A Dissertation for the Degree of Ph. D. In Geography

Study on Effect of Climate Change on Hydrological Response in the Xe Bang Fai River Basin

기후변화에 따른 라오스인민공화국의 시방파이 유역의 수문현상 예측에 대한 연구: SWAT 모델을 이용하여

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Abstract

Study on Effect of Climate Change on Hydrological Response in the Xe Bang Fai River Basin

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The Xe Bang Fai river basin is a sub-basin of the Mekong River Basin. The significant activity of agricultural land management in this basin area is cropping such as rice and vegetables plantation. All of these have been being grown well. The sector of agriculture is the significant part of irrigated region, additionally over the decade's quick outgrowth of population, industrialization and urbanization, especially transforms in activities of social and economic sector, have affected to enlarged, but the amount of streams flow in watershed are declining continuously. The Xe Bang Fai river basin is provisionally flooded due to Typhoon, which is affected from climate change nowadays, during wet season. Severe

heavy rainfall has continuously been found in this basin area, in which it has been become a cause of floods at downstream of the Xe Bang Fai river basin. Besides that, the precipitation is main variant in each year, but the precipitation intenseness is great, which this is pretty normal in the region of central Lao PDR. Consequently, the major objective of this thesis is to assess the climate variation on hydrology of the Xe Bang Fai river basin in Laos applying data driven and modeling methods.

In Chapter 2 represents the trends of annual and seasonal precipitation and additionally the trends of annual temperature in the Xe Bang Fai river basin, Lao PDR was evaluated using the Mann-Kendall test and Sen's Slope estimates method (MAKESENS). The purpose of this study is to look for the effect of climate variation by discussing a relationship with the current enlargement of hazardous natural disasters. The increased trend of precipitation, for instance annual monthly maximum etc., was observed at Signo and Mahaxay stations in the northern part of the Xe Bang Fai river basin. The annual decreased trend of precipitation related to drought risk was additionally observed at Donghen and Xepon stations in the southern part of the Xe Bang Fai river basin. The results of this study offer significant formation to manage the water resources in the basin area.

In Chapter 3 represents the river discharge simulation of the Xe Bang Fai river basin by using SWAT model. The hydrological model was successfully calibrated and validated in this basin by applying SUFI-2 algorithm. In the SWAT model, the sensitivity analysis of the hydrological model, the discharge parameter is not sensitive, but also the parameter of HRUs delineation thresholds followed by sub-watershed continuous affectation. The result of study indicated that 716 HRUs are suitable in this basin, in which the represented SUFI-2 algorithm is be modified while simulating flow in the Xe Bang Fai river basin. The calibration and validation model are implemented in the two periods: calibration periods (2001-2005) and validation period (2006-2010). In this study, the results of the monthly river discharge simulation R^2 and E_{NS} are 0.970 and 0.967 during the calibration periods and also 0.966 and 0.960 during the validation period. The SWAT model can generate good simulation results of monthly time processes which they are valuable for water resources management in the Xe Bang Fai river basin as well as the whole sub-watershed in the Mekong river basin. The model was already calibrated successfully. It can be applied for more analysis of climate variation and land use changes as well as other distinct management models on the hydrology.

In Chapter 4 represents the comparing calibrated model was run with the three climate change scenarios offered by the Mekong River Commission (MRC). In this study, these climate change scenarios were reconsidered to run the model during the period: 2001-2010 with the change factors of climate (IPSL CM5A-MR, GISS E2-R-CC and GFDL CM3) to design the surface runoff for the year 2030. Various research institutes studied the climate change factors, as the result IPSL CM5A-MR 2030, GISS E2-R-CC 2030 and GFDL CM3 2030, which represented the discharge in both dry season and wet season. In the study, the results of IPSL 2030, the discharge in the dry season (Feb-May) are lower than the baseline, while the end of the wet season is above the baseline. In the river discharge, the scenarios of climate change produced more 800 m^3/s for the months including July, August and September on the baseline of the Xebangfai@bridge station. The cause of the peak discharge in these months is the effect of southwest monsoon, which affects commonly the watersheds from middle of May to early October (wet season). This is predominant phenomena when air pressure is low more than Laos and result in heavy rainfall. The severe variation was found with three scenarios (IPSL CM5A-MR 2030, GISS E2-R-CC 2030 and GFDL CM3 2030), which causes the high volume monthly runoff, raises the large monthly runoff duration by expanding the large runoff season until the first week on September. The results of model simulation with the scenarios of climate change can be applied for preferable information in future researches.

Overall of this study concentrated on the effects of climate change on hydrological response in the Xe Bang Fai river basin, Lao PDR. After analyzing precipitation and temperature trends in this basin, the procedure conducted the model calibration and validation of stream flow. The following chapters, then, the study concentrated on the scenarios of climate change to design surface runoff for the

period of year 2030s in this basin. The results gained in this study increase the knowledge of climate change effects on hydrological response in Laos. In addition, the results of the study can be provided beneficial information to plan water resources management, especially Nam Theun 2 Dam for water management and also it will be useful information for planning flood disaster risk management in the Xe Bang Fai river basin. Moreover, the study offers valuable information to plan for developing hydropower project and flood disaster risk reduction by following Lao's government strategy on 8^{th} National Social-Economic Development Plan (2016-2020) about adaptation on climate change which are essential for the sustainable development of Lao PDR in the future.

Keyword: Climate Change, Hydrological Model, SWAT Model, Xe Bang Fai river basin, Mann-Kendall and Sen's Slope Method.

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Chapter 1. Introduction

1.1 Background

Water is the most valuable and important natural resources. It is main element of overall subsistence on the earth, which climate variation is one of the most significant ingredients for usable water resources. Also water is only the most essential demand for living, which it is possibly the single natural resources to relate overall appearances of people advancement from cultivation and industrial evolution to the cultural and religious worth imbed in social behavior of a society. Over the decade's quick outgrowth of population, industrialization and urbanization, transforms of social and economic activities have affected to various and raised requirement of available water. While the volumes of available water have remained stable, water has gradually become as the most significant national problems. Thus, it is important to study the climate variation and also simulate the surface runoff with suitable precision based on data driven and model methods.

The Xe Bang Fai river is an east-side the Mekong River tributary, accessing this River approximately 50 km south of Thakhek district (Kottelat, 2015). The Xe Bang Fai river is a major tributary of the Mekong River which is fed by 4 tributaries, namely Se Noy river, Ou La river, Phanang river and Ngom river. The Xe Bang Fai river basin is a sub-Basin of the Mekong River Basin where is located in the center part of Laos, with the total area of this Basin approximately is 10,345 km^2 or (4.36% of national area). The area of Basin has covered 2 provinces of Laos including Khammoune and Savannakhet province which the most area of this Basin has lied down on Khammoune province (Sioudom, 2013). The Xe Bang Fai River Basin is provisionally flooded due to Typhoon, which is affected from climate change nowadays, during wet season. Severe heavy rainfall has continuously been found in this basin area, in which it has been become a cause of floods at downstream of the Xe Bang Fai River Basin. Besides that, the precipitation is main variant in each year, but the precipitation intenseness is great, which this is pretty normal in the region of central Lao PDR.

In this region, the climate is classified into two different seasons, such as a dry season (November to April) and a wet season (May to October). The weather in this region is affected from tropical storms and depressions with northeast monsoons and the seasonal southwest, and also the shift of tropical cyclone disturbances and the Inter-tropical Convergence Zone (ITCZ). The annual mean temperature in the Xe Bang Fai River Basin ranges from 21.24 to 31.75°C based on average overall of the temperature. In the mountainous areas, the annual mean temperature drops to as low as between 15-25°C during January and February at cold night. This region receives approximately 1422 to 2500mm of annual rainfall, during the wet season which contributes more than 80% of the annual rainfall due to monsoons, tropical storms, tropical cyclones and depressions as explained above.

Water resources of the upper-stream of the Xe Bang Fai River Basin in the Khammouane province are mostly utilized for processing hydropower electricity generation. The Nam Theun 2 hydropower project was created on the Nam Theun River above the Xe Bang Fai River. This hydropower dam can generate 1,075 megawatts (MW) of power to neighboring Thailand (Descloux *et al.*, 2016). As the result of this hydroelectric dam generation was generated the impacts on local communities who live along in Xe Bang Fai River Basin. Independent research indicates that more than 120,000 people (Shoemaker *et al*, 2001) living along the River and some of its downstream has suffered a dramatic reductions in catches of wild fish, large flooding of paddy fields during the rainy season, losing of River bank gardens, health issues and other impacts related to main changes of water quality in the River's ecosystem (Lawrence, 2009).

According to the report of Mekong River Commission, Lao has several experiences regarding flooding along the Mekong River. The Xe Bang Fai River Basin is located in Khammouane province, in which it is impacted from tropical storm in rainy season. For instance, in the year 2011, the Laos confronted two tropical storms, namely HAIMA and NOCK-TEN. On June 24-26, tropical HAIMA hit the northern and central part of Lao PDR. Then between July 30 and 1 August, the tropical NOCK-TEN passed-over the central and southern parts of Laos. As the result of tropical NOCK-TEN, it resulted in the provinces of central and southern part of country affected, including Vientiane, Bolikhamxay, Khammouane, Savannakhet, and Champasak provinces respectively (MRC, 2011a). As the Lao's government report in 2011, the Xe Bang Fai River Basin was affected by two tropical storms as abovementioned. The both of them took heavy amount of rainfall caused the water levels increase of the Xe Bang Fai River and the Mekong River. As the result of both storms, numerous districts in Khammouane province, sited at the mouth of the Xe Bang Fai River highly affected by floods as shown in Figure 1.1.

In the Khammouane province on the downstream of the Xe Bang Fai River Basin, there are more than 400 villages or approximately 70 % of overall villages were suffered from these storms. Approximately 37,000 ha of rice fields or 63% of rainy season rice crop and 17,000 ha of crops were destroyed by flooding due to the increasing levels of the Xe Bang Fai river and the Mekong River. However, numerous organizations offering sustenance through the provincial authorities, but more than hundreds of households were remained press auxiliary, for instance food and sheltered place, after their residences were swept away by the inundation (Lao Embassy, 2011).

Major regions of irrigated rice fields and rain-fed are sited in these floodplains, but the structure of flood domination, especially levees and embankments have been built yet along these agricultural regions. So when severe inundations, the whole floodplain region in the Xe Bang Fai river basin were awash.

(a) (b)

Figure 1.1 Tropical Storm HAIMA and NOCK-TEN affected to Lao PDR in 2011: (a) Mekong River was flooding central part of Lao PDR and (b) the Xe Bang Fai river was flooding in area of the Phanan village, Boulapha district, Khammouane Province (Source: Google).

As the water availability is significant element of well-being and profitability. The agricultural sector in Lao PDR as well developing countries in the world, it serves as a backbone of the country's economy. At the present time, the Xe Bang Fai river basin mostly provides water to irrigated regime of around 12,000 ha in dry season. In previous study of Lao's government, approximately up to 100,000 ha of irrigated regime are able to extendible based on the topographic characteristic in this basin. Over 250,000 of local people living in this basin are not able to access to safe water yet, however most of them settle along the both of sides in the Xe Bang Fai river. According to the baseline data of health in 2000/2001 reported that more than 1600 households on the downstream area of the Xe Bang Fai river basin were used an unsafe drinking water, that's mean only a small part of households have accessed to some improved sanitation (Fewtrell and Kay, 2008). Thus, the water availability at the present and future identity in the Xe Bang Fai river basin requires to be estimated to assure for the framework on the sustainable water resources management and planning.

In addition to any models that can study the effect of climate change on the hydrological system in the Lower Mekong River (LMR). It will become a powerful tool for decision-marking, mitigation, measurement, planning for water resources management and controlling water quality. The outcome of study is able to support local human well-being who lives along the downstream. Therefore, Soil and Water Assessment Tool (SWAT) is assigned to use for this study, because of this hydrological model is the hydrological model which is the most used in the water sector broadly (Shao and Chu, 2012).

1.2 Objectives of the Study

The all purpose of this study is to evaluate the effect of climate variation on hydrology of the Xe Bang Fai river basin in Lao PDR. The procedure of this study is based on the recent and future situations by applying data driven and modeling methods. The specific purposes are described as follows below:

1. To study the trend of climate variation: precipitation and temperature in the Xe Bang Fai river basin.

2. To investigate the simulation of SWAT mode in the Xe Bang Fai river basin.
3. To forecast the future stream flow based on the effect of climate variation in the Xe Bang Fai river basin.
4. To offer base information for integrated water resource management and disaster risk protection.

This study are to provide base information for future study on climate change in the Xe Bang Fai river basin, in which water resource administrators and policy-makers may be use the results of this study for taking into consideration in improvement of the project's plan on sustainable integrated water resources management in the future.

1.3 Expected Results

Recently, Lao's government has focused on the reduction of severe events from disaster dangers, especially floods and droughts. Due to Lao's government understands the potential impact of climate change as intimately associated with disaster management and also the emergence of server happens such as floodwaters and drought. Mostly emphasizing with disaster management, it is one of the key policies of Laos' government for dealing with climate change, due to relationship between climate and disaster is absolute situation, which the neglecting to increase effects of climate change is serious.

With overall of the results given in this study improve knowledge of climate change effects on hydrological system in Laos. These results in this study can be applied to plan on water resources management and national disaster protection and mitigation in the future as following (1) Improved awareness of water resources administrators and line-agencies about future climate change situation; (2) An application of SWAT model based on climate change scenarios in this study regarding the possible effects of climate change on water availability and the requirement of future project which may be applied to other regions of the country; (3) Baseline information for future study on climate change in the Xe Bang Fai river basin, in which water resource administrators and sustainable water management policy-makers may be use the results of this study for taking into consideration in improvement of the project's plan.

Moreover, the study offers valuable information to plan for developing hydropower project and flood disaster risk reduction, which it is essential for the sustainable development in this country For results of this study regarding effects of climate change on hydrological response, the model obtained will be contributed to local and national level framework based on Lao's government strategy under the 8^{th} National Social-Economic Development Plan in 2016-2020.

1.4 The Dissertation Organization

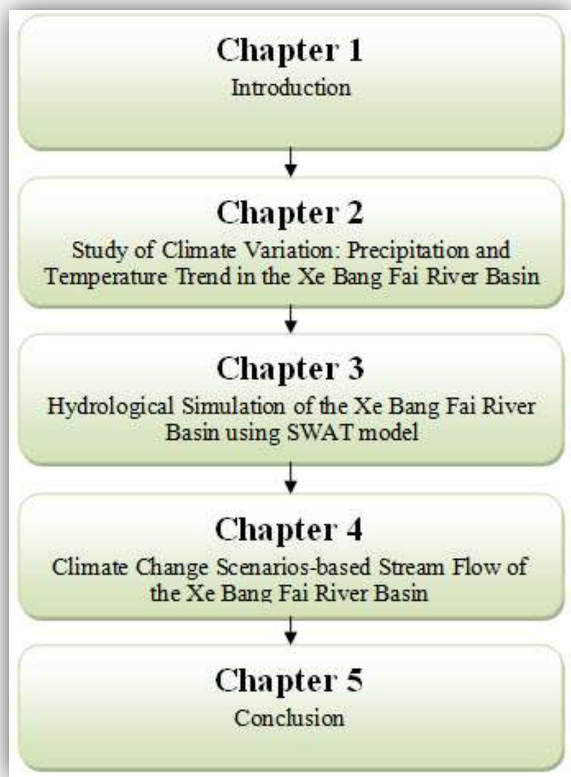


Figure 1.2 Chart of the Ph.D. Thesis

This dissertation composes of five chapters as shown in **Figure 1.2**. A short description of each chapter is summarized as follows:

In Chapter 1 presents the background, the purposes of this study and the organization of the dissertation.

In Chapter 2 identifies the trends of annual and seasonal precipitation and also the trends of annual temperature as well in the Xe Bang Fai river basin, in which is one of the Mekong River sub-basins. The time series of precipitation data is 1990-2012 and temperature data is 1990-2010. The study of climate variation trends is evaluated by the Mann-Kendall test and Sen's Slope estimates method (MAKESENS). The trend values of overall stations have portrayed on the spatial map for showing spatial distribution. The significant trend habitation is qualified using the values of Z. A positive value of Z demonstrates increasing trends, while negative value of Z indicates decreasing trends. Evaluating trends is completed at the specific α significance level, when the absolute Z value is greater than $Z_{1-\alpha/2}$, the null hypothesis (H_0) will be rejected and significant trend exists in the time series, where $Z_{1-\alpha/2}$ is obtained from the standard normal cumulative distribution.

