3	1.6	0.1	0.0	0.0
Evergreen forest	0.53	99.7	0.1	0.1	0.0	0.0
Water body	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Urban	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

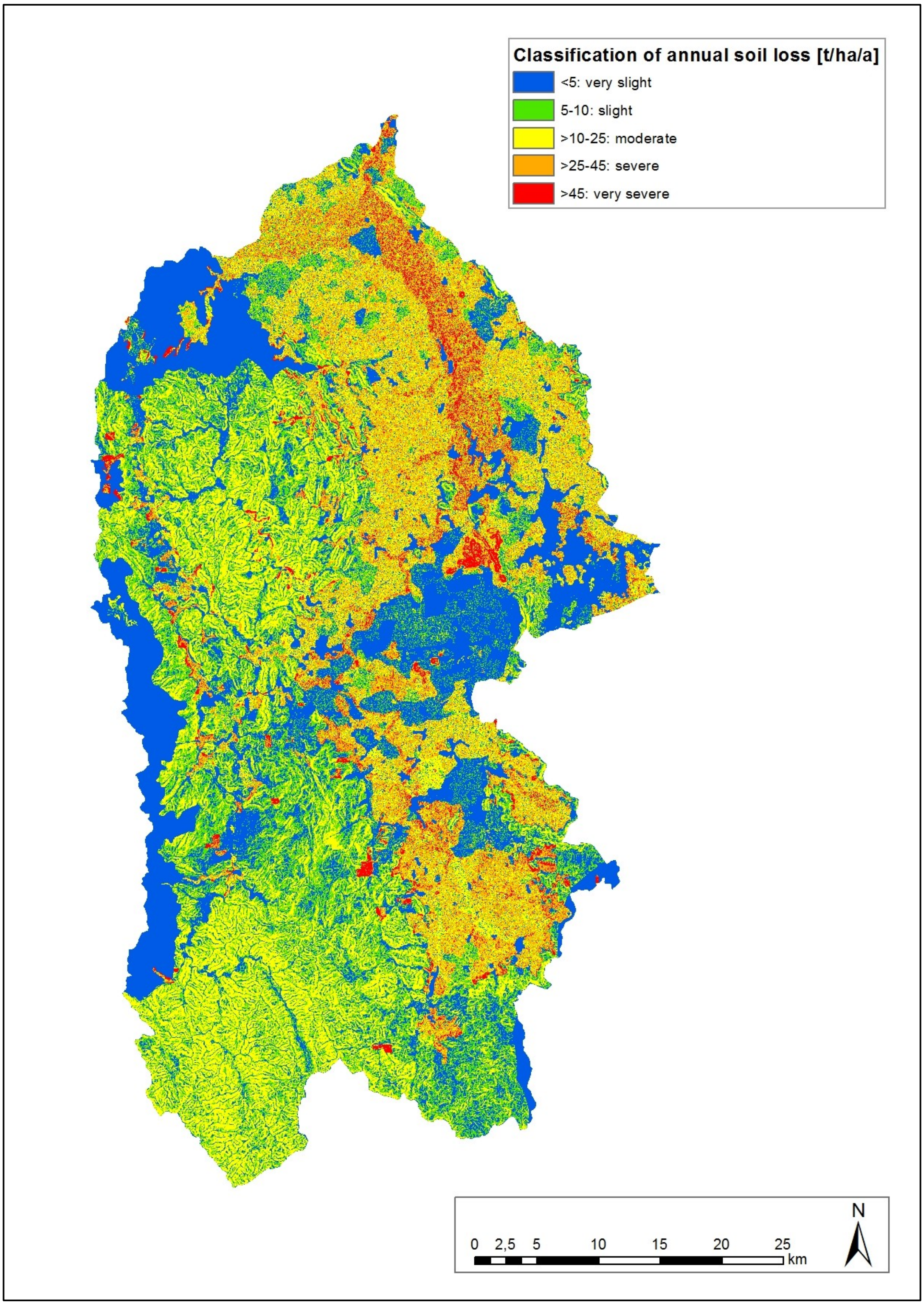


Figure 6-15. Classified annual soil loss rates within the Lam Pa Chi river basin

The soil loss severity is greatest (severe to very severe) along the lower and middle part of the Lam Pa Chi River and within the sub-catchment of the Huai Tha Koei River (Figure 6-16). Despite relatively low hillslope values these areas are especially prone to erosion due to soil characteristics and inappropriate land use types resp. practices. Especially these areas of severe and very severe soil loss indicate high erosion rates and land degradation where water and soil conservation measures are required and preliminary basin management strategies need to be developed.

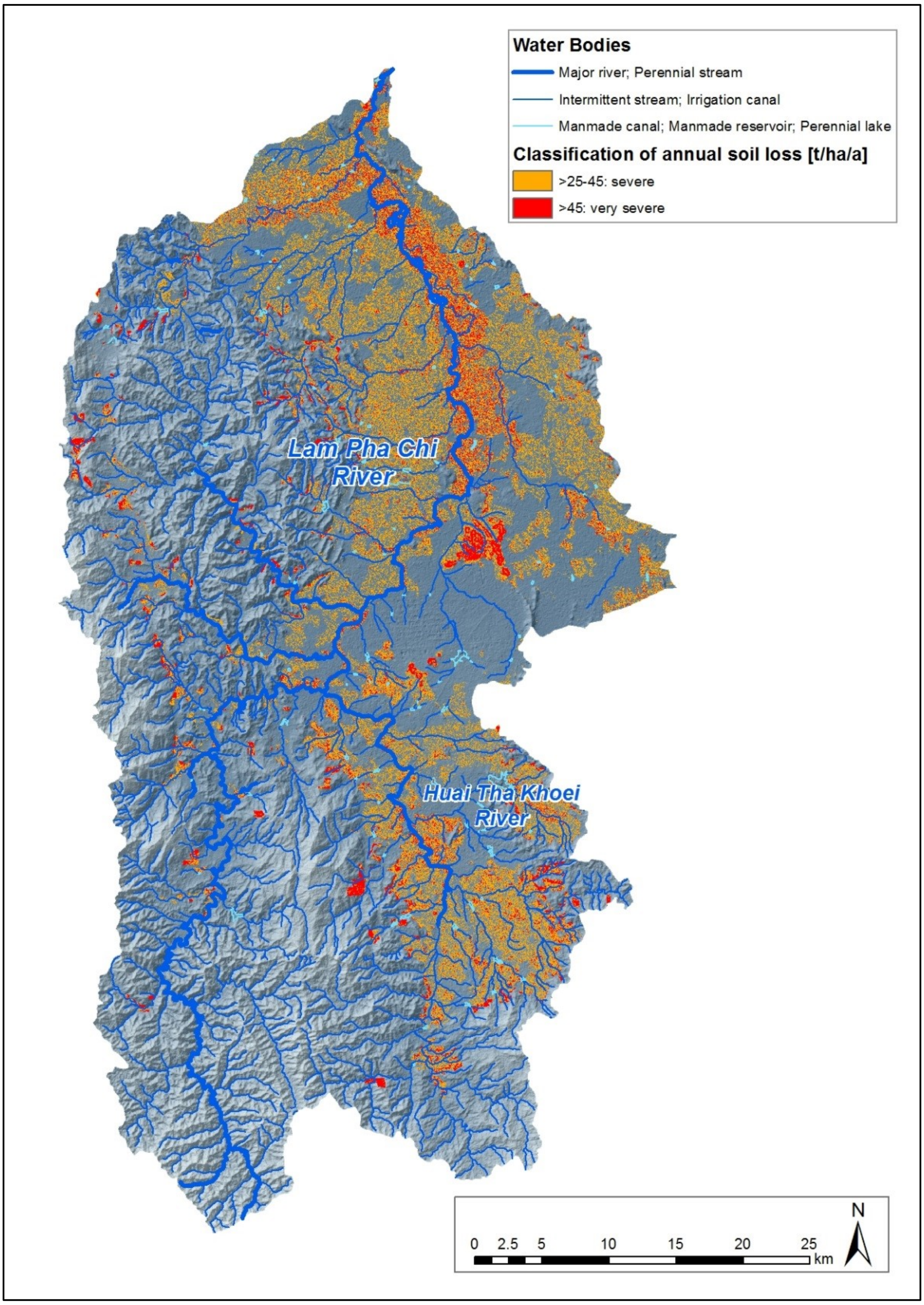


Figure 6-16. Severe and very severe soil loss rates within the Lam Pa Chi river basin

Whereas mean soil loss rates provide useful information about general severity of soil loss regarding specific land use or land cover types, total soil loss values and contribution to the total soil loss within the basin identify the main factors of the actual situation within the basin (Table 6-7). Field crop areas contribute 63.4% to the total soil loss covering 35.1% of the basin's area. The second largest contributing land cover type is deciduous forest with 26.4% of the total soil loss and an area share of 45.9%. All other land cover resp. land use types add considerably less to the total soil loss within the basin having partially high mean soil loss rates like mine pits with 54.03 t/ha/a or horticulture crops with 35.23 t/ha/a, but small area shares. Therefore efforts for soil loss reduction measures should be focused on field corps areas in the Western part and deciduous forest areas in the Eastern part of the basin (Figure 6-17).

No specifications can be made in the scope of this study regarding the different field crop types contributing most to the total soil loss within the basin. Only one single value for the RUSLE's *Land Cover Management Factor (C-Factor)* was available for the general land use type *field crops*.

Table 6-7. Mean soil loss rates, total soil loss and contribution to total soil loss of different land use types.

Land Use	Total area		Mean soil loss rate [t/ha/a]	Total soil loss [t/a]	Contribution to total loss [%]
	Area [ha]	Area [%]			
Mine pit	2,462	1.0	54.03	140,831	3.9
Horticulture crops	379	0.2	35.23	14,454	0.4
Field crops	85,818	35.1	25.45	2,311,781	63.4
Orchards	5,551	2.3	15.10	85,788	2.4
Deciduous forest	112,159	45.9	8.54	961,435	26.4
Perennial trees	390	0.2	8.27	113,108	3.1
Natural grassland	7,948	3.3	5.49	43,761	1.2
Mixed forest	390	0.2	3.90	1,573	0.04
Paddy field	4,762	1.9	1.87	8,395	0.2
Grassland	124	0.1	0.93	112	0.003
Evergreen forest	19,864	8.1	0.53	10,503	0.3
Water body	641	0.3	n.a.	n.a.	n.a.
Urban	3,760	1.5	n.a.	n.a.	n.a.