In Chapter 3 studies the hydrological characteristic by using SWAT model to simulate stream flow in the Xe Bang Fai river basin, in which covers an area of 10064 km^2 of 809,500 km^2. The dataset used for inputting SWAT model contains Digital Elevation Model (DEM), soil type, land use/ landcover, channel network, weather data and measured discharge. The model is calibrated and validated based on 2 time periods such as 2001-2005 and 2006-2010 respectively, with using the SUFI-2 algorithm technique in this study. The result of the calibration model is able to become baseline data for studying the impacts of the climate change scenarios 2030 in the chapter 4.

In Chapter 4 simulated climate change scenarios based on the climate change factors (CFs) provided by the expert of the Lao National Mekong Committee Secretariat (LNMCs) with FMMP/MRC modeling team. The dataset of time series is input to SWAT model scenarios. The CFs were produced from three the Global Climate Models (GCM), including (1) IPSL-CM5A-MR 2030, (2) GISS-E2-R-CC 2030 and (3) GFDL-CM3 2030. The new results of scenarios are evaluated by processing the calibrated model from the period 1993-2008 of the Xe Bang Fai river basin station, with the three CFs of global climate models and also using the Digital Elevation Model (DEM), slope map, land use/cover map soil map and overall parameters to use for forecasting surface runoff for the year 2030.

In Chapter 5 brief the conclusion of this study under the all factors illustrated and considered in the previous sections as mentioned above. Some of further involvement and commendation are expressed in this chapter.

Chapter 2. Study of Climate Variation: Precipitation and Temperature Trend using the Mann-Kendall Test and Sen's Slope Estimator in the Xe Bang Fai River Basin.

2.1 Introduction

Climate characteristic is the most significant driving factors for year-by-year variability in crop production and water availability in the Mekong River. Climate change has effected in the world hydrological cycle on availability of water resources change (Bazzaz and Sombroek, 1996). Precipitation and temperature are the main factors for hydrological change (Xia *et al.*, 2012). Precipitation is one of the various factors which are able to affect to a rate of river discharge (Milliman *et al.*, 2008). In the agricultural section (Lobell and Asner, 2003; Lobell *et al.*, 2006; Lobell and Field, 2007), moreover, rain-fed cultivation directly depends upon the magnitude of the temporal rainfall distribution. Changing precipitation characteristics and rising temperature are one of the main groups which are considered to climate change (Hayhoe *et al.*, 2007; Iizumi, 2011). Consequently, a study of weather trend in climatology, especially the time series of precipitation and temperature, is one of the remarkable research disciplines. Currently, numerous worldwide researches have preceded trend study of climate change. Mostly previous researches relating long-term climatic trends have concentrated on the impact of climate change (Venrick *et al.*, 1987; Widman and Schär Sc, 1997; Hu *et al.*, 2003; Alcamo *et al.*, 2007; Parry, 2007; Solomon, 2007; Lobell *et al.*, 2011). An annual precipitation and air temperature has obtained a major attention management from scholars across the world. Various researches have been performed that changes in annual precipitation and temperature are becoming clear on a global scale (Mann *et al.*, 1998; Karmeshu, 2012). Currently, reviews of relative researches are: Precipitation and temperature (Su *et al.*, 2006; Shunjiu, 2009; Longobardi and Villani, 2010; Qin *et al.*, 2010; Wang and Zhang, 2012; Duan *et al.*, 2015; Wu *et al.*, 2016), hydrological discharge (Yue and Wang, 2002; Zhang *et al.*, 2000; Yue *et al.*, 2003; Partal and Kahya, 2006; Hamed, 2008; Delgado *et al.*, 2010; Juahir *et al.*, 2010; Tao *et al.*, 2011), water quality (Hirsch *et al.*, 1982; Belle and Hughes, 1984; Berryman *et al.*, 1988; Hirsch *et al.*, 1991; McLeod *et al.*, 1991; Antonopoulos *et al.*, 2001; Khan *et al.*, 2003; Bouza-Deaño *et al.*, 2008). According to these researches, a level of potential climatic effects on hydrological region under diverse geographic areas is able to be hypothesized regarding the climate change in the catchment areas. Thus, climatic variation is major conditions for challenges on water resources management, with uncertainties of hydrological situations, which severe climate happening will normally result in expanding climatic variability that importantly enlarge the intra-annual changeability of river discharge (Chaulagain, 2003). Evaluation of climate variation impact on the long-term stream hydrology has turned into essential in late years for long-term sustainable integrated water resources management (Chiew *et al.*, 2011; Obeysekera *et al.*, 2011), especially developing countries are risk to servers weather happens based on current climatic variation that effects various economic losses (Mirza, 2003). In this study, the Xe Bang Fai river basin, surveys of long-term precipitation and temperature variations and data trend continue to go unremarked notwithstanding the truth that the area of this basin is suffering from severe problems such as environment, agricultural land and water resource management. The Xe Bang Fai river basin is located in the central part of Lao PDR. In the rainy season, numerous areas are impacted by monsoon (ReliefWeb, 2016a). Weather, the precipitation and temperature, is one significant factor for sustainable socio-economic development in Lao PDR. Consequently, the study of the climate change is a significant for this basin.

In this chapter, the main objective is to study the trend of annual and seasonal precipitation and also annual temperature in the Xe Bang Fai river basin, in which is one of the significant sub-basins of the Mekong River Basin. Monthly data of precipitation and temperature was got out of Natural Resources and Environment Institute (NREI), the Ministry of Natural Resource and Environment (MONRE) of Lao PDR. Overall data is illustrated in 2.3. In this study, the investigation of precipitation and temperature trend is explored using the Mann-Kendall test and Sen's Slope estimates (Mann, 1945; Kendall, 1975), which it is a non-parametric trend test. Mann-Kendall test is a method of statistical test extensively applied for the trend analysis in hydrological (Yue and Wang, 2004) and climatic time series (Mavrimatis and Stathis, 2011). This method has two benefits of utilizing this technique. The first is a non-parametric test, which this method does not need the data to be commonly distributed. The second advantage, this method has little sensitivity for immediate separation, because of inhomogeneous time series (Tabari *et al.*, 2011). In this study, Sen's slope was used to estimate the slope of trend line, which the slope of trend line is able to be assumed to be linear regression for non-parametric tests, with showing an increasing or a decreasing trend for all stations (Gilbert, 1987). Both techniques are based on the change points and trends detection, with its level of probability significance in a time series, which these test have been broadly applied climatological and hydrological data analysis (Mavrimatis and Stathis, 2011; Yue and Wang, 2004).

This explore applies the monthly precipitation data from 7 stations with least 22 years of the length between 1990-2012, and also monthly temperature data from 3 stations of 1990-2011 period. The study has carried out to uncover the proof of climate change and also demonstrate the relationships of hydrological characteristics in the Xe Bang Fai river basin. The outcome of this study regarding trend of climate change can offer significant information for researches on water resources management, hydropower development plans and water quality analysis.

2.2 Study Area and Data Collections

2.2.1 Study Area

(1) General Characteristics of Location

The Xe Bang Fai River Basin is located in the central part of Lao PDR, which extends across the Borlikhamxay and Khammouane province and a small proportion in Xiengkhouang province of Northern and a small proportion in Savannakhet province as shown in Figure 2.1. They study area is located between 16°40'00" - 18°00'00" North Latitude and 104°20'00"-106°30'00" East Longitude, with covers a total area of 10,064 km^2 of 809,500 km^2 of the Mekong River Basin area (LNMC, 2011a).

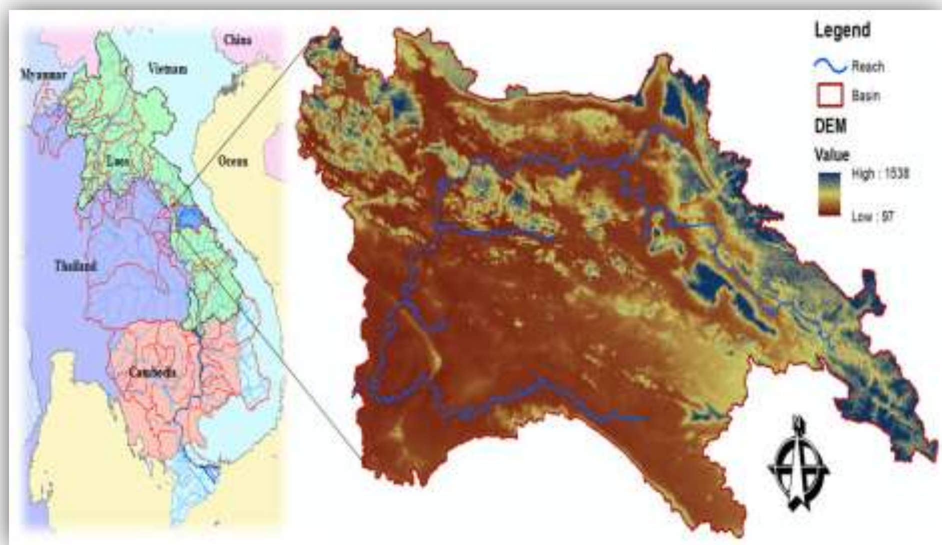


Figure 2.1 The location of the Xe Bang Fai river basin.

(2) Climate Characteristics

In this basin area, the climate characteristics of the Xe Bang Fai River Basin are described by two different seasons, such as a dry season (November to April) and a wet season (May to October) as shown in Figure 2.2. The annual mean temperature ranges from 21.24 to 31.75°C based on average overall of the temperature in the Xe Bang Fai River Basin (LNMC, 2011a). In the mountainous areas, the annual mean temperature drops to as low as between 15-25°C during January and February at cold night. This region receives approximately 1422 to 2500mm of annual rainfall, during the wet season (Champathangkham and Pandey 2013), which contributes more than 80% of the annual rainfall due to monsoons, tropical storms, tropical cyclones and depressions as explained above.

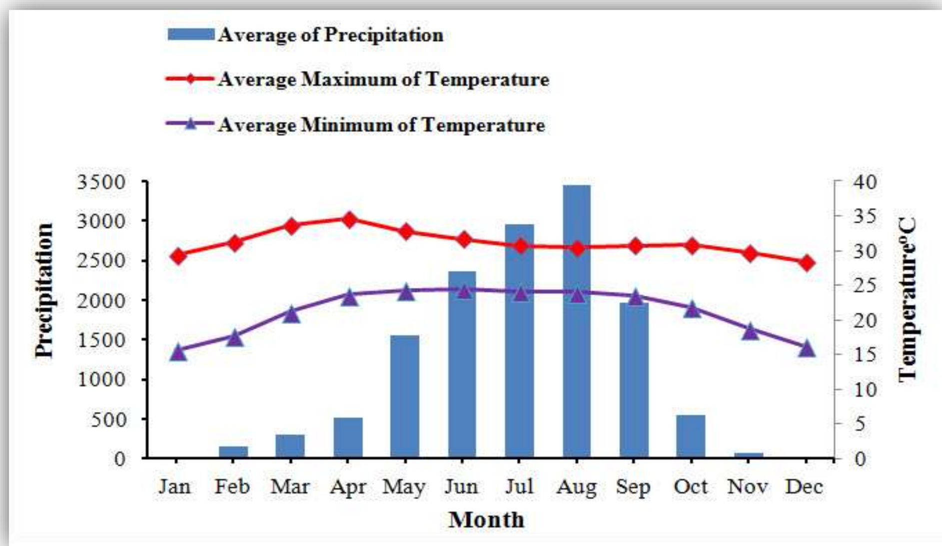


Figure 2.2 Average monthly of precipitation and temperature of the Xe Bang Fai river basin.

(3) General Topography

The total length of the Xe Bang Fai River Basin has approximately 370 km. The river basin originated in mountainous area of the Boualapha District, before flowing through Mahaxai District, Xe Bang Fai District before entering the Lower Xe Bang Fai River Basin floodplains in the areas of the southern border of Nong Bok District, Khammouane Province and the northern border of Xaybouli District, Savannakhet Province.

The river basin elevation ranges from 66 m to 1657 m above the mean sea level (MSL) as shown in Figure 2.3. The elevation of the river basin is mountainous area varies from 144m to 1657 m above MSL based on the elevation of the river basin. The topography of the study area is commonly hilly in upstream part and flat land in the middle to downstream. The large middle part, with having sources of water, is appropriate for agricultural activities and the last of lower part is appropriate for rice cultivation because of irrigation water is available. Notwithstanding, the availability of water resources is less in the river basin area during the dry season. The Xe Bang Fai river basin is still powerful rich in forest, water, land, biodiversity and other natural resources. The main land use/ land covers in the river basin area consist of forest area (51.79%), agricultural area (36.75%) and other land use/land covers are open barren and wood land (Champathangkham and Pandey 2013). In addition to the influential soil types of the study area are outstandingly Cambisols, Luvisols, Ferransols and Haplic Acrisols, (gravity, sandy, loamy and clay) (LNMC, 2011a).

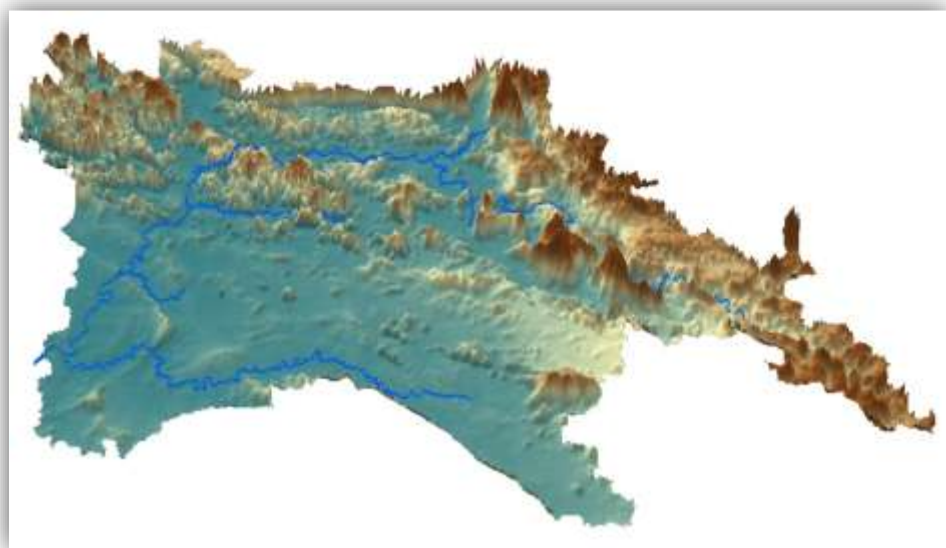


Figure 2.3 Topography of the Xe Bang Fai River Basin.

2.2.2 Data Collections

(1) Meteorological Data

Measured monthly precipitation data of seven stations surround the Xe Bang Fai River Basin is utilized to study the trend of climate change by using trend analysis. The names of the station are Signo, Mahaxay, Ban Veun, Thakhek, Xeno, Donghen and Xepone. In addition to the observed monthly temperature data surround of the river basin are also utilized for the analysis in this research from four stations includes monthly maximum and monthly minimum temperature. Overall of stations are namely of Thakhek, Xeno and Savannakhet. Overall of the data are got out of the local staff in the Natural Resources Research Center, Natural Resources and Environment Institute (NREI) of Lao PDR as shown in Table 2.1 and Figure 2.4.

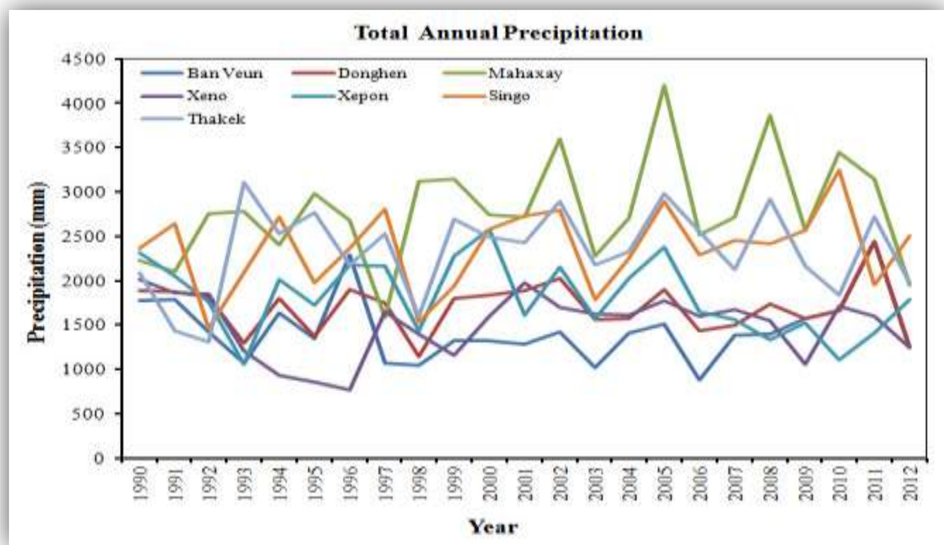
Table 2.1 Meteorological stations of the Xe Bang Fai river basin.