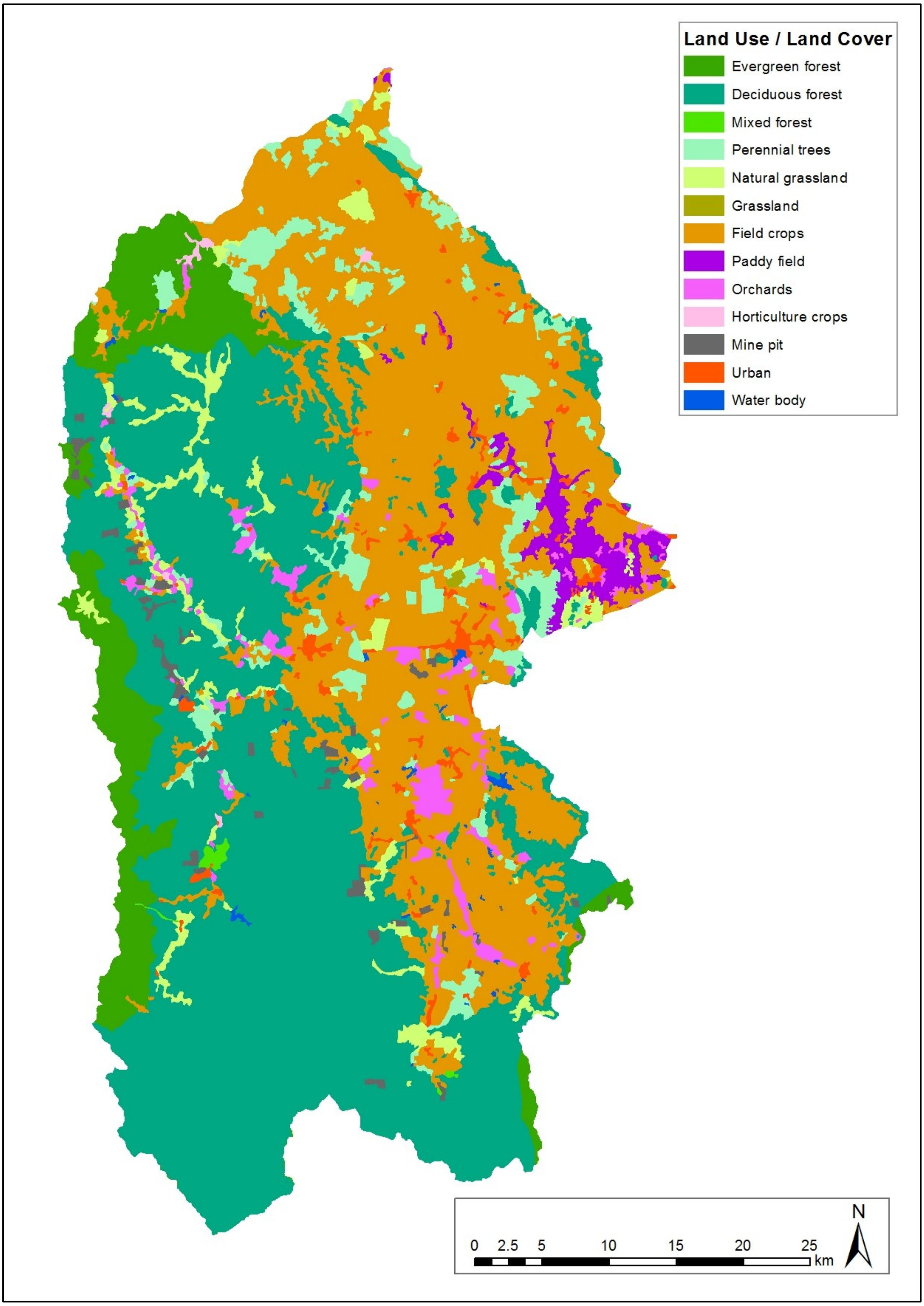


Figure 6-17. Land use / land cover types within the Lam Pa Chi river basin

Special focus for soil loss reduction measures should be put on field corps areas and deciduous forest areas due to high contribution rates to the total soil loss within the basin.

Districts

The share of areas with soil loss rates classified as severe or very severe are highest in the Chom Bung District (Figure 6-18) in the lower north-eastern part of the river basin and in the Dan Ma Kam Tia District (Figure 6-19) close to the mouth of the Lam Pa Chi River both dominated by field crops land use (Table 6-8). Within the Ban Kha District 12% of its area is classified as severely or very severely soil loss affected (Figure 6-20). These field crop areas are located within sub-catchment of the Huai Tha Koei River. The Suan Phung District shows only little and fairly scattered patches of severe or very severe soil loss. Major parts of this district are covered by deciduous or evergreen forests Figure 6-21).

Table 6-8. Total areas and shares of severely and very severely soil loss affected patches per district

District Name	Total Area [ha]	Area with *severe & very severe* soil loss rates [ha]	Share [%]
Chom Bung	46,020	14,589	31.7%
Dan Makham Tia	35,309	9,931	28.1%
K. Ban Kha	89,735	10,812	12.0%
Suan Phung	86,409	7,621	8.8%

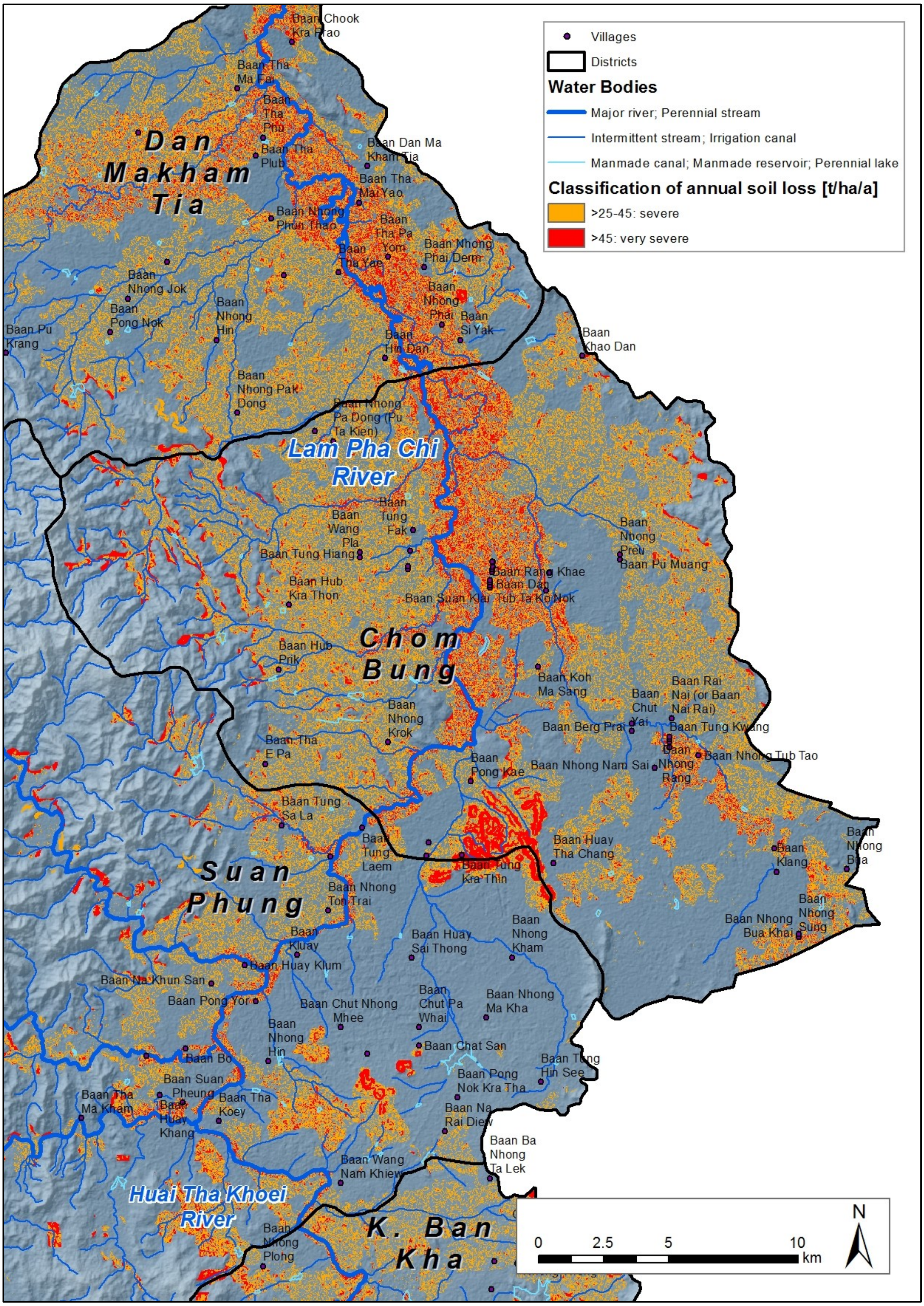


Figure 6-18. Severe and very severe soil loss in the Chom Bung District

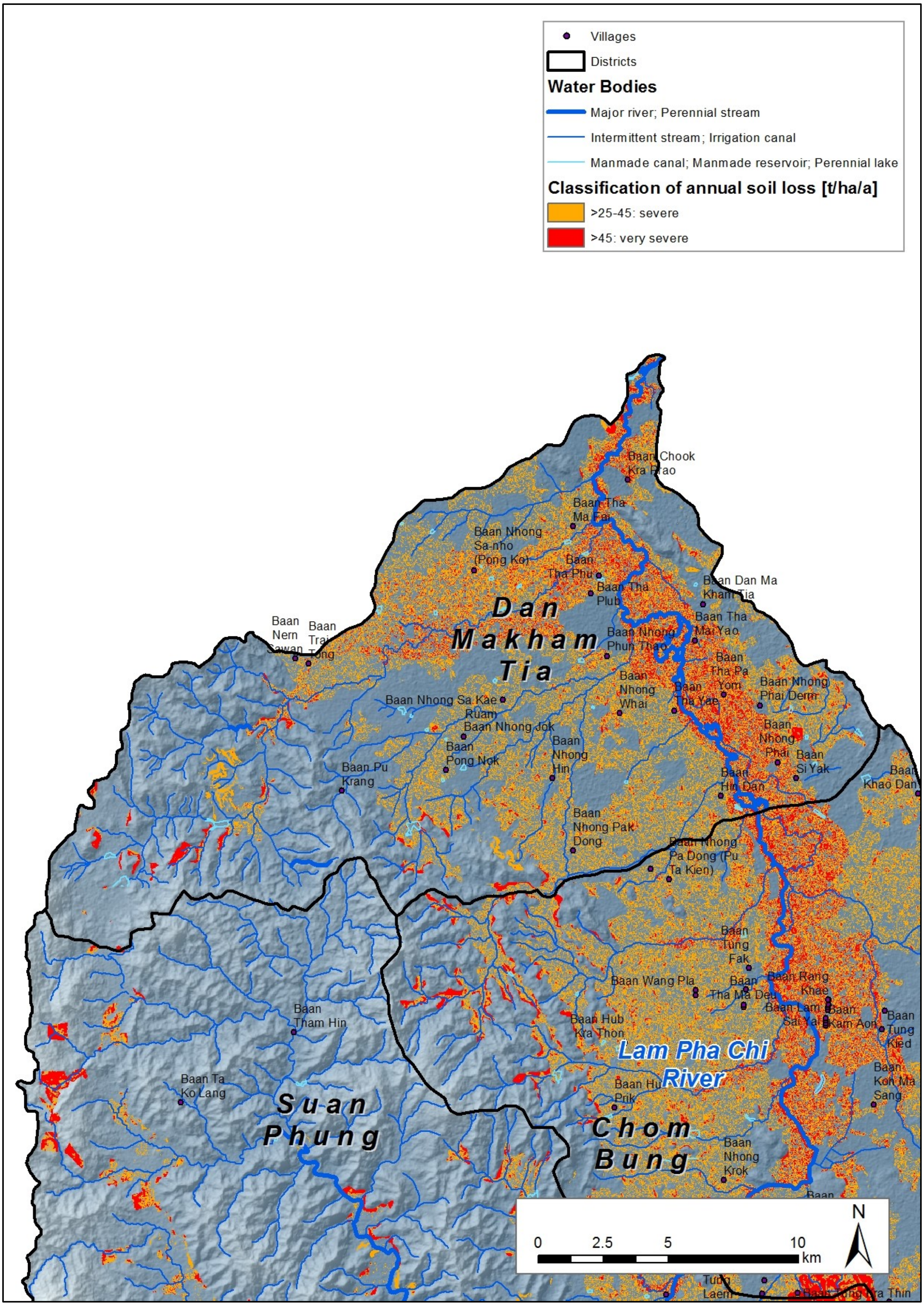


Figure 6-19. Severe and very severe soil loss in the Dan Makham Tia District

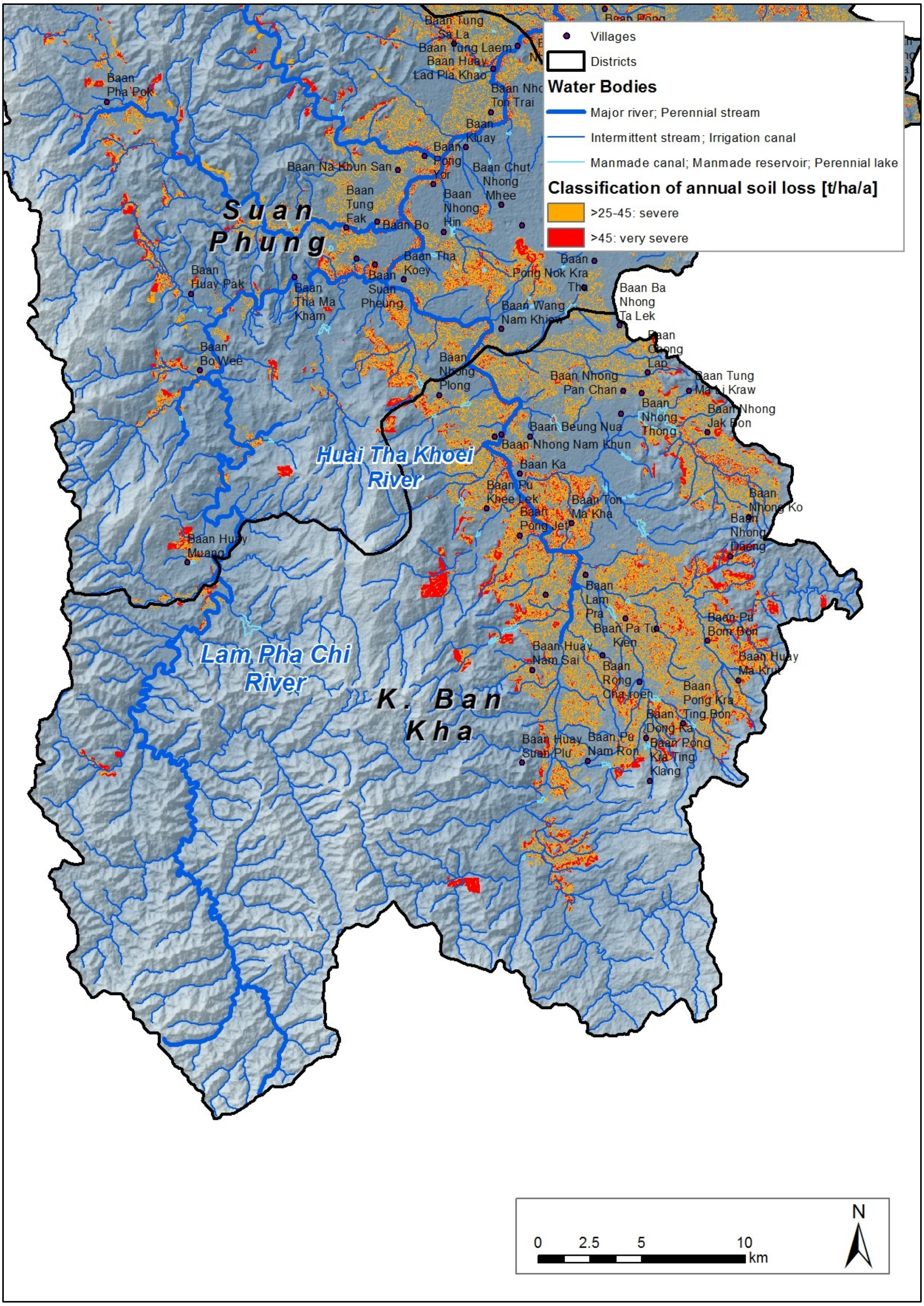


Figure 6-20. Severe and very severe soil loss in the Ban Kha District

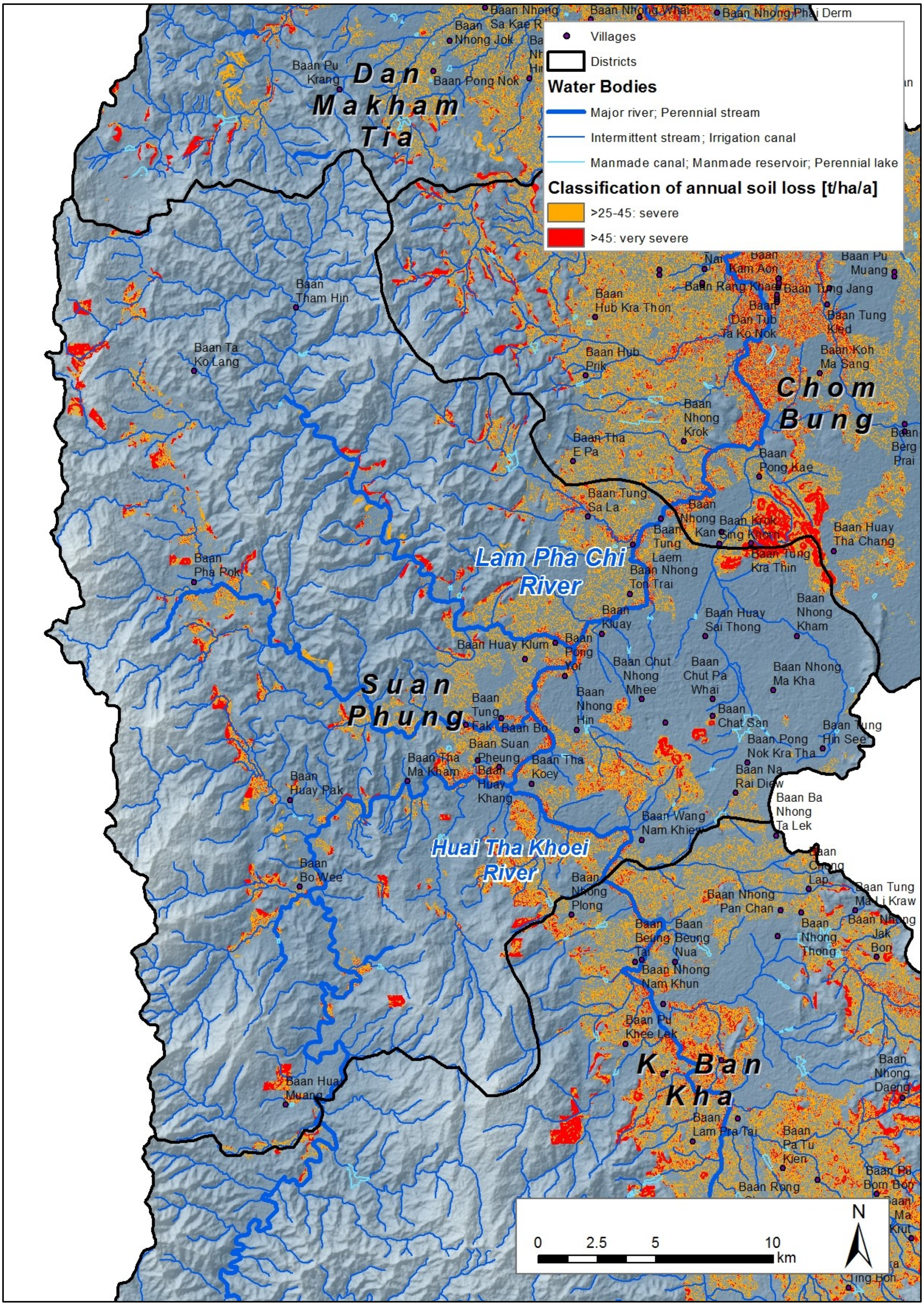


Figure 6-21. Severe and very severe soil loss in the Suan Phung District

6.5.5 Recommendations for further investigations

Improved soil loss assessment

This soil erosion assessment has to be considered as a preliminary study due to drawbacks related to data availability:

Table 6-9: Improved soil loss assessment

Data	Role	Recommendation
Precipitation	RUSLE's *Rainfall Erosivity Factor (R)* is based only on data of one rain gauge station in the center of the Lam Pa Chi river basin.	Additional, long term precipitation data would support a detailed regionalization of soil loss rates because the *Rainfall Erosivity Factor* is considered as one of the most influential parameters of the RUSLE calculation.
Topographic	The calculation of RUSLE's *Slope Length Factor (L)* and *Slope Steepness Factor (S)* is based on the ASTER-DEM (Digital Elevation Model) with a horizontal resolution of approx. 30x30m and a vertical resolution of approx. 16m. Both resolutions are inappropriate for detailed topographic analysis of slope length and slope steepness.	Detailed, high-resolution DEM-data derived by drone flights can provide topographic data with horizontal and vertical resolutions of several centimeters. This data can serve for detailed erosion assessment and flood risk assessment likewise.
LULC (Land use / Land cover)	The LULC data provided for this study appears to be inaccurate and not up-to-date. This fact limits the validity of RUSLE's *Land Cover Management Factor (C)* and the identification of focus areas for soil loss reductions measures.	Multispectral drone flight data combined with ground-truth data would considerably improve the localization of areas prone to soil loss.

Identification of (EbA)-measures: Functional Stream/Floodplain Zoning

This study does not allow to locate and formulate specific EbA-measures due to following reasons:

- <u>Rough soil loss assessment</u>: The study in hand gives a general view of the soil loss situation within the Lam Pa Chi river basin. The above listed drawbacks related to data quality would only serve for a very rough formulation of EbA-measures against soil loss without concrete localization and specification of such measures.
- <u>Missing information on riverine hydro-morphological conditions</u>: Besides onsite soil degradation excessive erosion and sedimentation causes considerable damage to riverine ecosystems by fine sediment intrusion in streams and colmation of the river bed, among others. These effects could not be analyzed and quantified in this study because of missing information about riverine and floodplain hydro-morphological conditions.

For comprehensive EbA-planning tackling erosion and sedimentation problems we recommend a comprehensive hydro-morphological study of major streams within the Lam Pa Chi applying the Functional Stream and Floodplain Zoning method developed by the ITT.

The *Functional Stream and Floodplain Zoning* method combines three assessment procedures to get extensive information on hydraulic conditions within streams, hydromorphological conditions of river channels and floodplains, and vegetational, topographical and land use conditions of the riverine landscape. The three procedures are:

1. Hydromorphological assessment of streams and their floodplains by evaluating 26 parameters via a visual survey protocol. This method bases on the German hydro-morphological field survey (MEIER, ZUMBROICH *et al.* 2013) and is adopted to conditions in the Tropics and Subtropics.
2. Hydraulic assessment of flow velocity, cross profile and discharge by instream measurements via the AquaProfiler™ equipment. This acoustic flow profiler measures flow, discharge and cross-profiles of streams very accurately and cost-efficient.
3. Floodplain assessment regarding vegetation, topography and land use via drone application. RGB- and multisprectral drone imagery is processed for derivation of land use / land cover (LULC) classification and Digital Elevation Model (DEM) generation.

The results of the Functional Stream and Floodplain Zoning method are:

Basic data for different applications

- Extensive and high-resolution information about hydrological, hydraulic, hydro-morphological information of streams.
- Detailed and up-to date land use / land cover classification with sub-meter accuracy.
- Digital Elevation Model (DEM) and 3-D model of the riverine landscape resp. floodplain.

Functional classification of stream and floodplain sections

- Stream and floodplain segments with different potentials and limitations regarding Ecosystem-based-Adaptation and other purposes.
- Functional classification of these segments into the management classes
    - Protection (Segments which are in natural or near-natural conditions to be secured by protection measures.)
    - **Activation** (Segments with great auto-dynamic ecological potential to be initiated by small-scale measures like dead-wood / rock intrusion to foster flow diversity.)
    - Development (Segments with strategic importance in the stream network and floodplain to be redesigned by ecological engineering measures like re-profiling, extraction of fixations, establishment of riparian buffer strips.)
    - Restriction (Segments with limitations regarding ecological development, e.g. urban areas of high flood vulnerability; only technical solutions like flood protection walls, channelization or fixation possible.)

Plan of measures

- Identification of appropriate measures within each river / floodplain segment according to its management class definition (see above).
- Prioritization of measures according to their ecological benefit, technical feasibility and costs.
- Detailed plans / maps with localization of measures for straight-forward implementation.

7 Potential Ecosystem-based Adaptation Measures

7.1 Introduction

In the scope of this study, potential ecosystem-based adaptation measures (EbA), which are potentially applied in the LPC basin were identified by review similar study on Natural Water Retention Measures (www.nwrm.eu) conducted for the EU. Original fact sheets of these measures are attached to this report draft. The measures listed in the attached table are ranked according to their multiple benefits regarding their above mentioned potential to reduce flood, erosion and drought risks. Subsequently, single measures with potential application in the LPC basin to decrease the identified flood, erosion and drought risk are described and potential locations for application highlighted.

In the final phase locations of high priority for implementing these measures can be identified. This localization procedure will be based upon the final results of the vulnerability analysis. In cooperation with local experts the suitability and feasibility of the measures will be evaluated. The implementation of the most promising measures will be discussed in a workshop with project staff and stakeholders.

Several creteria were set up to screen a potential measure which are able to be applied in the LPC to address erosion, flood, drought issues. The following list provides a list of potential EbA measures which were considered for this study (Figure 7-1).

Sector	Measures	Benefits: Drought risk reduction	Benefits: Flood Risk Reduction	Benefits: Erosion & Sediment Control	Sum of benefit points	Ranking	Spatial focus I	Spatial focus II	Example
Agricultural measures	Meadows and pastures	2	3	3	8	I	LULC: Field Crops, Paddy Fields, Orchads, Horticulture crops		
	Buffer strips and hedges	2	3	3	8	I	LULC: Field Crops, Paddy Fields, Orchads, Horticulture crops		Pineapple field
	Early sowing	2	3	3	8	I	LULC: Field Crops, Paddy Fields, Orchads, Horticulture crops		
	Strip cropping along contours	2	2	3	7	I	LULC: Field Crops, Paddy Fields, Orchads, Horticulture crops		Pineapple field
	Green cover	2	2	3	7	I	LULC: Field Crops, Paddy Fields, Orchads, Horticulture crops		Pineapple field
	Traditional terracing		2	3	5	II	LULC: Field Crops, Paddy Fields, Orchads, Horticulture crops	Steep slopes	Pineapple field
	Crop rotation	1	2	1	4	II	LULC: Field Crops, Paddy Fields, Orchads, Horticulture crops		
	Intercropping		2	2	4	II	LULC: Field Crops, Paddy Fields, Orchads, Horticulture crops		Pineapple field
	No till agriculture	2	2		4	II	LULC: Field Crops, Paddy Fields, Orchads, Horticulture crops		
Forestry measures	Land use conversion	3	3	3	9	I	Lower and middle Basin		Excursion locations (abandoned fields)
	Maintenance of forest cover in headwater areas	3	3	2	8	I	Upper Basin	Forest areas	Excursion locations
	Afforestation of reservoir catchments	3	2	3	8	I	Entire basin	Fallow land	
	Continuous cover forestry	2	2	2	6	II	Upper Basin	Forest areas	
	Sediment capture ponds	1	2	3	6	II	Lower and middle Basin	Fallow land	
	Peak flow control structures		1	3	4	II	Upper Basin	Forest areas	
	Appropriate design of roads and stream crossings		1	2	3	III	Entire basin	Stream-road crossings	GIS intersects
	Forest riparian buffers		1	2	3	III	Along major streams	Segments without riparian buffer strips	Excursion locations, Google aerial image
	Coarse woody debris		2		2	III	Along major streams	Lower and middle Basin	
Urban measures	Soakaways	3	3	1	7	I	LULC: Urban		
	Infiltration Basins	3	3	1	7	I	LULC: Urban		
	Infiltration Trenches	3	3	1	7	I	LULC: Urban		
	Detention Basins		3	2	5	II	LULC: Urban		
	Retention Ponds		3	2	5	II	LULC: Urban		
	Filter Strips	1	1	1	3	III	LULC: Urban		
Hydromorphological measures	Floodplain restoration and management	3	3	3	9	I	Along major streams	Lower basin	Excursion locations
	Restoration of natural infiltration to groundwater	3	3	3	9	I	Along major streams	Entire basin	
	Lake restoration	2	3	3	8	I	Along major streams	Lower and middle Basin	Excursion locations
	Basins and ponds	3	3	2	8	I	Along major streams	Entire basin	
	Restoration and reconnection of seasonal streams	1	3	3	7	I	Along major streams	Lower and middle Basin	
	Reconnection of oxbow lakes and similar features	1	3	3	7	I	Along major streams	Lower and middle Basin	Excursion locations
	Wetland restoration and management	3	2	2	7	I	Along major streams	Lower basin	
	Re-meandering	2	3	2	7	I	Along major streams	Lower and middle Basin	Excursion locations
	Stream bed re-naturalization	1	3	2	6	II	Along major streams	Lower and middle Basin	Excursion locations
	Natural bank stabilisation		3	3	6	II	Along major streams	Lower and middle Basin	Excursion locations
	Elimination of riverbank protection		3	3	6	II	Along major streams	Lower and middle Basin	Excursion locations
	Riverbed material renaturalization		2	3	5	II	Along major streams	Lower and middle Basin	
	Removal of dams and other longitudinal barriers		2	2	4	II	Along major streams	Entire basin	Excursion locations

Figure 7-1. EbA measures and their evaluation (more detail in attached file)

After screening, four measures were described for the LPC basin as shown in *Figure* 7-2.