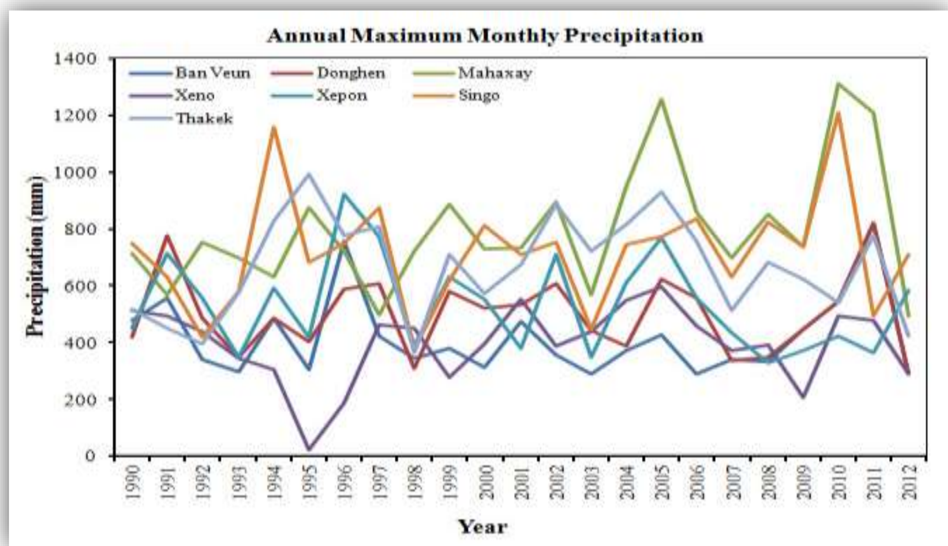
No.	Stations	Period of Data		Latitude	Longitude	Elevation (m)
		Precipitation	Temperature			
1	Signo	1990 - 2012		17° 51'	105° 3'	545
2	Mahaxay	1990 - 2012		17° 25'	105° 12'	155
3	Ban Veun	1990 - 2012		17° 3'	104° 54'	144
4	Thakhek	1990 - 2012	1990 - 2010	17° 23'	104° 49'	147
5	Xeno	1990 - 2012	1990- 2010	16° 40'	105° 00'	185
6	Savannakhet		1990 - 2010	16° 33'	104° 45'	150
7	Donghen	1990 - 2012		16° 42'	105° 16'	158
8	Xepon	1990 - 2012		16° 43'	106° 12'	170

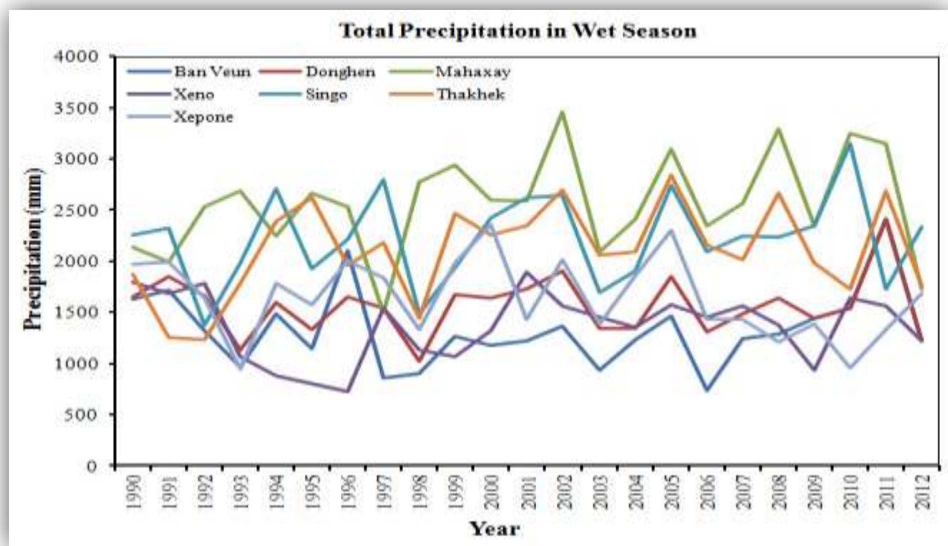
Figure 2.4 Meteorological stations of the Xe Bang Fai River Basin.

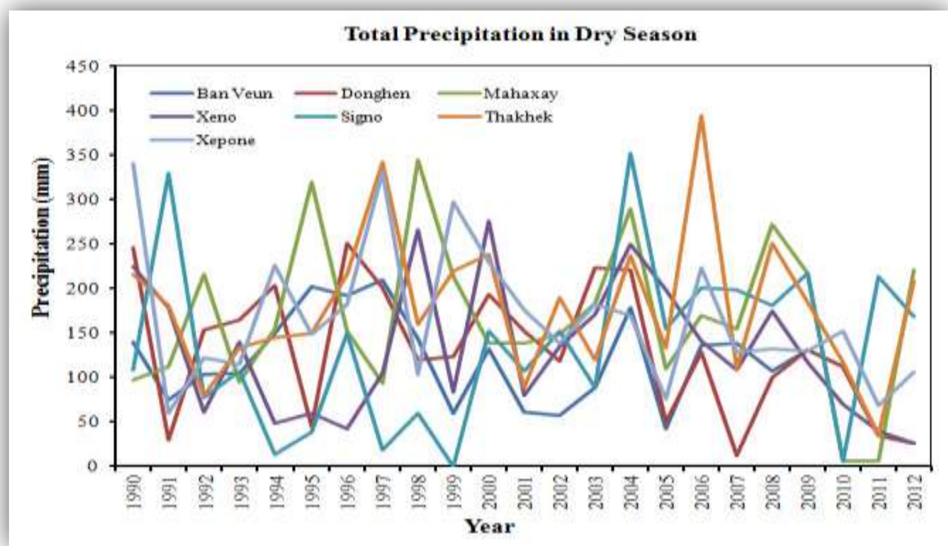
(2) Precipitation Data

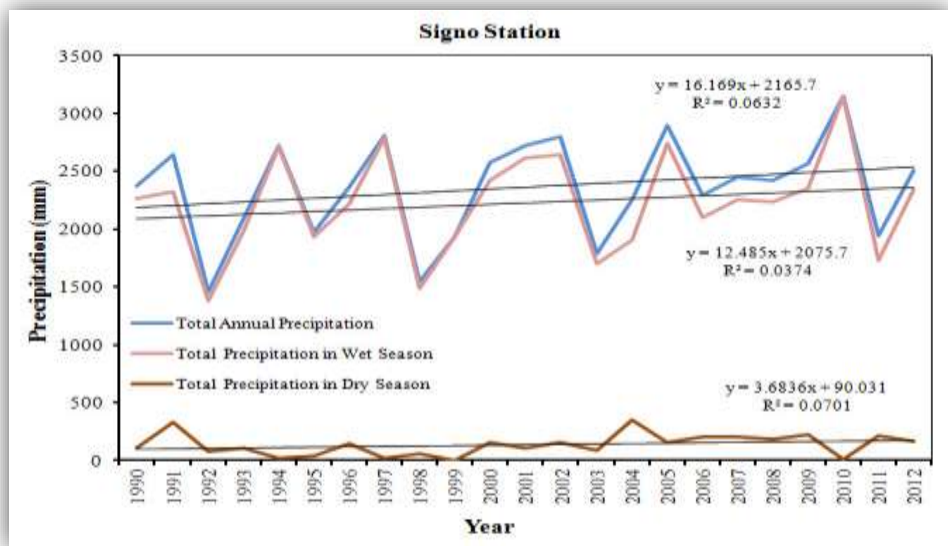
Observed monthly precipitation data for trend analysis in time-series data by Mann-Kendall test. The monthly precipitation data for the period 1989 to 2010 gained from the Natural Resources Research Center belong to the Natural NREI, Ministry of Natural Resource and Environment (MONRE) of Lao PDR. These data are reconsidered for statistical analysis which spatial data distribution of eight rainfall stations is shown in Figure 2.5. The monthly precipitation data gained were shifted to annual and seasonal of each precipitation station. Seasons were assigned as hereinafter: dry season (November to April) and a wet season (May to October). In the study, the dataset were watchfully indentified for homogeneity and missing data in the climate trend analysis.

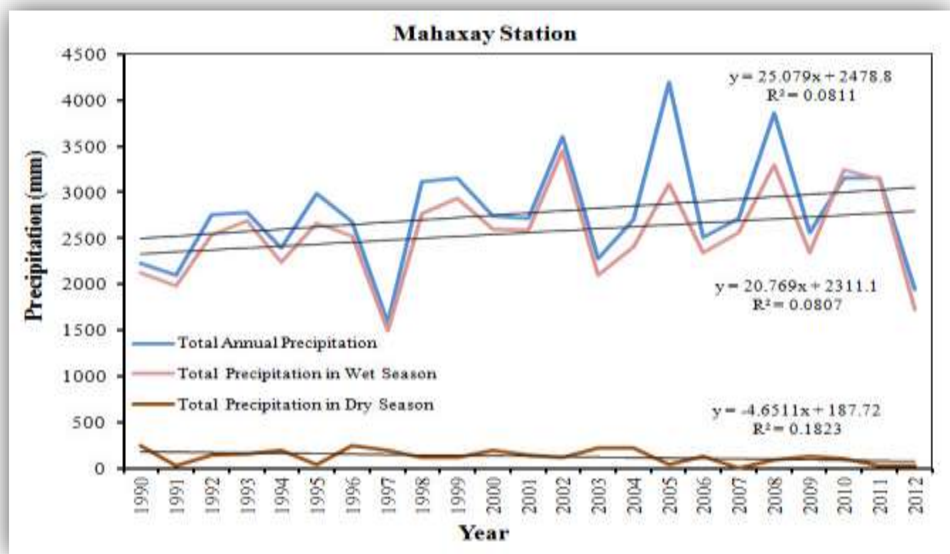



Annual Maximum Monthly Precipitation
Ban Veun
Donghen
Mahaxay
Xeno
Xepon
Singo
Thakek
Precipitation (mm)
0
200
400
600
800
1000
1200
1400
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Year

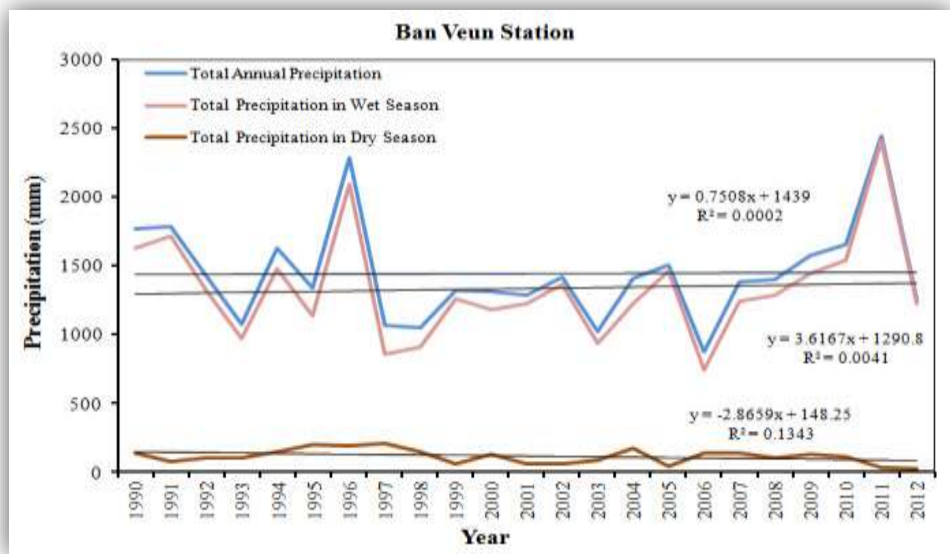

Total Precipitation in Wet Season
Ban Veun
Donghen
Mahaxay
Xeno
Singo
Thakhek
Xepone
Precipitation (mm)
0
500
1000
1500
2000
2500
3000
3500
4000
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Year


Total Precipitation in Dry Season
Ban Veun
Donghen
Mahaxay
Xeno
Signo
Thakhek
Xepone
Precipitation (mm)
Year
450
400
350
300
250
200
150
100
50
0
1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012

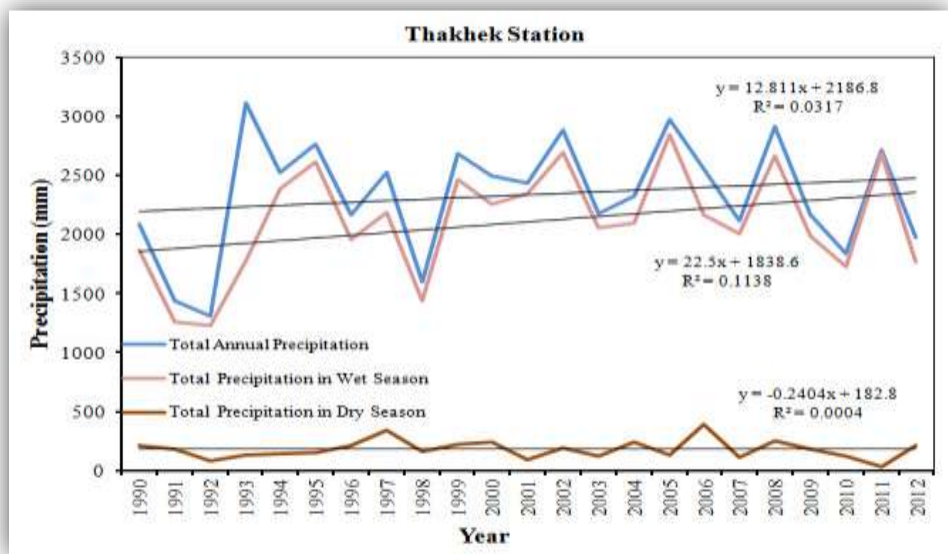

Signo Station
y = 16.169x + 2165.7
R² = 0.0632
y = 12.485x + 2075.7
R² = 0.0374
y = 3.6836x + 90.031
R² = 0.0701
Total Annual Precipitation
Total Precipitation in Wet Season
Total Precipitation in Dry Season
Precipitation (mm)
Year
3500
3000
2500
2000
1500
1000
500
0
1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012



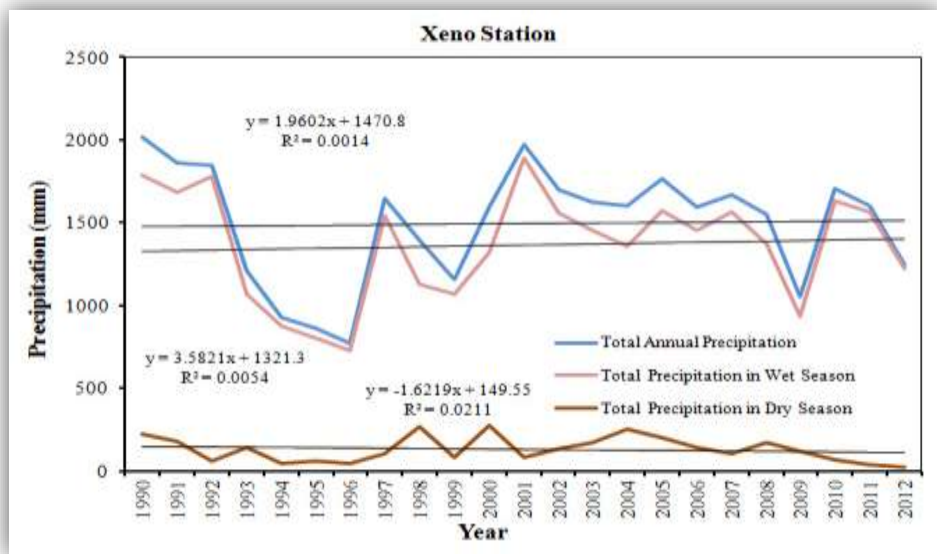
Mahaxay Station
Precipitation (mm)
Year
y = 25.079x + 2478.8
R² = 0.0811
y = 20.769x + 2311.1
R² = 0.0807
y = -4.6511x + 187.72
R² = 0.1823
Total Annual Precipitation
Total Precipitation in Wet Season
Total Precipitation in Dry Season



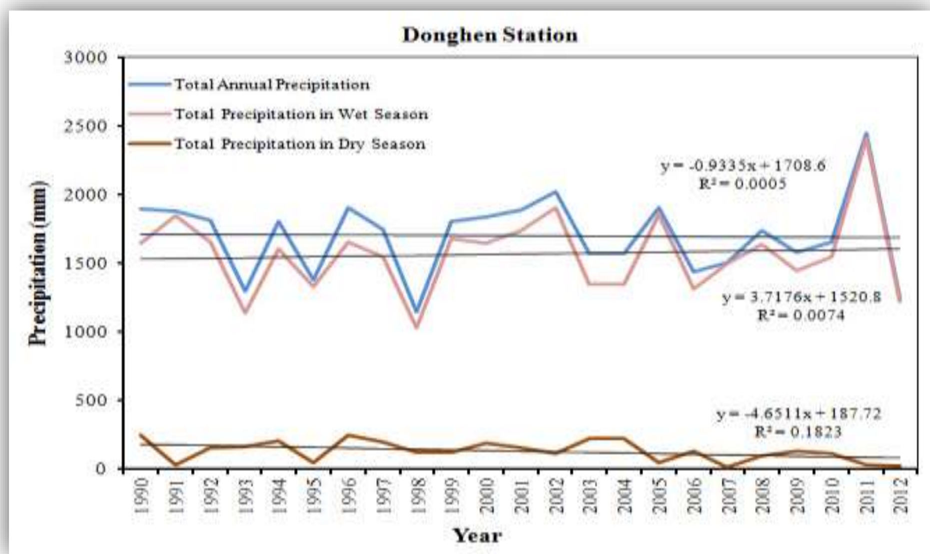
Ban Veun Station
Precipitation (mm)
Year
Total Annual Precipitation
Total Precipitation in Wet Season
Total Precipitation in Dry Season
y = 0.7508x + 1439
R² = 0.0002
y = 3.6167x + 1290.8
R² = 0.0041
y = -2.8659x + 148.25
R² = 0.1343



Thakhek Station
y = 12.811x + 2186.8
R² = 0.0317
y = 22.5x + 1838.6
R² = 0.1138
y = -0.2404x + 182.8
R² = 0.0004
Total Annual Precipitation
Total Precipitation in Wet Season
Total Precipitation in Dry Season
Precipitation (mm)
Year



Xeno Station
y = 1.9602x + 1470.8
R² = 0.0014
y = 3.5821x + 1321.3
R² = 0.0054
y = -1.6219x + 149.55
R² = 0.0211
Total Annual Precipitation
Total Precipitation in Wet Season
Total Precipitation in Dry Season
Precipitation (mm)
Year



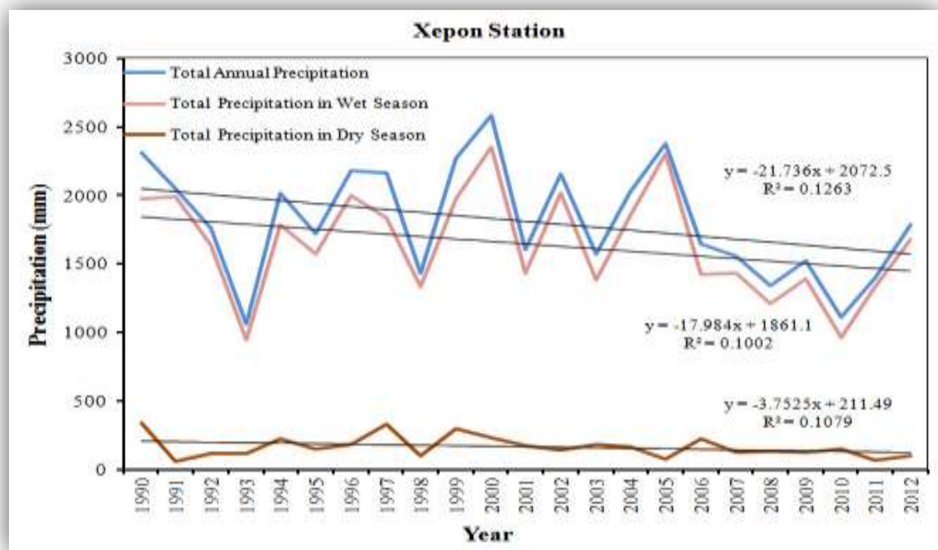
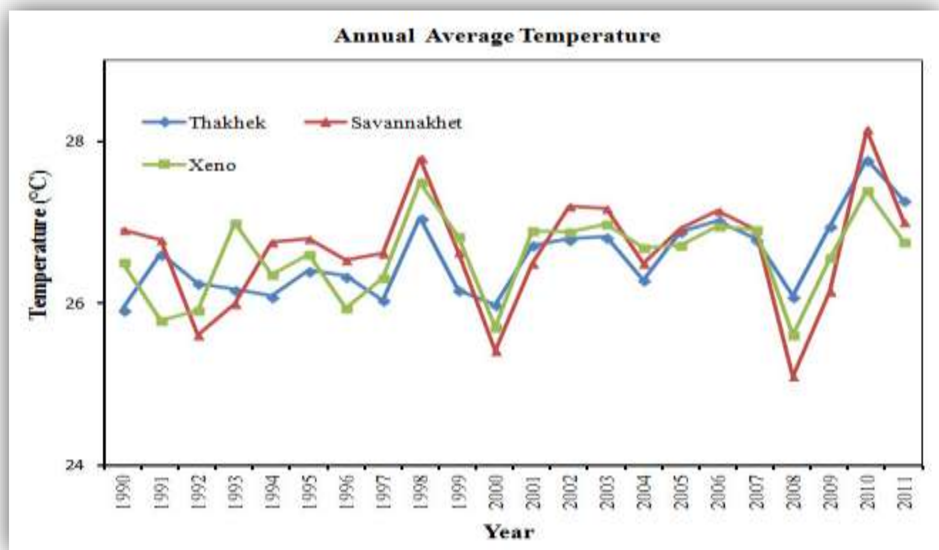
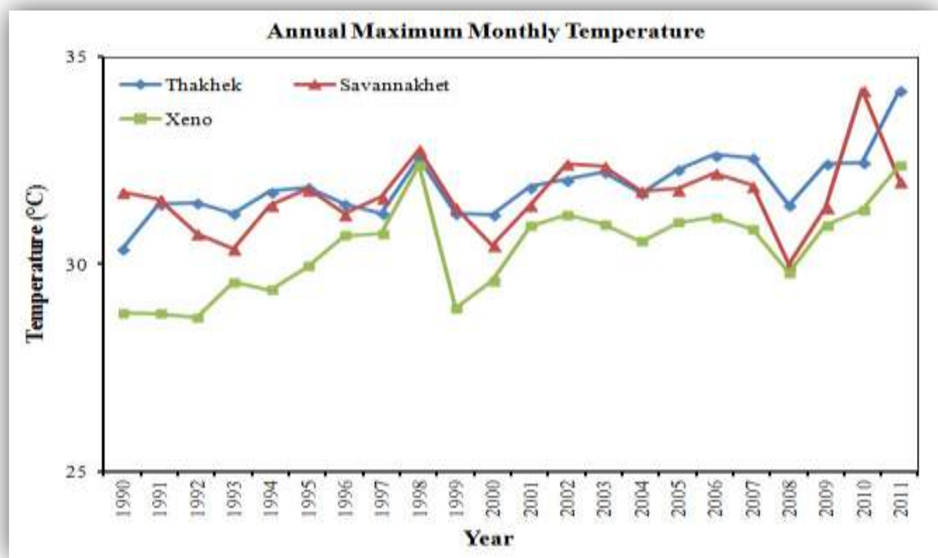


Figure 2.5 Precipitation Data of the Xe Bang Fai River Basin for Analysis (Total Annual Precipitation, Annual Monthly Maximum Precipitation, Total Precipitation in Wet Season and Total Precipitation in Dry Season).

(3) Temperature Data

Observed monthly temperature data for trend analysis in time-series data by Mann-Kendall test. The monthly temperature data for the period 1989 to 2010 gained from the Natural Resources Research Center belong to the Natural NREI, Ministry of Natural Resource and Environment (MONRE) of Lao PDR. These data are investigated for statistical analysis which spatial data distribution of four temperature stations is shown in Figure 2.6. The monthly temperature data received were shifted to annual average, annual monthly minimum and monthly maximum of each temperature station. In this study, the dataset were carefully indentified for homogeneity and missing data in the climate trend analysis.





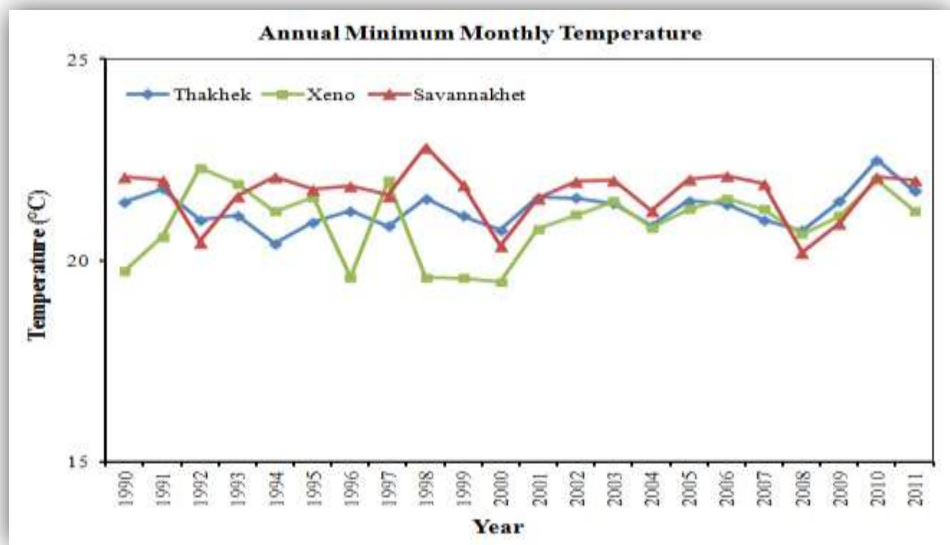


Figure 2.6 Temperature data of the Xe Bang Fai River Basin for Analysis (Annual temperature, Annual Monthly Maximum Temperature and Annual Monthly Minimum Temperature).

2.3 Methods

2.3.1 Trend Analysis Methods

A significant objective of numerous environmental mentoring is to detect trends or changes in the world over time. The purpose may be to seek for increased environmental data resulting from altering climate condition. Therefore, tests for the detection of important trends in the time series of climatological data are able to be grouped as parametric and non-parametric methods need. In the long-term climatic trends analysis, previously, there are methods of linear regression (parametric trend test) and Mann-Kendall test and Sen's slope estimator (non-parametric test). The linear regression method needs data to be independent and ordinarily distributed, which method is need the commonly distributed data for trend analysis (Karabulut *et al.*, 2008), while the method of Mann-Kendall test and Sen's slope estimator need solely that the data be independent, which those method does not required the non-normal data distribution (Libiseller and Grimvall, 2002; Xu *et al.*, 2010). Therefore, in this study, the two non-parametric methods (Mann-Kendall test and Sen's method) were explored to detect the trends of meteorological variables in the Xe Bang Fai river basin, because of these methods provide various advantages which have shown them valuable in analysis of climatological data. The missed data is accepted and the data doest need to adjust any specific data distribution, and also the method of Sen's in slope analysis is not extremely affected by single data errors (Salmi *et al.*, 2002).

(1) Mann-Kendall Trend Test

In this study, the method of Mann-Kendall Test (MKT) (Mann, 1945; Kendall, 1975) was used to compute the trend values of precipitation and temperature. The Mann-Kendall test is a non-parametric statistical approach used to test for trends in time-series data (Yu *et al.*, 1993; Partal and Kahya, 2006; Qin *et al.*, 2010). The null hypothesis of the Mann-Kendall test is the data independent and randomly ordered, for instance have no trend or serial correlation structure in the time-series (Hamed and Rao, 1998). The calculated process of the Mann-Kendall test reconsiders the time series of n data point and T_i and T_j two subsets of data where i {T_i, i= 1, 2, 3, . . . , n −1} and T_j {T_j, j= i+ 1, i+ 2, i+ 3, . . . , n+ 1}.

According to this test, the null hypothesis (H_0) is evaluated on the observations T_i as have no trend (the data is in depended and randomly ordered) and this is evaluated against the alternative hypothesis (H_1), in which there is trend either a decreasing (downward) and increasing (upward) monotonic trend (Yu *et al.*, 1993; Gocic *et al.*, 2013).The Mann-Kendall statistical test has been frequently used to compute the trends significance level in hydro-meteorological time series (Douglas *et al.*, 2000; Modarres and Silva, 2007; Tabari and Marofi, 2011). The Mann-Kendall test static S is computed as Equation (2.1) below:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(T_j - T_i) \qquad (2.1)$$

Where n is the number of data point T_j and T_i are the data values in time series *i* and *j* (*j*> *i*), respectively and $\text{sign}(T_j - T_i)$ is the sign function as shown in Equation (2.2) as follows:

$$sgn(T_j - T_i) = \begin{cases} +1, & if\ T_j - T_i > 0 \\ 0, & if\ T_j - T_i = 0 \\ -1, & if\ T_j - T_i < 0 \end{cases} \tag{2.2}$$

Where T_j and T_i are the data values in time series *i* and *j* (*j*> *i*), respectively.

In this study, according to the condition of time series with n ≥ 10, the *S* variance is itemized in Equation (2.3) as follows:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{i=1}^{q} t_i(t_i - 1)(2t_i + 5)\right] \tag{2.3}$$

Where n is the number of data points, q is the number of tied (zero difference between compared values) groups, and t_i indicates the number of data values in the i^{th} group. The values of $VAR(S)$ and S are utilized as shown in Equation (2.4) to calculate the test statistic Z as follows:

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{VAR(S)}}, & if\ S > 0 \\ 0, & if\ S = 0 \\ \dfrac{S+1}{\sqrt{VAR(S)}}, & if\ S < 0 \end{cases} \tag{2.4}$$

Where the statistic Z has a normal distribution, the habitation of a statistically significant trend is qualified using the values of Z. A positive value of Z demonstrates increasing (upward) trends, while negative value of Z indicates decreasing (downward) trends. Evaluating trends is completed at the specific α significance level, when the absolute Z value is greater than $Z_{1-\alpha/2}$, the null hypothesis (H_0) will be rejected and significant trend exists in the time series, where $Z_{1-\alpha/2}$ is obtained from the standard normal cumulative distribution as shown in Tables of Standard Normal Cumulative Distribution in Appendix 3.

(2) Sen's Slope Estimate

Sen's slope is non-parametric procedure that the true slope (change per unit time) is evaluated an existing trend by the Sen's method (Sen, 1968), which is developed to evaluate the trend slope in the same N pairs of data. Sen's slope estimator has been extensively applied in hydro-meteorological time series (Yue and Hashino, 2003; Yunling and Yiping, 2005; Gocic and Trajkovic, 2013; Abdou, 2014; Almazroui *et al.*, 2014). In this study, the Sen's slope was used to estimate the slope of trend line, which the trend line is able to be assumed to be linear regression for non-parametric tests, with showing an increasing or a decreasing trend for all stations (Mavrimatis and Stathis, 2011; Yue and Wang, 2004) as show in Equation (2.5).

$$Q_i = \frac{T_j - T_k}{j - k} \tag{2.5}$$

Where T_j and T_k are the data values at time series j and k ($j>k$), respectively.

If there are n values T_j in the time series, than $N = \frac{n(n-1)}{2}$ as slope estimate Q_i. The Sen's estimate of slope is the median of the N values of Q_i. The N values of Q_i are ranked from the smallest to the largest.

In this study, the slope median or Sen's estimator is qualified as shown in Equation (2.6) below.

$$Q_{med} = \begin{cases} Q_{[(N+1)/2]}, & \text{if } N \text{ is odd} \\ \frac{1}{2}\left(Q_{[N/2]} + Q_{[(N+2)/2]}\right), & \text{if } N \text{ is even} \end{cases} \tag{2.6}$$

The Q_{med} sign reflects the reflection of the data trend, while its value shows the trend steepness. To assign that the slope of median value is statistically distinct than zero, one should get the confidence interval of Q_{med} at unique probability.