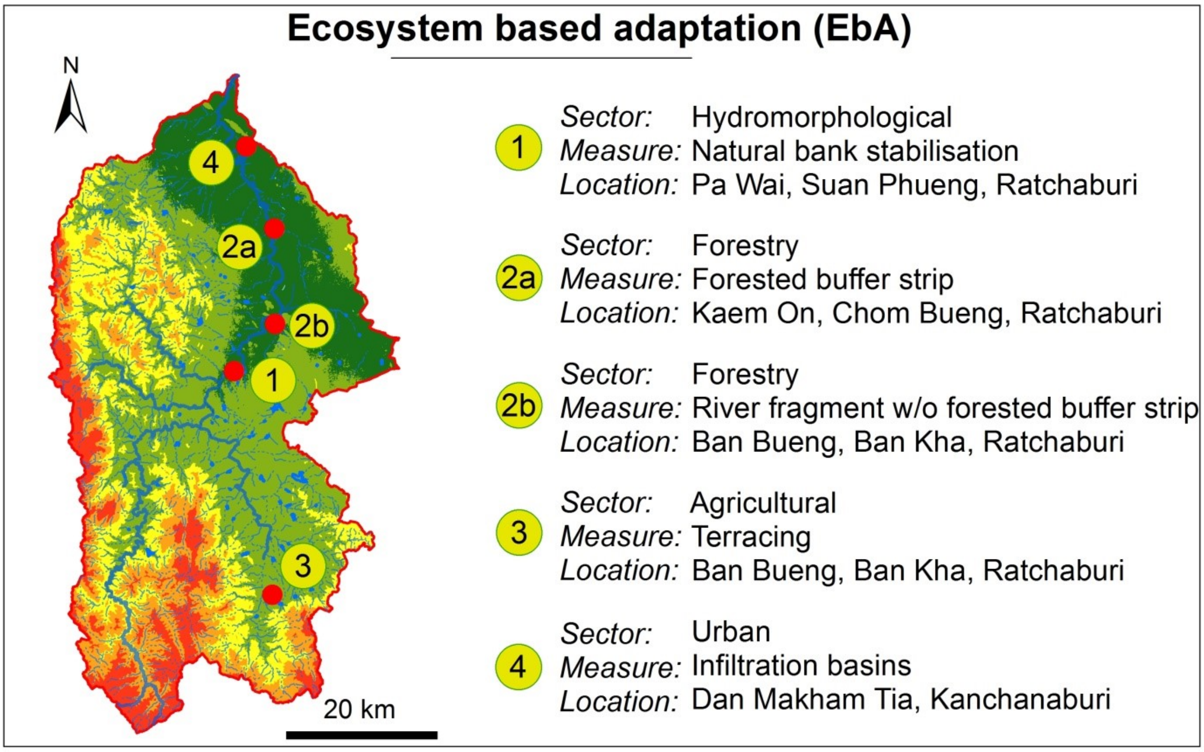


Figure 7-2*. Overview of EbA measures proposed*

The following sections discuss on each selected measure.

7.2 EbA – An example on Natural bank stabilization

7.2.1 General description

Even where streams retain relatively natural patterns of flow and flooding, stream corridor restoration might require that stream banks be temporarily stabilized while floodplain vegetation recovers. The objective in such instances is to mitigate the accelerated erosion associated with unvegetated banks, and to reduce erosion to rates appropriate for the respective stream system. In these situations, the initial bank protection may be provided by bioengineering approaches using natural materials like vegetation, wood, and rock (USDA, 2001).

These approaches employ plant materials in the form of live woody cuttings or poles of readily sprouting species, which are inserted deep into the bank or anchored in various other ways. This serves the dual purposes of resisting washout of plants during the early establishment period, while providing some immediate erosion protection due to the physical resistance of the stems. Plant materials alone are sufficient on some streams or some bank zones, but as erosive forces increase, they can be combined with other materials such as rocks, logs or brush, and natural fabrics. In some cases, woody debris is incorporated specifically to improve habitat characteristics of the bank and near-bank channel zones (USDA, 2001).

Figure 7-3. Potential for natural bank stabilization at construction site for a new weir close to Pa Wai (Suan Phueng, Ratchaburi)

7.2.2 Location

The potential site to apply this measure is located at Pa Wai, Suan Phung Ratchaburi, within the LPC (the measure No. 1 in *Figure* 7-2)

7.2.3 Benefits

Major benefits for applying this EbA:

- The replacement of concrete bank stabilization structures with near-natural structures helps slowing down the flow velocity and hence contributes with retention effects during flood events.
- The bioengineered bank protection diversifies the bank structures and thereby creates different riparian habitats for both aquatic and terrestrial species.
- Vegetated river banks serve as buffer strips filtering pollutants and sediments coming with the water flow from adjacent agricultural areas.

7.2.4 Technical specification

The effective planning, design, and operation of this type of measure requires the involvement of a local planning authorities, environmental regulators, private companies specialized in bioengineering techniques, private landowners and land managers, farmers and other bodies with responsibilities water management (e.g. irrigation bodies, drainage boards, etc).

This measure can be implemented through different solutions, with very different costs. It is crucial to carry out beforehand an analysis of the local needs in order to choose the best bank revitalization solution.

Among the different natural bank stabilization techniques are shown in *Table* 7-1.

Table 7-1. *N*atural bank stabilization techniques. Source: (USDA, 2001)

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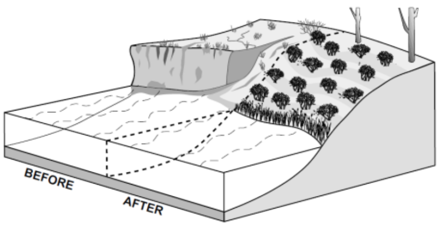
Bank Shaping and Planting



Regrading streambanks to a stable slope, placing topsoil and other materials needed for sustaining plant growth, and selecting, installing and establishing appropriate plant species.

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- Most successful on stream banks where moderate erosion and channel migration are anticipated.
- Reinforcement at the toe of the embankment is often needed.
- Enhances conditions for colonization of native species.
- Used in conjunction with other protective practices where flow velocities exceed the tolerance range for available plants, and where erosion occurs below base flows.
- Stream bank soil materials, probable groundwater fluctuation, and bank loading conditions are factors for determining appropriate slope conditions.
- Slope stability analyses are recommended.

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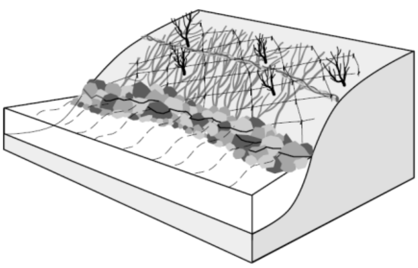
Brush Mattresses



Combination of live stakes, live facines, and branch cuttings installed to cover and physically protect streambanks; eventually to sprout and establish numerous individual plants.

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- Form an immediate protective cover over the stream bank.
- Capture sediment during flood flows.
- Provide opportunities for rooting of the cuttings over the stream bank.
- Rapidly restores riparian vegetation and streamside habitat.
- Enhance conditions for colonization of native vegetation.
- Limited to the slope above base flow levels.
- Toe protection is required where toe scour is anticipated.
- Appropriate where exposed stream banks are threatened by high flows prior to vegetation establishment.
- Should not be used on slopes which are experiencing mass movement or other slope instability.

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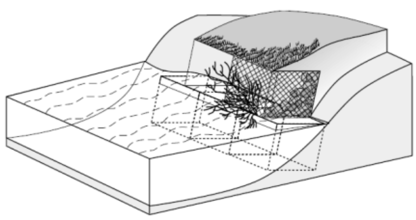
Vegetated Gabions



Wire-mesh, rectangular baskets filled with small to medium size rock and soil and laced together to form a structural toe or sidewall. Live branch cuttings are placed on each consecutive layer between the rock filled baskets to take root, consolidate the structure, and bind it to the slope.

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- Useful for protecting steep slopes where scouring or undercutting is occurring or there are heavy loading conditions.
- Can be a cost effective solution where some form of structural solution is needed and other materials are not readily available or must be brought in from distant sources.
- Useful when design requires rock size greater than what is locally available.
- Effective where bank slope is steep and requires moderate structural support.
- Appropriate at the base of a slope where a low toe wall is needed to stabilize the slope and reduce slope steepness.
- Will not resist large, lateral earth stresses.
- Should, where appropriate, be used with soil bioengineering systems and vegetative plantings to stabilize the upper bank and ensure a regenerative source of stream bank vegetation.
- Require a stable foundation.
- Are expensive to install and replace.
- Appropriate where channel side slopes must be steeper than appropriate for riprap or other material, or where channel toe protection is needed, but rock riprap of the desired size is not readily available.
- Are available in vinyl coated wire as well as galvanized steel to improve durability.
- Not appropriate in heavy bedload streams or those with severe ice action because of serious abrasion damage potential.

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7.3 EbA - An example on Forest riparian buffers / Buffer strips and hedges[4]

7.3.1 General description

These are two measures appointed by the European Union Natural Water Retention Measures (NWRM) project. The first measure refers to the presence of forest in the riparian zones of watercourses. The latter refers to buffer strips as areas of natural vegetation cover including grass, bushes or trees. These strips can be found at the margins of arable land, transport infrastructure or watercourses.

Buffer strips offer good conditions for effective water infiltration and slowing surface flow; they therefore promote the natural retention of water. They can also significantly reduce the amount of suspended solids and nutrients originating from agricultural runoff. Hedges across long, steep slopes may reduce soil erosion as they intercept and slow surface run-off water before it builds into damaging flow, particularly where there is a margin or buffer strip alongside.