The confidence interval about the time slope (Gilbert, 1987; Hollander, 2013; Wolfe and Chicken, 2013; Sprent and Smeeton, 2016) can be calculated as shown in Equation (2.7) follows:

$$C_\alpha = Z_{1-\alpha/2}\sqrt{VAR(S)} \tag{2.7}$$

Where $VAR(S)$ is defined in Equation (3.3) and $Z_{1-\alpha/2}$ is gained from the standard normal distribution table. In this study, the confidence interval was qualified at two significance levels (α = 0.01 and α = 0.05).

Then, $M_1 = \frac{N-C_\alpha}{2}$ and $M_1 = \frac{N+C_\alpha}{2}$ are calculated. The lower and upper limits of the confidence interval, $Q_{\min}$ and $Q_{\max}$, are the M_1^{th} largest and the $(M_2+1)^{th}$ of the N ordered slope estimates (Gilbert, 1987). The slope Q_{med} is statistically distinct than zero ($Q_{med} \neq 0$) if the two limits ($Q_{\min}$ and $Q_{\max}$) have related sign.

2.4 Results

The observed monthly data of precipitation from seven stations and temperature from four stations in the Xe Bang Fai river basin were used to evaluate the climate trends by applying the Mann-Kendall Test method. The results of this study are illustrated in Table 2.3 and Table 2.4, with the long-term the Mann-Kendall test trends of the Z values of annual and season in the Xe Bang Fai river basin. In Figure 2.6 and Figure 2.7, the statistical values of the precipitation and temperature were interpreted by spatial mapping. The overall trend values of their stations have been portrayed on the spatial map with blue color showing increasing trend (Upward) and red color showing a decreasing trend (Downward). Trend Assessment is completed at the specific α significance level, when the absolute Z value is greater than $Z_{1-\alpha/2}$, the null hypothesis (H_0) will be rejected and significant trend exists in the time series, where $Z_{1-\alpha/2}$ is obtained from the standard normal cumulative distribution as shown in Appendix 3. The detailed results are itemized in the Appendix 1.

2.4.1 Precipitation Trend

Figure 2.7 (a) represents the distribution map of historical total annual precipitation based on the spatial mapping of long-term Mann-Kendall Test trend of total annual precipitation in the Xe Bang Fai river basin. According the figure is obviously the trend of total annual precipitation of each station in the basin area. The result of trend analysis found that there are four stations with a decreasing (downward) trend in the Xe Bang Fai river basin including Ban Veun, Xeno, Donghen and Xepon. In addition, with increasing trend focuses in three stations namely Signo, Mahaxay and Thakhek. In the northern part of the Xe Bang Fai river basin, one station as Signo has homologous precipitation trend. This is reconsidered initial as the climatic homogeneity of each region in this basin.

Figure 2.7 (b) represents the distribution map of annual maximum monthly precipitation by the spatial mapping of long-term Mann-Kendall Test trend of annual maximum monthly precipitation in the Xe Bang Fai river basin. The Mann-Kendall Test trend of annual maximum monthly precipitation in this basin has been observed that there are three stations (Ban Veun, Donghen and Xepon) with decreasing trend and there are four stations (Signo, Mahaxay, Thakhek and Xeno) with increasing trend distribution in the overall basin area. Another seeking of this figure is stations with increasing trend in the northern part to central part of the basin. While increased annual maximum monthly precipitation is investigated as increased severe flood situation. The event of flooding environment is extrapolated to have changed badly in most of region of the Xe Bang Fai river. Regularly, the hazardous flood is happened every year in the river mouth of the basin.

Figure 2.7 (c) represents the distribution map of historical total precipitation in a wet season by the spatial map of long-term Mann-Kendall Test trend of total precipitation in the wet season in the Xe Bang Fai river basin. The total precipitation in the wet season in northern and southern parts of this basin is homologous to other part of basin with the total annual precipitation, the increasing trend of precipitation in the wet season has been observed four stations concentrated in the central and northern part of this basin as Mahaxay, Thakhek, Signo and BanVeun station with increasing trend distribution in the overall basin area and also with decreasing trend there are two stations (Donghen and Xepon).

Figure 2.7 (d) represents the spatial distribution map of historical total precipitation in the dry season based on spatial map of long-term Mann-Kendall Test trend of total precipitation in the dry season in the Xe Bang Fai river basin. The total precipitation in the dry season has been observed five stations (BanVeun, Thakhek, Xeno, Donghen and Xepon) with a decreasing trend and two stations (Signo and Mahaxay) with increasing trend distribution in the overall basin. Another finding of this spatial map is observed two stations with increasing trend in northern and central part of the Xe Bang Fai river basin, in which two stations (Signo and Mahaxay) were as homologous increasing trend as shown in Figure 2.7 (a), (b) and (c).

And also two stations (Donghen and Xepon) were a homologous decreasing trend as shown in Figure 2.7 (a), (b) and (c) in the southern part of the Xe Bang Fai river basin, in which this area is water shortage in dry season.

The computation of the trend statistics is quantified by Mann-Kendall Test trend which the monthly series data of precipitation is used to evaluate the trend statistics in the Xe Bang Fai river basin. The results are itemized in Table 2.2 and the detailed results are itemized in the Appendix 1: A1, A2, A3, A4 and A5.

Table 2.2 Results of the Mann-Kendall Test (Z value) and Sen's Slope (Q_{med} value) for precipitation series data

Station	Statistic Values	Total Annual Precipitation	Annual Maximum Monthly Precipitation	Total Precipitation in Wet Season	Total Precipitation in Dry Season
Signo	Z	1.056	0.845	0.792	1.929
	Q_{med}	19.69	4.000	17.000	5.536
Mahaxay	Z	1.162	1.849	1.215	0.370
	Q_{med}	25.820	11.667	25.489	1.109
Ban Veun	Z	-0.211	-0.449	0.211	-1.743
	Q_{med}	-2.850	-1.000	3.775	-2.600
Thakhek	Z	0.211	0.106	1.056	-0.053
	Q_{med}	3.311	1.250	20.143	-0.167
Xeno	Z	-0.475	0.079	0.264	-0.792
	Q_{med}	-5.831	0.333	2.190	-1.850
Donghen	Z	-0.660	-0.158	-0.264	-2.166
	Q_{med}	-6.856	-2.000	-1.208	-5.200
Xepon	Z	-1.902	-1.295	-1.479	-1.426
	Q_{med}	-22.333	-6.190	-20.143	-3.208

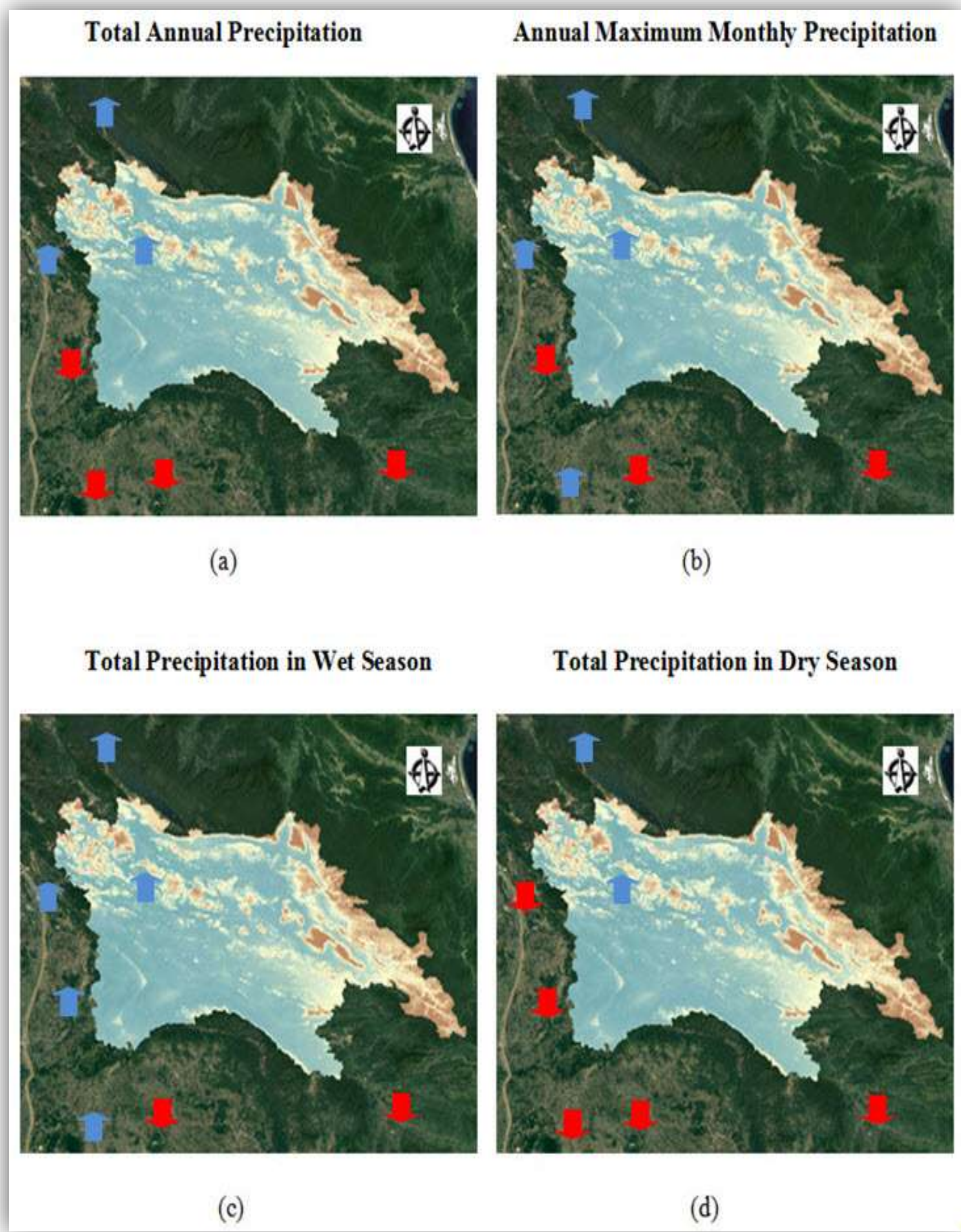


Figure 2.7 Spatial distribution of precipitation stations with increasing, decreasing by the long-term Mann-Kendall test trend for (a) total annual precipitation, (b) annual maximum monthly precipitation, (c) total precipitation in wet season and (d) total precipitation in dry season during the period 1990-2012.

2.4.2 Temperature Trend

As the result of temperature trend analysis statistically, Figure 2.8 (a), (b) and (c) represents the spatial distribution map of historical average temperature with long-term Mann-Kendall Test (MKT) trend of annual average temperature in the Xe Bang Fai river basin. According the figure is obviously the trend of annual average temperature of each station in this basin. The result of trend analysis found that overall three temperature stations (Thakhek, Savannakhet and Xeno) with increasing trend in the Xe Bang Fai river basin. In the western part of the basin, the Thakhek station shows statistically significant of (MKT > 2) based on annual average temperature as same as the Xeno station in the southern part of the basin, with comparing Z value of annual maximum monthly temperature as shown in Figure 2.8 (b).

Figure 2.8 (b) represents the spatial distribution map of historical annual maximum monthly temperature of long-term term Mann-Kendall Test trend of annual maximum monthly temperature in the Xe Bang Fai river basin. With increasing trends concentrate in three stations with Thakhek, Savannakhet and Xeno. In the southeast part of the basin, one station, as Savannakhet shows statistically significant of (MKT > 1) than annual mean temperature and annual minimum monthly temperature. With comparing annual maximum monthly temperature and annual minimum monthly temperature, this is considered elementary as the climatic homogeneity of each part in the Xe Bang Fai river basin.

Figure 2.8 (c) represents the spatial distribution map of historical annual minimum month temperature by long-term term Mann-Kendall Test trend of annual minimum monthly temperature in the Xe Bang Fai river basin. Overall of the stations are increasing trend in this figure. These stations (Thakhek, Sanvannakhet and Xeno) are low increasing trend of Z value (MKT < 1). According to the comparison with annual maximum monthly temperature, overall stations illustrate similar increase trend. For natural disasters, especially flooding, the effect by temperature increase is not as clear as precipitation, nevertheless, there are previous researches regarding the global warming is declared that temperature variation have an indirect impact on natural disasters. Therefore, it is main cause of accelerating the process of global water cycle thus expands the possibility of severe precipitation situation.

Table 2.3 Results of the Mann-Kendall Test (Z value) and Sen's Slope (Q_{med} value) for temperature series data

Station	Statistic Values	Annual Average Temperature	Annual Maximum Monthly Temperature	Annual Minimum Monthly Temperature
Thakhek	Z	2.876	3.271	0.846
	Q_{med}	0.054	0.075	0.016
Savannakhet	Z	0.790	1.523	0.678.
	Q_{med}	0.014	0.035	0.005
Xeno	Z	5.470	3.553	0.423
	Q_{med}	0.027	0.119	0.012

The computation of the trend statistics is quantified by Mann-Kendall Test trend which the monthly series data of temperature is used to evaluate the trend statistics in the Xe Bang Fai river basin. The results are itemized in Table 2.3 and the detailed results are itemized in the Appendix 1: A5, A6 and A7.

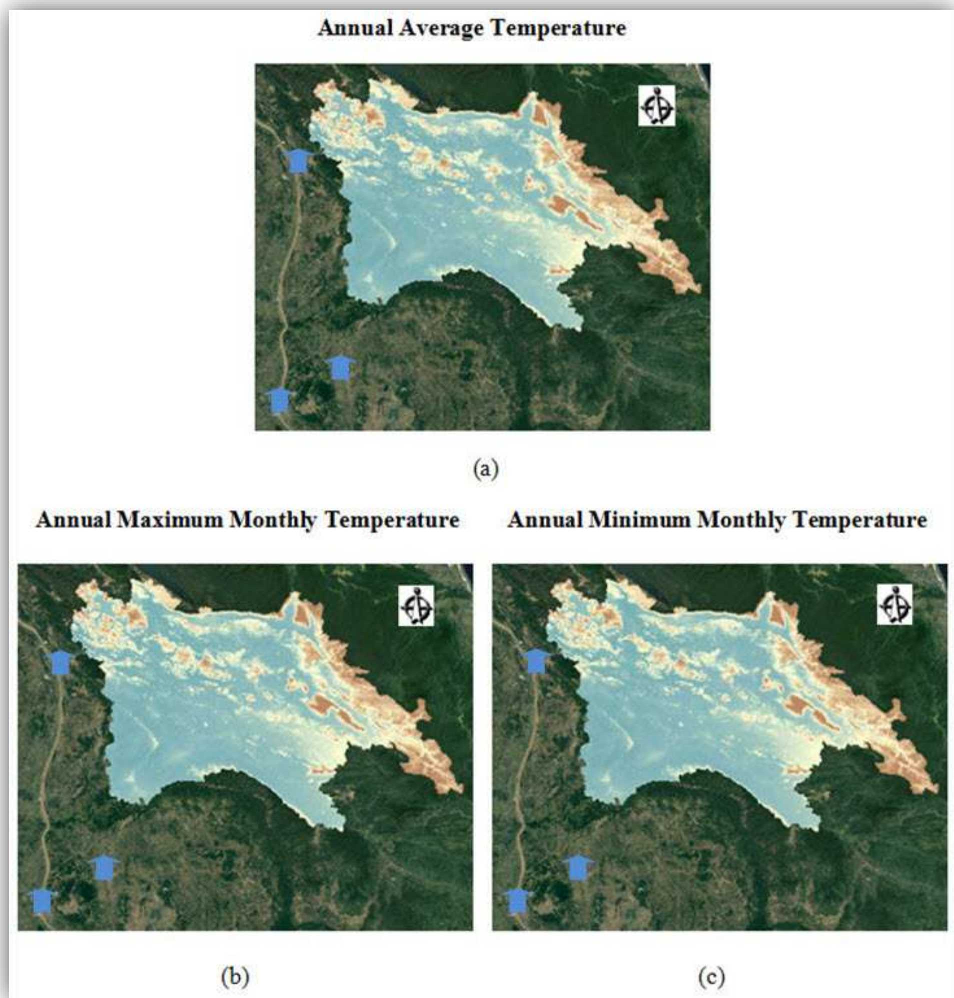


Figure 2.8 Spatial distribution of temperature stations with increasing, decreasing by the long-term Mann-Kendall test trend for (a) annual average temperature (b) annual maximum monthly temperature and (c) annual minimum monthly temperature during the period 1990-2011.

2.5 Discussions

The climate characteristics in the Xe Bang Fai river basin are divided by two different seasons as follows: a dry season (November to April) and a wet season (May to October). The basin is affected by the tropical monsoons, which the south-west monsoon inverts its maximum activity in particular on the effect of windward side.The annual mean temperature in the Xe Bang Fai river basin ranges from 21.24°C to 31.75°C as a minimum and maximum respectively in addition to the mountainous part of the basin, the annual mean temperature was dropped ranges from 15°C-25°C at cold night. The annual rainfall of wet season in this area will contributed more than 80% of the annual rainfall when it was affected from tropical storms and cyclones et.

The Xe Bang Fai river basin is sometime flooded because of typhoon during wet season. Severely heavy amount of rainfall has often been measured in the region, which is the cause of the flooding in the downstream part of the Xe Bang Fai river basin. As shown in Figure 3.6, the precipitation is increased trend at Mahaxay station. Furthermore, the rainfall is uncertain in every year but the rainfall denseness is high level which it is very regular in this basin area and central part of Laos.

The increased trend of annual maximum monthly precipitation level was observed in the central part of the Xe Bang Fai river basin at Mahaxay station. In addition, the decreased trend of annual precipitation related to drought risk which it was observed in the southern part of the Xe Bang Fai river basin at the Donghen and Xepon station. This area is water shortage of water in dry season.

2.6 Summary

In this study, the trend analysis of climate variation in particular precipitation and temperature data in the Xe Bang Fai river basin of Lao PDR. This chapter is carried out by Mann-Kendall Test to look for the impact of climate change and also this method attempts to associate with these alterations to latterly raised natural disaster.

In the statistical analysis, the climate data including precipitation data (seven stations) focused on total annual precipitation, annual maximum monthly precipitation, total precipitation in rainy season, total precipitation in dry season; and temperature data (three stations) focused on annual average temperature annual maximum monthly temperature and annual minimum monthly temperature.

As the results of trend analysis of precipitation data during period 1990-2012, the total annual precipitation is increased at three stations, annual maximum monthly precipitation increased at four stations, total precipitation in wet season is increased at five stations, and total precipitation in dry season is increased at two stations as shown in Figure 2.6 respectively.

From the results of trend analysis of temperature data during period 1990-2012, the overall of three temperature stations of temperature are increased by analyzing Mann-Kendall test trend including average annual temperature, annual maximum monthly temperature and annual minimum monthly temperature as shown in Figure 2.7.

In addition to the results recommend more investigations in the Xe Bang Fai river basin, to test other available meteorological series data in this basin, in which could be valuable in perception the impact of the climate alteration in the research region.

Chapter 3. Hydrological Simulation of the Xe Bang Fai River Basin using SWAT Model for Water Resources Assessment

3.1 Introduction

Water is main considerable factor for developing sustainable social and economic section. In addition water is greatly significant for human survival. Currently, the social-economic growth has rapidly developed with various activities, for instance the growth of global population (Pangare, 2006), climate change (Müller-Wenk *et al.*, 2010), water pollution (Duan *et al.*, 2013), land use/land cover change (Vörösmarty, 2010). According to the rapid development of social-economic development, for instance industries, deforestation, agricultural land and livestock are main condition for producing water pollution. Overall of those pollution sources including deterioration and eutrophication were discharged into natural water resources which it has threaten to human life. Recently, the inadequacy of water quantity and quality are steadily and it has become the main points of sustainable development of communities in this decade. Consequently, to ensure that water resources management (e.g. quantity and quality) will be improve to develop a sustainable human society forward.

The Xe Bang Fai river basin is a sub-watershed of the Lower Mekong River Basin. The existing water resources and land use/land cover system of this region are unfavorably influenced by the rapid growth of development, for instance construction, land agricultural management practices etc, which overall of these has affected to local people, ecosystem, deforestation, surface soil erosion and sediment transportation. Consequently, there is also a requirement for researching hydrology in the Xe Bang Fai river basin, which is able to support the framework on planning and management of catchment area. In addition it is able to preserve the frightening degradation of soil, water resources and environment in Lao floodplain area better. The investigation of water resources and flooding hazard in the Mekong River Catchment have been implemented by my simulation of hydrological model explores for environmental impact assessment (Rossi *et al.*, 2009; Kite, 2001). The Lao National Mekong Committee (LNMC) under Ministry of Natural Resources and Environment (MONRE) has played the significant role in exploring water resource problems by supporting from the Mekong River Commission (MRC), which has taken into account regarding urban development, population growth and environmental pollution (Jacobs, 2002). Therefore, the investigation on the future hydro-meteorology in each of sub-basin of the Mekong River Catchment has been studied by using the high-resolution Japan Meteorological Agency (JMA) AGCM (Hapuarachchi *et al.*, 2008; Kiem *et al.*, 2008). Recently, there some studies about an increased level of wet days in the sub-basin of Mekong River basin, which is one of various indicators for addressing brief information of the extreme flooding in the Xe Bang Fai River Basin (Champathangkham and Pandey, 2013; LNMC, 2011a). Previous studies are although not able to certify a detail on study of the hydrological modeling in the Xe Bang Fai River Basin. The hydrological simulation is quite significant to forecast the flood occurrences in the future.

The Soil and Water Assessment Tool (SWAT) is developed by Dr. Jeff Arnold for the USDA-ARS (Arnold *et al.*, 1998) .This tool is a distributed hydrological and physically-based model, which has wildly been used to investigate the hydrological effect for managing water resource (Arabi *et al.*, 2008; Neitsch *et al.*, 2011). This hydrological model is used to forecast amount of surface runoff and soil loss (Morgan, 2001; Grønsten and Lundekvam, 2006; Champathangkham and Pandey, 2013), climate change impact on water quality modelling (Andersson, 2006; Shrestha *et al.*, 2013), estimating impact of land use/land cover change (Sheng *et al.*, 2003; Wu *et al.*, 2007; Wang *et al.*, 2014) and modelling water quality (Debele *et al*, 2008; Abbaspour *et al.*, 2007; Zhang *et al.*, 2013). In hydrological studies based on SWAT model, the research of Gassman *et al.* (2007) has most been reviewed, because of this research is comprehensively used, which the SWAT model-based numerous researches needed to calibration model and analyzing uncertainty method for accuracy assessment (Abbaspour *et al.*, 2004).

In this study, the SWAT model and the method of uncertainty analysis will be implemented in the Xe Bang Fai River Basin of Lao PDR. We concentrated on the calibration, validation and using SWAT2012 model for hydrological simulation of the Xe Bang Fai River Basin. The main purpose of this chapter is to test the accomplishment and potentiality of ArcSWAT ver. 2012.10 model for forecasting river discharge in the Xe Bang Fai River Basin, which contribute to the water resources management in the Xe Bang Fai River Basin and it will become useful information for protection and management of natural resources and environmental in this basin. All of these will be good condition for the sustainable country development under the new high policy of Lao's government focusing natural resources and environment management, especially water resources being influence potentiality of Lao PDR development.

3.2 Materials and Research Methodology

In this section, hydro-meteorological data (e.g. the river discharge and weather data) and geographical data (e.g. stream network, soil data, land use and digital elevation model (DEM) collected from the related line agencies with the Mekong River Commission (MRC), namely the Department of Meteorology and Hydrology (DMH) and Natural Resources and Environment Institute

(NREI) under Ministry of Natural Resources and Environment (MONRE) of Lao PDR. The materials and research methodological procedures on river discharge simulation in the Xe Bang Fai river basin were analyzed based on SWAT model (Arnold *et al.*, 1998). The main analysis procedure is carried out as following the below diagrammatic structure as shown in Figure 3.1.

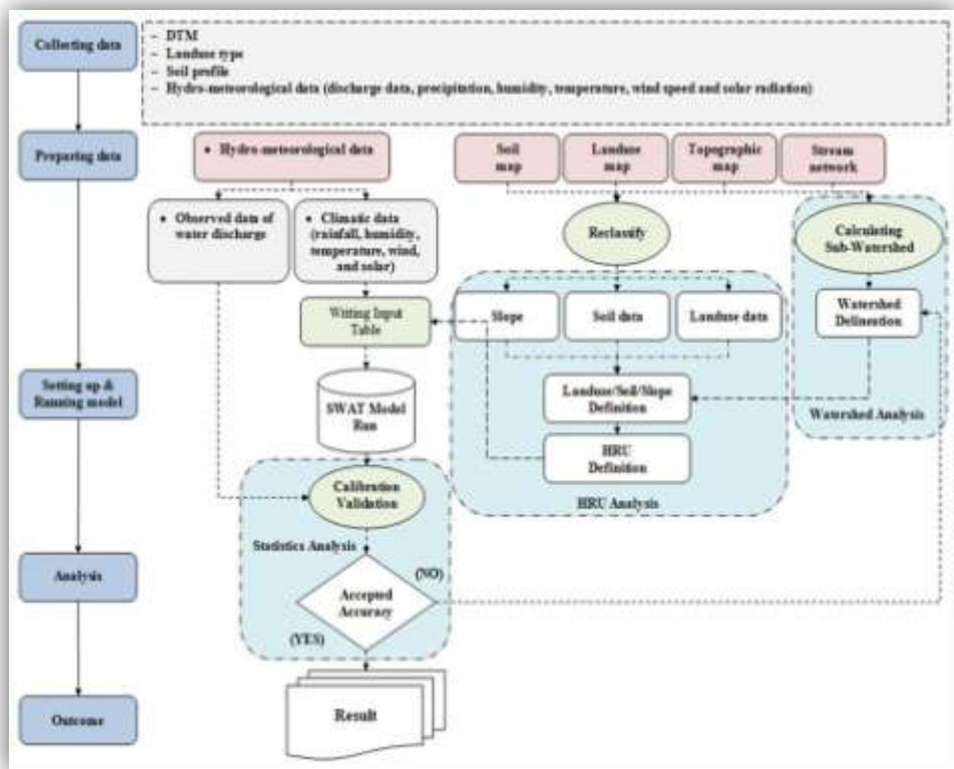


Figure 3.1 Schematic chart of Hydrological Model based on the concepts of SWAT Model

3.2.1 Geographical Data

(1) Digital Elevation Model (DEM)

Topographical characteristics is assigned upon a DEM, which its characteristics illustrates the any elevation point in a given basin area at a definite spatial resolution. A DEM (30x30m) resolution has generated by NASA, which was collected from the Natural Resources research Center, Natural Resources and Environment Institute (NREI) as shown in Figure 3.2. The DEM is applied to investigate the basin delineation by designing the drainage structures of the land surface terrain. The parameters of sub-basin including slope length of the terrain, slope gradient and also the characteristics of stream network including channel width and length, channel slope were acquire DEM.

Figure 3.2 Digital Elevation Model (DEM) of the Xe Bang Fai river basin.

(2) Land Use/Land Cover

Land Use/Land Cover (LULC) is one of the most significant factors which directly affect to evapotranspiration, runoff and erosion of soil surface in the catchment area. In this study, the

LULC map 2010 from Mekong River Commission (MRC) is selected to use in SWAT model for analyzing the values of HRUs. This LULC map was carried out by Forest Inventory and Planning Division (FIPD), Ministry of Agriculture and Forestry, Lao PDR to capture the situation in 2002 by visual interpretation SPOT satellite image at 1:50,000 and 1:100,000 scale with field verification. This LULC map is collected from the Natural Resources research Center, Natural Resources and Environment Institute (NREI). In this study, the LULC map have reclassified based on the available topographic map (1:50,000) as represent the real situation. The reclassification of LULC map is completed to show the pattern of LULC utilization based on the types of specific LULC, for instance forest and pasture and crop types as show in Figure 3.3 and Table 3.1.

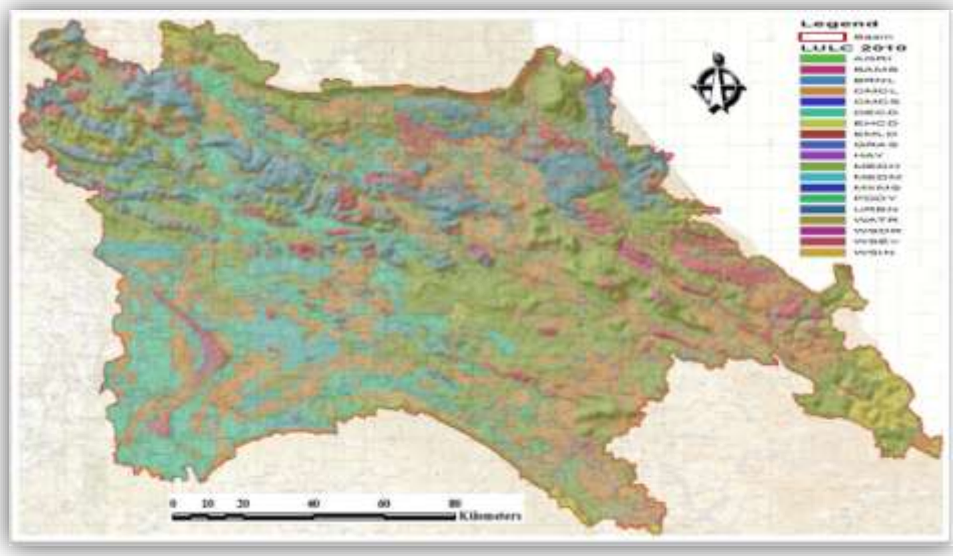


Figure 3.3 Land use/Land cover map of the Xe Bang Fai river basin

Table 3.1 Land use/Land cover classes of the Xe Bang Fai river basin

No.	Land Use/Land Cover	SWAT (code)	Area (km2)	Area (%)
1	Evergreen, high cover density	EHCD	0.38118	0.004294
2	Bamboo	BAMB	22.1878	0.249969
3	Barren Lands/ Rock	BRNL	1020.118	11.492683
4	Unstocked Forest	CMCL	2310.607	26.031377
5	Crop mosaic, cropping area<30	CMCS	0.291458	0.003284
6	Dry Dipterocarp, Gallery Forest	DECD	903.001	10.173240
7	Lower & Upper Dry Evergreen	EHCD	198.3573	2.234700
8	Lower Dry Evergreen	EMLD	2.282240	0.025712
9	Grassland	GRAS	0.73123	0.008238
10	Ray	HAY	37.09417	0.417904
11	Upper Mixed Deciduous, Mixed Broad leaved and Conifer, Coniferous Forest	MEDH	2613.402	29
12	Lower Mixed Deciduous, Mixed Broad leaved and Conifer and Coniferous Forest	MEDM	407.5446	4.591411
13	Forest Plantation	MXMS	0.001709	0.000019
14	Rice Paddy	PDDY	659.8202	7.433557
15	Urban or Built up Areas	URBN	0.1116	0.001257
16	Water	WATR	0.08484	0.000956
17	Savannah/Open Wood land	WSDR	28.7186	0.323545
18	Scrub, Wood-and shrubland, evergreen	WAEV	667.9046	7.524636
19	Swamps	WSIN	3.5986	0.040542
	Total		8876.238	100

(3) Soil Data

In SWAT model, soil data is needed as input file for hydrological model to create Soil and Soil chemical input file, these file consist of information about the initial nutrient and physical characteristics and also pesticide levels of the soil in the HRU. The

SWAT model needs various properties of physical chemistry and soils texture, for instance soil texture, property of organic carbon, hydraulic property, volume density and available water capacity. In study, the soil map of the Xe Bang Fai river basin has taken from the Natural Resources Research Center belongs to the Natural Resources and Environment Institute (NREI), which covers the most regime of lower Mekong River catchment. The Soil map of Lao PDR was generated by field survey and interpretation of old soil map at scale map (1:250,000) in 1998 as shown in Figure 3.4 and Table 3.2. For various characteristics of each soil types were described in analysis procedure of this model.

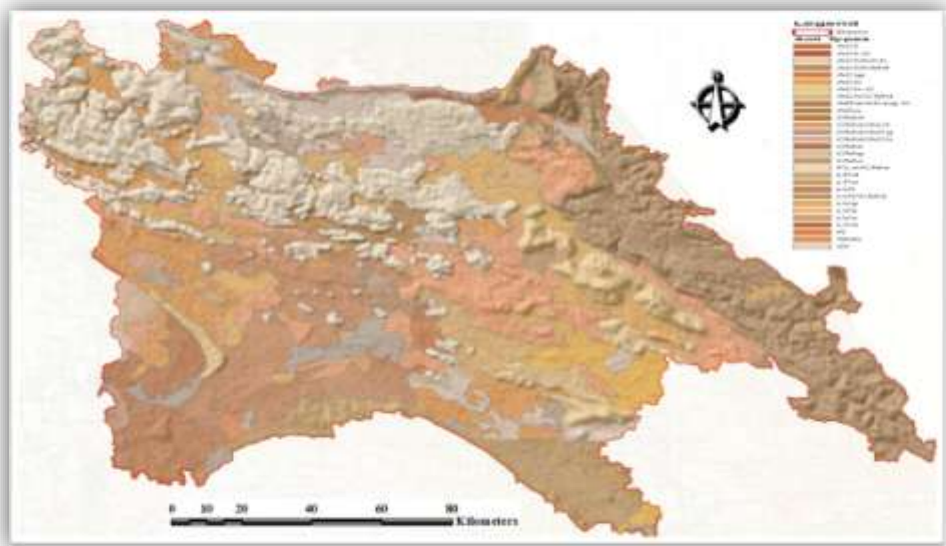


Figure 3.4 Soil type map of the Xe Bang Fai river basin.