The focus of this section will be put on riparian buffers which are treed areas alongside streams and other water bodies. While most commonly associated with set asides following forest harvest, riparian buffers can also be found in urban, agricultural and wetland areas. By preserving a relatively undisturbed area adjacent to open water, riparian buffers can serve a number of functions related to water quality and flow moderation. For instance, riparian buffers serve to slow water as it moves off the land decreasing sediment inputs to surface waters. Moreover, trees in riparian areas can efficiently take up excess nutrients and may also serve to increase infiltration.

7.3.2 Location

The potential site to apply this measure is shown as measure No. 2a and 2b in Figure 7-2. The LPC was analyzed using Google Earth imagery to identify examples of river fragment with and without buffer strips. *Figure* 7-4 is an example of the main river with buffer strips on both margins. Beyond the forest agriculture is practiced enhancing nutrient pollution and erosion. The width of the strips is variable. Environmental law regulations in some countries suggest a width of 30 meters for rivers thinner than 10 meters and of 50 meters for rivers wider than 10 meters. As shown previously the width will impact the efficiency of the key ecosystem functions offered by the buffer strips.

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[4] To see a complete description of these measures please refer to:

http://nwrm.eu/sites/default/files/nwrm_ressources/f1_-_forest_riparian_buffers.pdf

http://nwrm.eu/measure/buffer-strips-and-hedges

Figure 7-4. Example of a forested buffer strip

Figure 7-5. Example of a fragment of the river without forested buffer strips

On the other hand, as it can be seen in *Figure* 7-5, in this example agriculture is practiced up to the margins of the rivers. Therefore, nutrients and sediments can be directly transported to the river. Erosion can be an important problem especially when the soil is exposed after the harvest. In the following table the coordinates and date for each image can be found.

7.3.3 Benefits

This ecosystem-based adaptation measure has several benefits which are shown in the following table (Table 7-2).

Table 7-2. Key functions of riparian buffers. Source: (Parkyn 2004)

Key functions	Explanation
Stream bank stability	Root systems of trees and grasses stabilize river banks and land cover reduces surface erosion
Filtering overland flow	Surface roughness provided by vegetation reduces the overland flow velocity enhancing sedimentation.
Fish spawning habitat and cover	Tree roots, overhanging branches and woody debris proved key habitat (hiding and resting places) for a wide variety of fish and crayfish
Habitat for adult phases of insects	Some insects spend weeks, even months, as adults in the terrestrial area. Riparian vegetation is a key element offering ecosystem services (e.g. humidity, lower temperature, food resources) necessary to many insect species

Key functions	Explanation
Shade for temperature regulation	Shade regulates temperature, especially in summer, where an increase of temperature due to the lack of shade can be lethal to some invertebrates and fish. In winter, hotter temperatures can affect spawning of some fishes (e.g. trout)
Shade for instream plant control	Shade removal provides light for instream plant growth sometimes reducing the levels of dissolved oxygen and affecting pH leading to stress for aquatic ecosystems
Woody debris and leaf litter	Riparian trees add leaf litter and wood that are an important source of habitat diversity for invertebrates and fish. Leaf litter can be a food resource for some stream invertebrates
Plant nutrient uptake from groundwater	Roots of riparian plants intercept groundwater reducing nutrient input to streams
Denitrification N control	Denitrifying bacteria can remove substantial quantities of nitrate from groundwater passing though riparian wetlands
Reduction of direct animal waste	Preventing direct access of stock to waterways prevents hoof-damage to river banks and direct input of nutrients, organic matter and pathogens
Downstream flood control	Well-developed riparian vegetation increases the roughness of river margins, slowing down flood-flows. This reduces the peak flows downstream but may results in some local flooding. Riparian wetlands provide temporary storage of water during rain events
Terrestrial biodiversity	Riparian zones contain a high diversity of soil and water conditions, resulting correspondingly diverse terrestrial plant and animal communities

The main mechanisms by which riparian forests improve water quality include surface and subsurface pollutant transport processes. According to Parkyn (2004) the main reduction observed in surface transport is due to:

- Infiltration within the buffer zone which reduces surface runoff,
- Reduction of surface runoff velocity due to an increase of hydraulic roughness,
- Physical filtering of dense vegetation

These mechanisms prevent sediments (and pollutants attached to soil particles such as phosphorus and others) to reach the watercourses. This is especially important in the Lam Pa Chi where erosion and in-stream sedimentation are current problems. Moreover, riparian buffer also influence the subsurface pollutant transport by:

- Uptake by vegetation in the strip
- Denitrification, which is the microbial transformation of different organic forms of nitrogen (e.g. nitrate, nitrite) to a gaseous form (N_2).

The reduction nutrient input into the main streams of the basin will help prevent further water quality problems such as eutrophication.

7.3.4 Technical specification

Riparian buffer

The effectiveness of a riparian buffer zone is related to its width. The following figure shows a scheme of riparian tree vegetation along a watercourse, at the bottom a relationship between the different ecosystem services related to the width of the strip is shown.

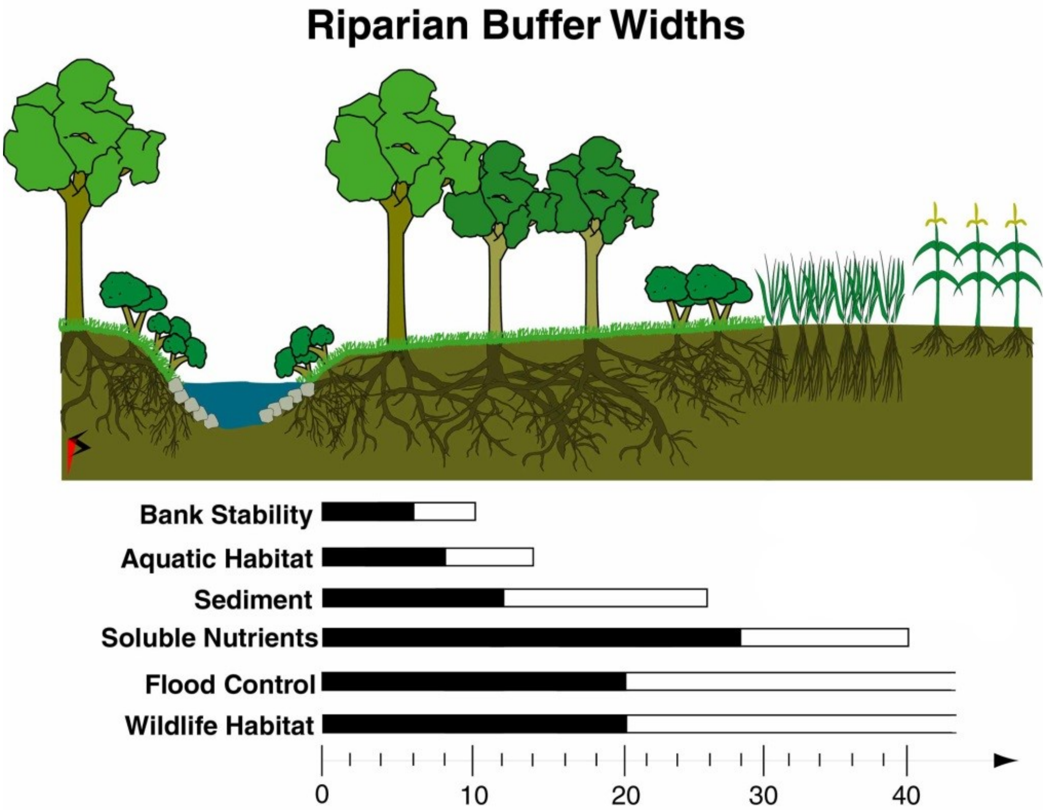

Figure 7-6. Example of a riparian buffer zone related to its efficiency and width. In black the minimum width required, in white the maximum (Schultz, Dick).

While implementing this measure it is important to consider the width of the strip and the kind of vegetation to be planted. It is recommended to use local tree species since they are adapted to the climatic conditions. This measure could tackle one of the main problems identified for the basin: erosion/sedimentation. Furthermore, it will have a positive impact on the water quality. However, a thorough assessment is still needed to identify the exact locations to be reforested.

Finally, the main challenge to implement this measure lies on the acquisition of land (in case of private property) to reforest the river margins. The total cost will strongly depend on the price of the acquired land. If farmers and land owners are involved in the implementation process and can see the main benefits of this measure, it could be culturally accepted and be successfully implemented. In this regard, the river basin committee or working group will be an important management body to accompany this process.

7.4 EbA – An example on Terracing in pineapple cultivation

7.4.1 General description

Figure 7-7. Making small level bench terraces in Northern Thailand (Source: FAO, 2012)

Terracing is a common agricultural practice in the hilly slopes (Figure 7-7). By reducing the effective slope of land, the terracing can reduce erosion and surface run-off as well as facilitating cultivation (NWRM, 2013). In the Northern Thailand, this method is applied to provide level platforms cultivating tea, coffee, vegetables, and flowers on sloping areas (FAO, 2012). Several researches have demonstrated the high effectiveness of terracing method at preventing erosion, reducing sediment yield, conserving soil moisture, protecting landscape quality, and increasing land value (Foster, 2005). Spatial analysis shows that approximately 24% surface terrains of the Lam Pa Chi have slope over 20 degrees and a substantial parts of these sloping terrains are used for cultivating cassava, sugarcane, and pineapple. Large sloping areas provide potential to apply terracing measure to plantation in the basin.

7.4.2 Location

The proposed site to apply ecosystem-based measure of terracing is located at Tambon Ban Bueng, Amphoe Ban Kha, Changwat Ratchaburi, Thailand (the measure No. 3 in *Figure* 7-2). This is a large farm cultivating pineapple and pineapple mixed sugarcane. The region has tropical climate with average rainfall is 1150 mm/year; annual temperature fluctuates between 25-32 ^{o}C. The results from 30m-solution-digital-elevation model indicate that the slope of the terrain changes from 15 to 25 degrees.