Table 3.2 Soil classes of the Xe Bang River Basin.

No.	Land Use/Land Cover	SWAT (code)	Area (km2)	Area %
1	Ferric Acrisol	ACf	429.30	1.72
2	Ferric Acrisol-skeletic	Acf-C	172.28	0.69
3	Ferric Acrisol/Haplic Acrisol	Acf/Ach	173.51	0.70
4	Ferric Acrisol/Dystric Cambisol	Acf/CMd	34.34	0.14
5	Stagni-gleyic Acrisol	Acgj	92.65	0.37
6	Haplic Acrisol	Ach	8672.28	34.81
7	Haplic Acrisol-skeletic	Ach-C	52.03	0.21
8	Haplic Acrisol/ Dystric Cambisol	Ach/CMd	8.70	0.03
9	Albic Arenosol/Gleyi-plinthic Acrisol-skeletic	Ara/Acpg-C	41.38	0.17
10	Ferralic Arenosol	Aro	18.28	0.07
11	Dystic Cambisol	CMd	911.38	3.66
12	Dystric Cambisol/Ferric Acrisol	CMd/Acf	53.84	0.22
13	Dystric Cambisol/Gleyic Acrisol	CMd/Acg	41.48	0.17
14	Dystric Cambisol/Haplic Acrisol	CMd/Ach	721.04	2.89
15	Eutric Cambisol	Cme	753.99	3.03
16	Gleyic Acrisol	CMg	302.59	1.21
17	Ferralic Cambisol	Cmo	7814.84	31.37
18	Eutric Fluvisol/Eutric Cambisol	Fle/Cme	19.46	0.08
19	Eutric/Dystric Leptosol, Haplic Lixisol-skeleti	Lpe/LPd	2512.62	10.09
20	Ferralic Luvisol (Lpe)	LVf	6.11	0.02
21	Ferralic Luvisol/Dystric Cambisol	LVf/CMd	30.03	0.12
22	Gleyic Luvisol	LVg	37.79	0.15
23	Haplic Luvisol	LVh	22.14	0.09
24	Chromic Luvisol	LVx	18.47	0.07
25	Haplic Lixisol	LXh	32.86	0.13
26	Rock	R	1870.95	7.51
27	Haplic Solonetz	SNh	19.97	0.08
28	Water	W	48.34	0.19
	Total		8876.238	100

3.2.2 Hydro-Meteorological Data

(1) Precipitation

In study, monthly observed rainfall data for years (1998-2010) are used to input to SWAT model. The data from eight hydro-meteorological stations are applied to import the SWAT model, namely Signo, Mahaxay, Ban Veun, Thakhek, Xeno, Savannakhet, Donghen and Xepone, but only one station are located in the Xe Bang Fai River Basin, namely Mahaxay station. The MQUAD program is used to collect the amount of rainfall in which it is embeds in the MRC toolbox of the Mekong River Commission (MRC) (Shrestha *et al.*, 2013). MQUAD program is based upon the multi-quadric analysis generated by hard (1971). This program is developed to assess the areal rainfall (e.g. average rainfall in watershed) by computing the multi-quadratic surface based on available raindrop measure data, for instance the surface passes over overall measure points. The specified area of user has assigned by surface, including one or more watershed area, and the surface is generated from a grid of evaluated point rainfall values computed by the software. The each grid values are then collected to generate an average rainfall depth of each watershed area. This procedure is replayed for each time process of the input point rainfall datasets

(2) Climate Data

Climate data including wind speed, relative humidity, solar radiation and the daily maximum and daily minimum temperature are used to input to hydrological model. These data are most important for running hydrological model. In this study, the observed daily weather data for (1998-2010) are used to input the SWAT model for simulating the stream flow in the model to real stream flow in the natural water as much as possible by calibration model based on statistic analysis. All of these hydro-meteorological data are collected from the Natural Resources Research Center, Natural Resources and Environment Institute (NREI) in Lao PDR as show in **Figure 3.5**.

Figure 3.5 Hydro-meteorological stations surrounding the Xe Bang Fai River Basin.

(3) Discharge Data

The average natural discharge in the Xe Bang Fai River Basin is approximately 220m^3/s, with a maximum discharge capacity of Nam Theun 2 Hydropower (315m^3/s) (Nam Theun 2 *et al.*, 2003).

Gauged daily discharge data for the period of years (1998-2010) at Xebangfai@Bridge station under controlling of Department of Meteorology and Hydrology (DMH) under Ministry of Natural Resource and Environment (MONRE) is used for calibration and validation model based on ArcSWAT hydrological model. Annual average stream flow at Xebangfai@Brridge stream gauging flow is approximately 375 m^3/s for the period of 1994-2008. The station of gauging discharge is the Xebangfai@Bridge station as shown in the Figure 3.6.

Figure 3.6 Stream gauge of the X Bang Fai river basin.

3.3 Methods

3.3.1 SWAT Model

SWAT model is the public mathematic tool actively supported by the United State Department of Agriculture, Agricultural

Research Service at the Glass-land, Soil and Water Research, Texas, USA. SWAT is the hydrological model working in the scale of a river basin and a continuous time. The SWAT model is a spatially distributed hydrological model generated to forecast the scale of water, sediment and agricultural chemical loads such as nutrient and pesticide transportation in large complicated catchments with altering soils, land use/land cover and the conditions of management practices over long periods of the times (Douglas-Manki *et al.*, 2010). This hydrological tool can work for both of small and large basin area by dividing the watershed area into similar patterns. As a physically-based mathematic model, it uses hydrologic response units (HRUs) to represent spatial difference in characteristics of slope, land use/land cover and soil type within a basin area. Currently, SWAT model is developed into various versions (Neitsch *et al.*, 2011), which it is attached to ArcGIS interface called ArcSWAT. It is computationally powerful tool which users can apply to research a long-time impacts. The basic component of hydrological model in SWAT model includes groundwater flow, surface and peak runoff, sediment yield and evapotranspiration for each HRU.

$$\mathrm{SW}_t = \mathrm{SW}_0 + \sum_{i=1}^{t}\left(\mathrm{R}_{day} - \mathrm{Q}_{surf} - \mathrm{E}_a - W_{seep} - \mathrm{Q}_{gw}\right) \qquad (3.1)$$

Where, SW_t is the final soil water content (mm), SW_o is the initial soil water content on day i (mm), t is the time (days), R_{day} is the amount of precipitation on day i (mm); Q_{surf} is the amount of surface runoff on day i (mm), E_a is the amount of evapotranspiration on day i (mm), W_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm) and Q_{gw} is the amount of return flow on day i (mm).

In this study, the equation of SCS runoff is applied in mathematic mode. This method is an empirical simulation which it was widely in hydrological mode in the 1950s decade. This method is the first used in United State, which researched implicating rainfall-runoff relationships) of small rural basins (Elhakeem and Papanicolaou 2009). The model was generated to provide a corresponding for assessing the runoff volume under alerting soil types and land use/land cover (Hernandez *et al.*, 2000). The equations SCS curve number (3.2) is described by (SCS, 1972).

$$Q_{surf} = \frac{(R_{day} - I_a)^2}{(R_{day} - I_a + S)} \tag{3.2}$$

Where, Q_{surf} is the accumulated runoff or rainfall excess (mm H_2O); R_{day} is the rainfall depth for the day (mm H_2O); I_a is the initial abstractions which includes surface storage, interception and infiltration prior to runoff (mm H_2O); and S is the retention parameter (mm H_2O).

The retention parameter (S) differs spatially, because of alterations in type of soils and land use; management of land practices; slope and time periods. SWAT model-based the retention parameter (S) and forecasting of lateral flow are shown in Equation (3.3):

$$S = 25.4\left(\frac{1000}{CN} - 10\right) \tag{3.3}$$

Where, *CN* is the Curve Number for the day.

In case, the initial abstraction (I_a) is defined as 0.2*S*. The equation of Q_{surf} based on Equation (3.4) as:

$$Q_{surf} = \frac{(R_{day} - 0.2S)^2}{(R_{day} + 0.8S)} \tag{3.4}$$

Runoff phenomenon is only able to happen when $R_{day} > I_a$.

These above-equations is broadly used in SWAT model for studies involving rainfall-runoff relationships from local scale across global scale by Neitsch *et al.*, (2011)

3.3.2 SWAT CUP

The SWAT-CUP is a computably-based program using calibration and validation models of SWAT (Alamirew, 2012). SWAT-CUP is a public domain program, which include five various algorithms, for instance Sequential Uncertainty Fitting SUFI-2 (Setegn *et al.*, 2010; Strauch *et al.*, 2012; Abbaspour, 2015); Particle Swarm Optimization, (PSO), Generalized Likelihood Uncertainty Estimation (GLUE) (Alamirew, 2006; Blasone *et al.*, 2008; Nott *et al.*, 2012); Parameter Solution (ParaSol) (Alamirew, 2006; Nott *et al.*, 2012); and Markov Chain Monte Carlo (MCMC) (Kuczera *et al.*, 1989; Alamirew, 2006; Joseph *et al.*, 2013) procedures to SWAT. All of these empower the sensitivity analysis, analysis of calibration, validation. In this study, the SUFI-2 algorithm is used in the calibration and validation model of the Xe bang Fai river basin. The brief definitions and also procedures of SUFI-2 are described below.

(1) SUFI-2

The uncertainties of parameter are computed from overall the input and output source uncertainties, for instance the uncertainty in the input soil type, the land use/ land cover, rainfall data, observed data and parameters in SUFI-2. The uncertainty simulation is computed based on the 95% feasting uncertainty (95PPU) which is indicated to as the p-factor. The 95PPU is quantified at the 2.5% and 97.5% functions of the cumulative diffusion of an output variable attained through Latin hypercube sampling (Abbaspour *et al.*, 2007; 2015). Another gauge calculating the strength of an uncertainty or calibration analysis is the r-factor which is the average density of the 95PPU region subdivided by the standard deviation value of the gauged data.

The advantage of forecasting uncertainty and calibration is discussed based upon the proximity of the p-factor to 100% (e.g. overall observations classified by the forecasting uncertainty) and the r-factor to 1 (e.g. achievement of a rather little uncertainty region) (Talebizadeh *et al.*, 2009). If the both factors are sufficient values, in the part of parameter hypercube, a homogeneous distribution is clarified as the following parameter distribution. The advantage of goodness-of-fit method in SUFI-2 is computed by the Nash-Sutcliffe (NS) coefficient and R^2 between the best values of simulation and observed data. The average density of both the r factors and the 95PPU region ($\bar{r}$) are quantified by equations (3.5) and (6.6) (Luo *et al.*, 2014).

$$\bar{r} = \frac{1}{n}\sum_{t_i}^{n}\left(y^{M}_{t_i,97.5\%} - y^{iM}_{t_i,2.5\%}\right) \tag{3.5}$$

$$r - factor = \frac{p-factor}{\sigma_{obs}} \tag{3.6}$$

Where, $y^{M}_{t_i,97.5\%}$ and $y^{M}_{t_i,2.5\%}$ represent the upper and lower boundaries of the 95PPU, and$\boldsymbol{\sigma_{obs}}$ is the standard deviation of the measured data.

The other factor is the goodness-of-fit which can be calculated by the Nash-Sutcliff efficiency (E_{NS}) and coefficient of determination (R^2) (Setegn *et al.*, 2008) between both of the final best simulations and the observations Nash-Sutcliffe coefficient (E_{NS}) and coefficient of determination (R^2) are quantified by equation (3.7) and (3.8).

(2) Coefficient of Determination (R^2)

R^2 is the mathematical statistic with line regression providing a gauge of how good observed outcomes are duplicated by the model. The R^2 range is assigned between 0 and 1 which the high values describing less error variance. In previous study, the regularly values are higher than 0.5 can be accepted (Santhi *et al.*, 2001; Van Liew *et al.*, 2003).

$$R^2 = \frac{\left[\sum_i (Q_{m,i}-\overline{Q}_m)(Q_{s,i}-\overline{Q}_s)\right]^2}{\sum_i (Q_{m,i}-\overline{Q}_s)^2 \sum_i (Q_{s,i}-\overline{Q}_s)^2} \tag{3.7}$$

Where, $Q_{m,i}$ is the measured flow at time i; $Q_{s,i}$ the simulated flow at time i; $\overline{Q}_m$ is the average measured flow; $\overline{Q}_s$ is the average simulated flow.

(3) Nash- Sutcliffe coefficient (E_{NS})

E_{NS} is the normalized statistics that is used to assign the related amplitude of the residual variance comparing the observed data variance (Nash and Sutcliffe, 1970). The E_{NS} range is between ($-\infty$) to 1, with E_{NS} =1 is the optional value. In case $E_{NS} < 0$, the measured average is a better forecaster than the model; if $E_{NS} = 0$, the measured average is as good a forecaster as the model and if $E_{NS} > 0$, the model is a better forecaster of measured data than the measured average (Legate *et al.*, 1999; Wilcox *et al.*, 1990). Based on Moriasi *et al.*, (2007), the very good to sufficient value of E_{NS} lies in the range of 1 to 0.5 respectively.

$$E_{NS} = 1 - \frac{\sum_i (Q_m - Q_{s,i})^2}{\sum_i (Q_{m,i}-\overline{Q}_m)^2} \tag{3.8}$$

Where, Q_m is the measured flow; $Q_{s,i}$ the simulated flow at time i; $Q_{m,i}$ is the measured flow at time i; $\overline{Q}_m$ is the average measured flow; $\overline{Q}_s$ is the average simulated flow.

3.3.3 Model Setup

(1) Data Preparation

Overall of the spatially distributed dataset required for adding the ArcSWAT interface after installing in ArcGIS. The main dataset of SWAT model include spatial data and non-spatial data during years (1998-2010). The spatial dataset consist of the Digital Elevation Model (DEM), stream network, land use/land cover and soil data. The non- spatial dataset is hydro-meteorological data containing stream discharge and weather data. All of these are also input in SWAT model to predict the stream discharge of the Xe Bang Fai river basin based on accuracy assessment as mentioned above.

(2) Watershed Delineation

The watershed delineation of the Xe Bang Fai river basin is based on its DEM characteristics. DEM is delineated the watershed area and be also analyzed the drainage patterns of the land surface terrain in the Xe Bang Fai river basin. In the analysis, stream delineation of watershed is generated by the mask area function in ArcSWAT interface, which the stream networks in SWAT model are digitized from DEM based on procedure of automatic delineation. The hydrological model will overall of the non-draining areas to generate a flow direction, and overlay the digitized stream network into the DEM to identify the stream networks location.

The ArcSWAT offers the minimum, maximum and advised scale of the sub-watershed zone in term of hectare to identify the minimum drainage region. Mostly, the smaller the threshold region, the more detailed the drainage systems and the number of sub-watersheds and HRUs. Moreover, In addition, more method of spaces and times are required. In this study, the smaller area approximately 5000 hectare (50 km^2) is assigned to receive all sub-watershed of the X Bang Fai river basin and the outlet of this basin is identified where it is later taken as a calibration point of the simulated flows. As a final result, 11 sub-watersheds in the Xe Bang Fai river basin are generated as shown in Figure 3.7.

Prosperous performance of terrain procedure in ArcSWAT interface module illustrated in creation of suitable databases for the sub-watershed parameters and amplified topographic report of the Xe Bang Fai river basin, statistics of area elevation in each sub-watershed is shown in Table 3.3.

Figure 3.7 Sub-watershed delineation and discharge network of the Xe Bang Fai river basin.

Table 3.3 Topographic statistics of sub-watershed in the Xe Bang Fai river basin.