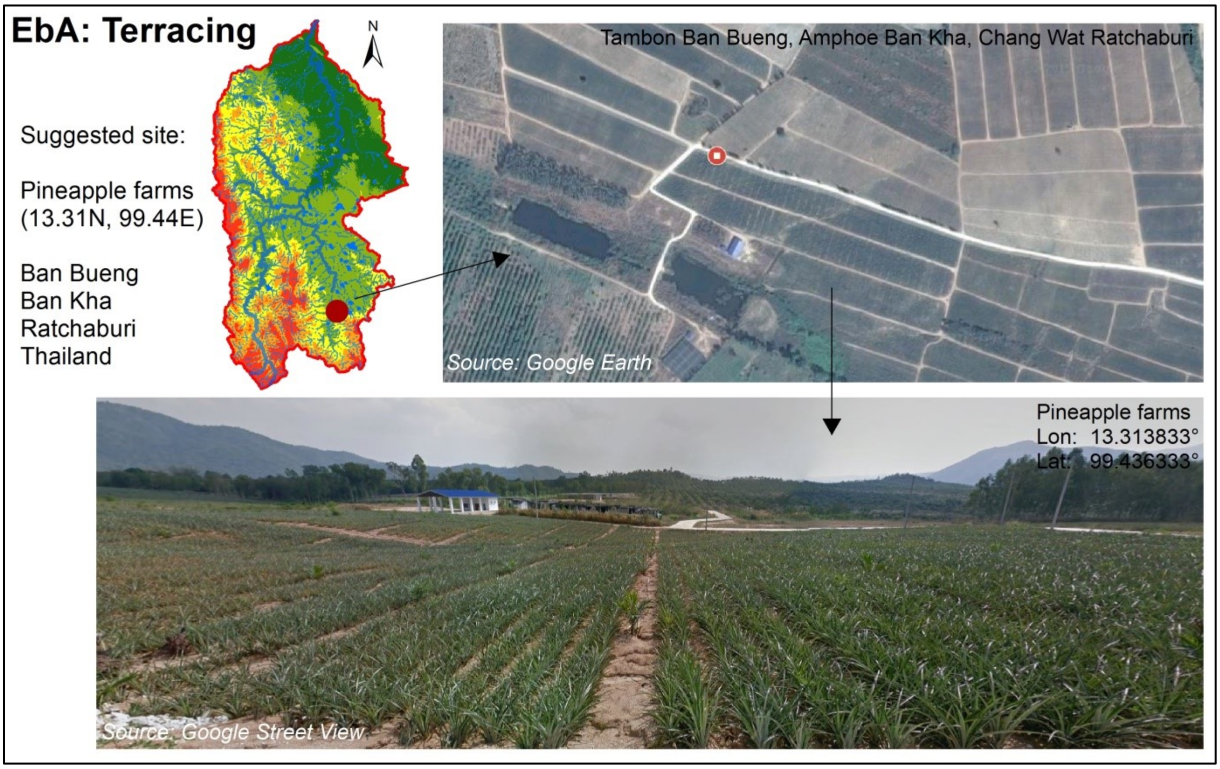

Figure 7-8. Proposed site for applying terracing measure

Terraces require a significant investment to build and maintain (NWRM, 2013). Farming with terraces may be inconvenient, and they may limit the choice of farming practices. So far, the terracing measure is not observed in agricultural practice in the Lam Pa Chi Basin and therefore it is required to have further detail investigations before applying into the field.

7.4.3 Benefits

The key benefits for applying traditional terracing measure are mentioned in *Table* 7-3.

Table 7-3*. Key benefits for applying traditional terracing measure*

Key functions	Explanation
Slowing & Storing runoff	The leveled platforms can are able to store runoff on surface or in small canals along contours. Smaller sloping degrees of terrain also slow down the surface runoff.
Reducing runoff	Land cover, smaller sloping degrees increase evapotranspiration, infiltration rate/or groundwater recharge and increase soil water retention
Soil conservation	Reducing erosion and/or sediment delivery. Controlling erosion helps to maintaining soil fertility.
Flood risk reduction	Slowing, storing and reducing surface runoffs contribute directly to reducing flood flows. Higher infiltration, and increased soil water retention indirectly reduce flood risk.
Filtration of pollutants	By increasing infiltration rates, traditional terracing may provide filtration benefits, but no evidence was found.
Aesthetic/ cultural value	Traditional terracing contributes to the cultural heritage and landscape character of areas where it is implemented. Abandonment may result in homogenisation of these landscapes and undesirable land use change (NWRM, 2013 after Duarte et al, 2008)

7.4.4 Technical specification

There are several terracing types as shown in Figure 7-9. Crop types, climatic condition, soil features, slope degrees, tradition in agricultural practices are the main factors determining the terracing methods, which will be used. The length of terrace, the width of the bench, horizontal gradients range, slope limits, risers and riser slopes are the major technical specifications involved designing terraces. These specifications are discussed in detail by FAO (1988).

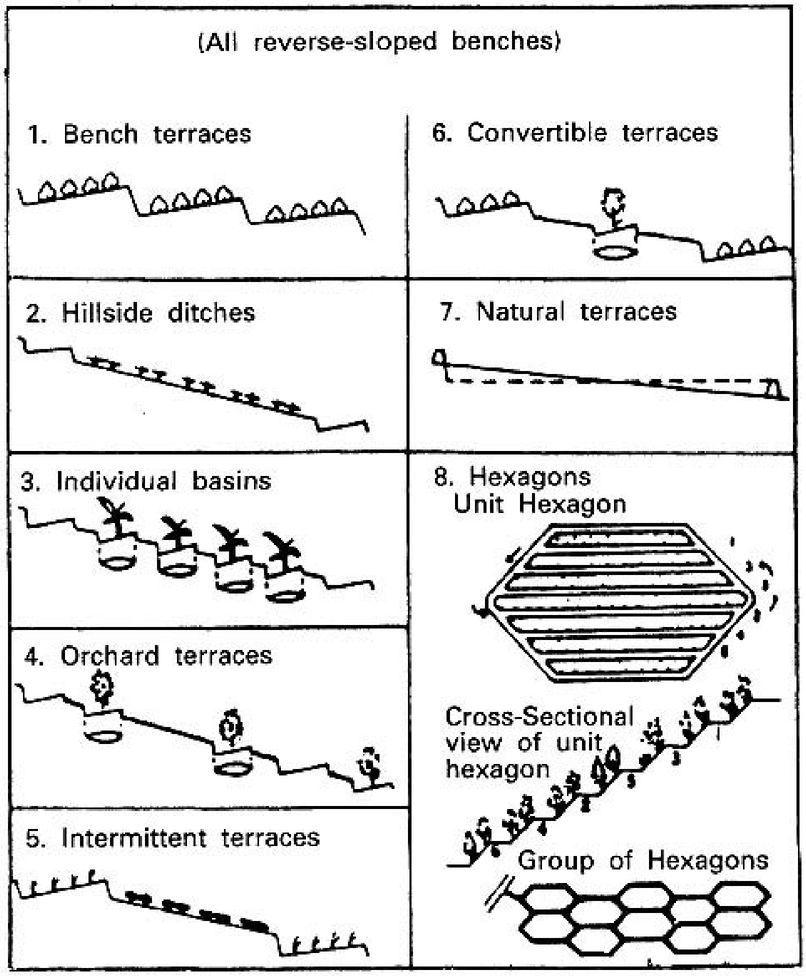

Figure 7-9. Types of traditional terracing measures
Source: http://www.fftc.agnet.org/htmlarea_graph/library/20110804181442/eb448f1.jpg

Constructing terraces are gradual process and must be done when the soil is neither too dry nor too wet (FAO, 1988). Slope, soil, width of bench, presence of rocks or tree stumps, and tools used define the construction cost but the wider the bench the more costly it will be. The constructed terraces should be protected at their risers and outlets from erosion.

7.5 EbA – An example on Infiltration basin in urban areas

7.5.1 General description

A stormwater infiltration basin holds runoff and lets it soak into the ground. The basins are open facilities with grass or sand bases. They can either drain rapidly or act as permanent ponds where water levels rise and fall with stormwater flows. Infiltration facilities can be designed to handle all runoff from a typical storm but could overflow in a larger one. Since the facility is designed to soak water into the ground, anything that can clog the base will reduce performance and be a concern. Water leaves the basin in form of percolation to the aquifer as well as through overflow after heavy rainfall events. Generally, infiltration basins are managed like detention ponds but with greater emphasis on maintaining the ability to infiltrate stormwater to the groundwater.

7.5.2 Location

The location of of the example on infiltration basin in urban areas in the LPC is shown as the measure No. 4 in *Figure* 7-2. The sampling locations for applying this measure is shown in Figure 7-10 and Figure 7-11.

Figure 7-10. Small settlement with potential sites for the construction of infiltration basins

Figure 7-11. Potential site “1” for infiltration basin construction (view from East to West)

7.5.3 Benefits

Infiltration Basins reduces the volume of runoff from a drainage area. In addition they can be very effective at pollutant removal via filtering through the soils. They contribute to groundwater recharge and baseflow augmentation thus providing additional water reserves for drought periods.

Figure 7-12. Infiltration basin after rainfall event

Infiltration basins are simple and cost-effective to construct. A negative aspect is that comprehensive geotechnical investigations are needed to proof that the underground is feasible for this technique (not feasible in areas with compacted or clayey soils) as well as the relatively large land area demand.

7.5.4 Technical specification

There are a bulk of literatures discussing technical specification of infiltration basin. Further information can read at http://nwrm.eu/measure/infiltration-basins). Other similar terms of infiltration pond, recharge basin, seepage basin are very helpful to expand the understanding the technical specification of this measure.

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9 Annex

Annex 1. Mae Klong river basin

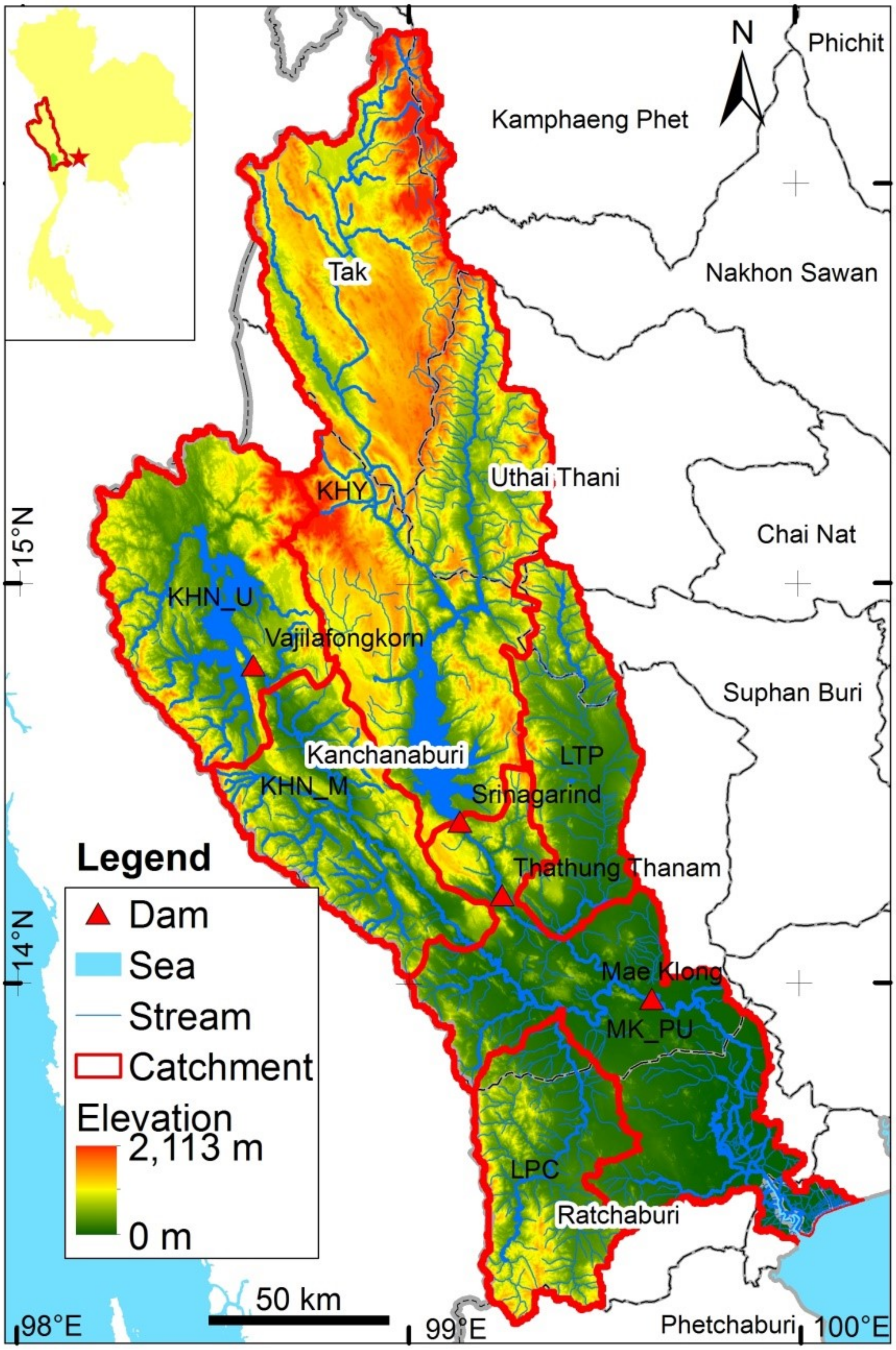

Figure A- 1. Mae Klong River Basin

Annex 2. Some features of river basin in Thailand

Table A- 1. River basin in Thailand

Basin No	River Basin Name	Watershed area [km^2]	Annual run-off [million m^3]	Specific annual runoff [million m^3 /km^2]
1	Part of Salawin	17,920	8,156	0.455
2	Part of Mekong	57,422	15,800	0.275
3	Kok	7,895	5,119	0.648
4	Chi	49,477	8,035	0.162
5	Mun	69,700	21,767	0.312
6	Ping	33,892	6,686	0.197
7	Wang	10,791	1,429	0.132
8	Yom	23,616	1,430	0.061
9	Nan	34,330	9,518	0.277
10	Lower Chao Phraya	20,125	4,925	0.245
11	Sakae Krang	5,191	519	0.100
12	Pasak	16,292	2,708	0.166
13	Tha Chin	13,681	2,815	0.206
14	Mae Klong	30,864	12,943	0.419
15	Prachinburi	10,481	4,502	0.430
16	Bang Pakong	7,978	4,900	0.614
17	Part of Tonle Sap	4,150	1,193	0.287
18	East Coast Gulf	13,830	25,960	1.877
19	Phetchaburi	5,603	1,140	0.203
20	West Coast-Gulf	6,745	1,013	0.150
21	Peninsular-East Coast	26,353	35,624	1.352
22	Tapi	12,225	17,380	1.422
23	Thale Sap Songkhla	8,495	7,301	0.859
24	Pattani	3,858	3,024	0.784
25	Peninsular-West Coast	21,172	9,918	0.468
Thailand		**512,066**	**214,128**	**0.418**

Annex 3. Water Demand calculations used for the WEAP model

Subbasin 1		Water Demand [million m^3]												
Crops	Area [km^2]	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total year
Bananas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cassava	171.71	0.00	0.00	0.00	0.00	6.97	17.17	23.18	20.91	18.37	15.37	9.48	0.00	111.46
Corn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eucalyptus	79.07	7.27	6.88	7.11	7.36	6.63	8.25	6.96	6.37	5.53	6.14	6.87	7.04	82.39
Mixed Crops	57.24	2.08	1.97	1.96	1.97	2.19	5.23	6.76	6.91	4.98	3.31	2.79	1.68	41.81
Pineapple	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rice	40.48	0.00	0.00	0.00	0.00	0.00	7.62	8.14	7.52	5.57	0.00	0.00	0.00	28.85
Sugar Cane	388.67	54.61	51.69	48.54	43.76	36.38	26.55	41.59	62.03	62.96	63.43	61.41	55.97	608.93
Total	737.17	63.95	60.54	57.61	53.09	52.16	64.81	86.62	103.73	97.42	88.25	80.55	64.68	873.44

Subbasin 2		Water Demand [million m^3]												
Crops	Area [km^2]	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total year
Bananas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cassava	10.80	0.00	0.00	0.00	0.00	0.44	1.08	1.46	1.32	1.16	0.97	0.60	0.00	7.01
Corn	1.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eucalyptus	2.75	0.25	0.24	0.25	0.26	0.23	0.29	0.24	0.22	0.19	0.21	0.24	0.24	2.87
Mixed Crops	9.37	0.34	0.32	0.32	0.32	0.36	0.86	1.11	1.13	0.81	0.54	0.46	0.27	6.84
Pineapple	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rice	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sugar Cane	1.02	0.14	0.14	0.13	0.11	0.10	0.07	0.11	0.16	0.16	0.17	0.16	0.15	1.59
Total	25.57	0.74	0.70	0.69	0.69	1.12	2.29	2.91	2.83	2.33	1.89	1.45	0.67	18.31

Subbasin 3		Water Demand [million m^3]												
Crops	Area [km^2]	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total year
Bananas	0.48	0.03	0.03	0.03	0.03	0.04	0.06	0.07	0.07	0.07	0.07	0.05	0.00	0.55
Cassava	8.97	0.00	0.00	0.00	0.00	0.36	0.90	1.21	1.09	0.96	0.80	0.50	0.00	5.83
Corn	2.16	0.00	0.00	0.00	0.00	0.09	0.22	0.29	0.26	0.23	0.19	0.12	0.00	1.40
Eucalyptus	4.84	0.45	0.42	0.44	0.45	0.41	0.51	0.43	0.39	0.34	0.38	0.42	0.43	5.05
Mixed Crops	7.21	0.26	0.25	0.25	0.25	0.28	0.66	0.85	0.87	0.63	0.42	0.35	0.21	5.27
Pineapple	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rice	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sugar Cane	0.94	0.13	0.12	0.12	0.11	0.09	0.06	0.10	0.15	0.15	0.15	0.15	0.14	1.47
Total	24.60	0.87	0.82	0.83	0.84	1.26	2.40	2.95	2.84	2.38	2.01	1.58	0.78	19.56

Subbasin 4		Water Demand [million m^3]												
Crops	Area [km^2]	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total year
Bananas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cassava	14.56	0.00	0.00	0.00	0.00	0.59	1.46	1.97	1.77	1.56	1.30	0.80	0.00	9.45
Corn	1.95	0.00	0.00	0.00	0.00	0.08	0.19	0.26	0.24	0.21	0.17	0.11	0.00	1.26
Eucalyptus	7.52	0.69	0.65	0.68	0.70	0.63	0.78	0.66	0.61	0.53	0.58	0.65	0.67	7.83
Mixed Crops	4.78	0.17	0.16	0.16	0.16	0.18	0.44	0.56	0.58	0.42	0.28	0.23	0.14	3.49
Pineapple	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rice	0.69	0.00	0.00	0.00	0.00	0.00	0.13	0.14	0.13	0.10	0.00	0.00	0.00	0.49
Sugar Cane	3.41	0.48	0.45	0.43	0.38	0.32	0.23	0.36	0.54	0.55	0.56	0.54	0.49	5.34
Total	32.90	1.34	1.27	1.26	1.25	1.80	3.23	3.96	3.86	3.36	2.89	2.34	1.30	27.87

Subbasin 5		Water Demand [million m^3]												
Crops	Area [km^2]	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total year
Bananas	1.14	0.07	0.07	0.07	0.08	0.10	0.15	0.17	0.17	0.16	0.16	0.12	0.00	1.31
Cassava	17.19	0.00	0.00	0.00	0.00	0.70	1.72	2.32	2.09	1.84	1.54	0.95	0.00	11.16
Corn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eucalyptus	10.00	0.92	0.87	0.90	0.93	0.84	1.04	0.88	0.81	0.70	0.78	0.87	0.89	10.42
Mixed Crops	31.16	1.13	1.07	1.07	1.07	1.19	2.85	3.68	3.76	2.71	1.80	1.52	0.91	22.76
Pineapple	118.14	4.03	3.90	4.03	4.16	4.45	5.91	6.11	5.22	4.61	4.75	4.39	3.62	55.17
Rice	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sugar Cane	89.52	12.58	11.91	11.18	10.08	8.38	6.11	9.58	14.29	14.50	14.61	14.14	12.89	140.26
Total	267.16	18.72	17.81	17.24	16.32	15.66	17.78	22.74	26.34	24.52	23.64	21.99	18.31	241.08

Annex 4. EbA measures and their evaluation

(See attached excel file)