Sub Watershed	Minimum	Maximum	Mean	Area (Km2)	Area (%)
1	103	1533	376.56	1105.23	12.45
2	119	827	284.06	182.59	2.06
3	144	1402	410.09	610.54	6.88
4	103	954	355.18	993.05	11.19
5	111	835	254.66	650.19	7.33
6	124	1414	330.42	587.82	6.62
7	173	1657	576.02	829.21	9.34
8	133	535	183.42	619.24	6.98
9	108	903	262.27	1334.30	15.03
10	66	894	222.57	1085.66	12.23
11	124	556	185.55	878.30	9.90
		Total		8876.12	100

(3) Hydrologic Response Unit (HRU)

In SWAT model, the analysis of HRU definition presents that notable feature of HRU definition represents based on a single HRU for each of sub-watershed area, in which the notable feature soil, slope and land use/land cover within the watershed area are analyzed to be the soil, slope and land use/land cover of each sub-basin. The single HRU within each sub-watershed cannot appropriately indicate the characteristics of the sub-watersheds. As the result of the simulated stream discharge, it represents the insufficient result when compared to the observed discharge flows in the measured stations of the Xe Bang Fai river basin. In this study, the better of discharges flow assessment in the multiple scenarios is provided by threshold combination of 10% land use, 10% soil and 10% slope, respectively. The results of the multiple scenarios overlay in the whole area of the Xe Bang Fai river basin shows in 716 HRUs. This scenario represents in the amplified land use, soil and slope database, comprising several HRUs, which alternately show the result of various research area. The simulation between the predictions of default model and observed discharge generates the best Nash-Sutcliffe efficiency (NSE). The characteristics of land use, soil and slope are distributed within each HRU have the greatest effect on the predicted stream discharge. As the percentage of soil, land use/land cover and slope threshold rises, the exact evapotranspiration reduces due to eradicated land use classes. Consequently, the HRUs characteristics are the main factors influencing to the river discharge. The last region based on classes of slope, soil and land use/land cover after assigning threshold criteria, the application is given in Table 3.4, Table 3.5, and Table 3.6, respectively.

Table 3.4 Land use classes of the Xe Bang Fai river basin after Threshold assigned

No.	Land Use Details	SWAT code	Area (Km^2)	Area (%)
1	Barren land	BRNL	1030.78	11.61
2	Crop mosaic, cropping area >30	CMCL	2424.75	27.32
3	Evergreen, high cover density	EHCD	145.74	1.64
4	Mixed (evg&decide), high cov den	MEDH	2736.30	30.83
5	Mixed (evg&decide) med-low cover de	MEDM	393.34	4.43
6	LMB Paddy field	PDDY	644.28	7.26
7	Deciduoud	DECD	906.45	10.21
8	Wood- and shrubland, evergreen	WSEV	594.49	6.70
	Total		8876.12	100

Table 3.5 Slope classes of the Xe Bang Fai river basin after Threshold assigned

No.	Slope Ranges (%)	Area (Km^2)	Area (%)
1	<2	2363.87	26.63
2	2-10	1436.07	16.18
3	10-45	588.32	6.63
4	>45	4487.86	50.56
	Total	8876.12	100

Table 3.6 Soil classes of the Xe Bang Fai river basin after Threshold assigned

No.	Soil Details	Soil Texture	SWAT code	Area (Km2)	Area (%)
1	Ferric Acrisols	Clay	ACF	4375.52	4.93
2	Haplic Acrisol	Clay	ACh	1044.55	11.77
3	Dystric Leptosol	Loamy	LPd	1410.21	15.89
4	Rock	Rock	R	1697.51	19.12
5	Eutric Cambisol	Loamy	CMe	421.71	4.75
6	Gleyic Luvisol	Loamy	LXh	85.11	0.96
7	Haplic Lixisol	Loamy	LXh	36.50	0.41
8	Gleyic Cambisol	Loamy	CMg	284.49	3.21
9	Stagni-gleyic Acrisol	Clay	ACgi	31.55	0.36
10	Dystric Cambisol/Haplic Acrisol	Loamy	CMd/ACh	154.52	1.74
11	Haplic Acrisol-skeletic	Clay	Ach-C	412.95	4.65
12	Dystric Cambisol	Loamy	CMb	759.84	8.56
13	Ferralic Cambisol	loamy	CMo	21.08	0.24
14	Ferric Luvisol/Dystric Cambisol	Loamy	LVf/CMd	785.79	8.85
15	Haplic Luvisol	Loamy	LVh	24.71	0.28
16	Dystric Cambisol/ Ferric Acrisols	Loamy	CMd/ACf	61.22	0.69
17	Ferric Acrisols/ Dystric Cambisol/	Clay	ACf/ACh	509.21	5.74
18	Eutric Leptosol	Loamy	LPe	5.62	0.06
19	Ferric Acrisols/ Dystric Cambisol	Clay	ACf/CMd	216.61	2.44
20	Haplic Acrisol/ Dystric Cambisol	Clay	Ach/CMd	410.52	4.62
21	Dystric Cambisol/Gleyic Acrisol	Loamy	CMd/Acg	64.90	0.73
	Total			8876.12	100

(4) Weather Data Input

In this study, the meteorological data to be applied hydrological model simulation is imported once which the HRU distribution has been assigned. These data are defined in term of dbf format complying with the ArcSWAT format.

The outlet location of the Xe Bang Fai river basin as measured station, including temperature measure, wind speed, solar radiation measure and humidity measure as shown in Figure 3.5, all of these data are prepared in term of dBase format as per Data Transfer Tool (DTT) attached to the MRC Toolbox. The coordinate systems of observed stations have been given in term of X and Y projected coordinates system for overall measuring stations and outlet of watershed, recognized the precipitation station namely Mahaxai, Ban Hai Naden (Kuanpho), Ban Veun, Thakek, Nakhoutchan, Signo, Seno, Donghen, Phalane, Sepone and Ban Dong station. In a period of 1989-2010 is prepared in accordance with ArcSWAT format by DTT and MQUAD attached to MRC Toolbox as described in (3.2.2 Precipitation) and combined into the model using the weather data input wizard.

(5) Calibration and Validation Model

In SAWT mode, the calibration is the step of improvement or interpolation of specific parameters based on the advised ranges. This procedure is to optimize the output of model in order to their parameters matches with measured datasets. In the modification, the many various parameters for adjustment are able to differ based on the actual condition of study area and user experience. These values are able to be modified manually or automatically until the model output will be get an optimal value and fit with the measured data. In this study, SWAT-CUP is used for calibration model as the outlet of river discharge of the Xe Bang Fai river basin. For the validation model in SWAT-CUP is the step of assigning the degree in which simulate a precise delegation of the measured dataset from the outlook if the designed uses of the SWAT model. The monthly flow data at the Xebangfai@bridge station during the years 1998-2010 is used for calibration and validation and the monthly discharges of 1998-2000 years was skipped from model warm up.

In this study, the calibration model of SWAT model is completed by Calibration and Uncertainty Programs called SWAT-CUP and this model is calibrated and validated as shown below, the model execution is able to be estimated using generated index mostly as the coefficient of determination (R^2), Nash-Sutcliffe efficiency (E_{NS}) and others attached in SWAT-CUP. In the analysis principle of SWAT-CUP model is sensitive parameters modification. In the model adjustment, the SWAT-CUP model was divided into two periods: calibration model period 2001-2005 and also validation model period 2006-2010.

(6) Sensitive Analysis

SWAT is an inclusive conceptual model and it also uses numerous parameters differing extensively in space and time while modifying inputs into output. To get the good results, each parameter has been input to the database tables requires to be defined a value representative to the condition of the study watershed. To obtain at proper value of each parameter, it is important to realize the related sensitivity of a parameter involving model calculated outputs.

In SWAT model, the analysis of sensitivity assigns the most sensitive parameters, in which the sensitivity analysis eventually recognizes the set of parameters to be used in the following calibration procedure. This process was executed for parameter controlling surface runoff response, subsurface response and watershed response. Parameters to be used for adjustment associated with nutrient and pesticide; snowmelt movement were performed from sensitivity analysis like the watershed based on this study does not have snowmelt supplement and also pesticide yield as well, but the nutrient loading in the Xe Bang Fai river basin is considered in the current study based on water quality assessment. The result of sensitivity analysis involving the controlling sensitive parameters, the value begins from the most sensitive values to least sensitive parameter is shown in Table 3.7.

3.4 Results

3.4.1 Parameter Sensitivity Analysis

In calibration model of SWAT-CUP, the analysis of parameter sensitivity has estimated the related values of sensitivity of the parameters. The eight sensitive parameters are used to adjust the values of stream flow simulation of the Xe Bang Fai river basin, including base flow alpha factor (ALPHA_BF), initial SCS runoff curve number to moisture condition II (CN2), available water capacity of the soil layer (SOL_AWC), Manning's "n" value for the main channel (CH_N2), effective hydraulic conductivity in main channel alluvium (CH_K2), Manning's "n" value for the tributary channels (CH_N1, base-flow alpha factor for bank storage (ALPHA_BNK), soil evaporation compensation factor (ESCO), groundwater delay time (GW_DELAY) and groundwater "revap" coefficient (GW_REVAP) based on the sensitivity analysis. For the discharge calibration model, the most sensitive parameters are the ones controlling the surface runoff response. The most sensitive parameters for the calibration of the discharge are the ones governing the surface runoff response, the subsurface response, and the watershed area response. Overall of sensitive parameters were calibrated by SUFI-2 algorithm as shown in Table 3.7.

Table 3.7 Sensitive parameters and fitted values after calibration model using SUFI-2

Parameter name.	Rank	Fitted Value	Min Value	Max Value
v_ ALPHA_BF.gw	1	-0.046	-0.052	-0.038
a_ CN2.mgt	2	0.683	0.584	0.692
r_SOL_AWC.sol	3	0.160	0.156	0.172
v_ CH_N2.rte	4	0.635	0.597	0.671
v_CH_K2.rte	5	125.258	124.756	126.125
v_ CH_N1.sub	6	0.546	0.575	0.598
v_ALPHA_BNK	7	0.675	0.628	0.735
v_ ESCO.hru	8	0.944	0.922	0.958
v- GW_DELAY.gw	9	205.950	196.112	208.315
v_GW_REVAP.gw	10	0.155	0.148	0.157

3.4.2 Simulated Monthly Discharge Calibration and Validation

The hydrograph comparison between simulated monthly discharge and measured data is a satisfying result for the calibration and validation model based on periods, respectively. The discharge calibration and validation model were represented in the Xe Bang Fai river basin for five years from the period (2001-2005) for the calibration model and the period (2006-2010) for the validation model, along with one year of the warm-up period model. In this study, the simulated monthly discharge matches the measured values for the periods of calibration and validation model with R^2 = 0.970, 0.966 and E_{NS} = 0.967, 0.960 for measuring locations, respectively. The Coefficient of Determination (R^2) and Nash-Sutcliffe Efficiency (E_{NS}) of the simulation are shown in Table 3.8 and Table 3.9, in which there is a good agreement between monthly measured and simulated discharges.

From the hydrograph of the monthly measured and simulated discharges at the Xebangfai@Bridge station during the calibration period (2001-2005) as shown in Figure 3.8 illustrated in that we can observe that the monthly simulated discharges closely match the monthly measured discharges, especially at the peak of river discharge in August, 2005, the monthly measured and simulated discharges are higher than others, because of it was the year of heavy rainfall in Lao PDR. The most areas along the main tributaries of Mekong River Basin were impact of flooding. According to MRC (2006), year 2005 is certainly the most serious flood for the central region of Lao PDR, especially Khammouane and Savannakhet Province. The results illustrates that SWAT model can simulate the hydrological characteristics of the Xe Bang Fai river basin very well. Consequently, the model is able to be applied for the hydrological studies in basin.

Table 3.8 Statistical analysis of the simulated and measured monthly discharge at the Xebangfai@bridge station.

Time Period		Measured 2001-2010	Simulated 2001-2010
Average	m^3/s	401.47	409
Standard Deviation	m^3/s	623.88	588.68
Maximum	m^3/s	3691.52	3356
Minimum	m^3/s	14.24	2.29

Table 3.9 Results of the monthly simulated and measured at the Xebangfai@bridge station.

Time Period	Calibrated 2001-2005	Validated 2006-2010
Coefficient of Determination (R^2)	0.970	0.966
Nash-Sutcliffe Efficiency (E_{NS})	0.967	0.960

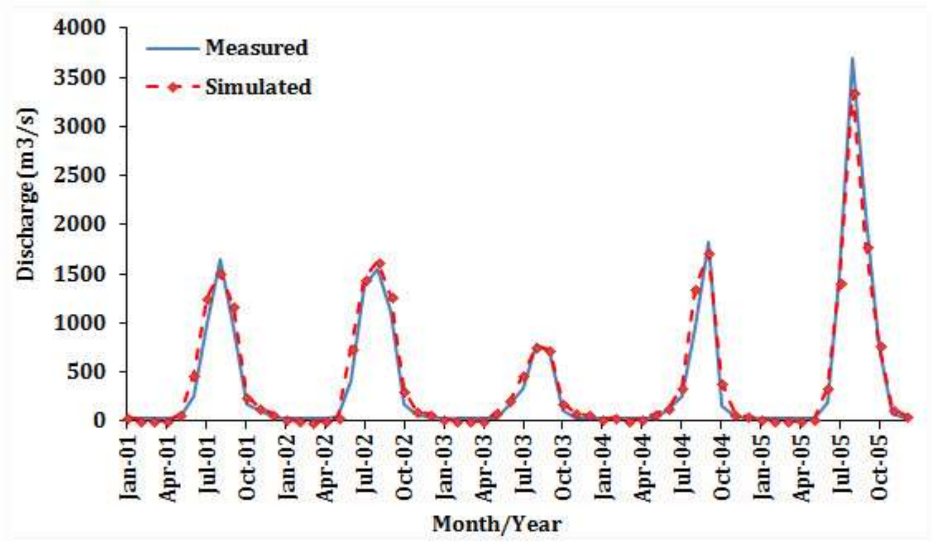


Figure 3.8 Result of the calibration of the monthly discharge period (2001-2005)

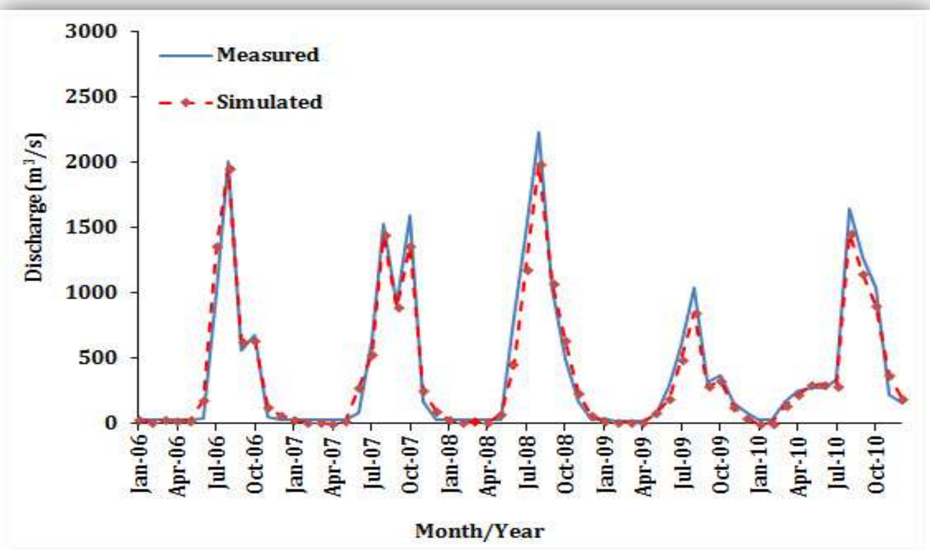


Figure 3.9 Result of the validation of the monthly discharge period (2006-2010)

The comparison of monthly hydrographs between measured and simulated of the flow at Xebangfai@Bridge station during validation period (2006-2010), we can observe that the SWAT model under-forecasted the values of high peak as shown in Figure 3.9 above. The poor forecasting of the peak flows of the SWAT model has been informed by previous researchers such as Borah and Bera (2004), Gassman *et al.* (2007) and Rosenthal *et al.* (1995), which the SWAT model performance for this study region is very good in the period of model validation also with $R^2 > 0.85$ and $E_{NS} > 0.85$ for both of the measuring locations. Hence, the SWAT model is able to adopted for the hydrological assessment of Mekong River Basin, especially overall of the watershed in Laos. From this hydrograph of monthly measured and simulated discharges is illustrated at the peak of river discharge in October, 2007 (MRC, 2008); June, 2008 (MRC, 2009) and October, 2010 (MRC, 2011a). These years are heavy rainfall in Khammouane and Savannakhet Province. The most area was flooded by affecting from tropical storm. Nonetheless, this condition is not reflected in the measured runoff data in Figure 3.9, in which it is assumed that there may be some uncertainty in the data.

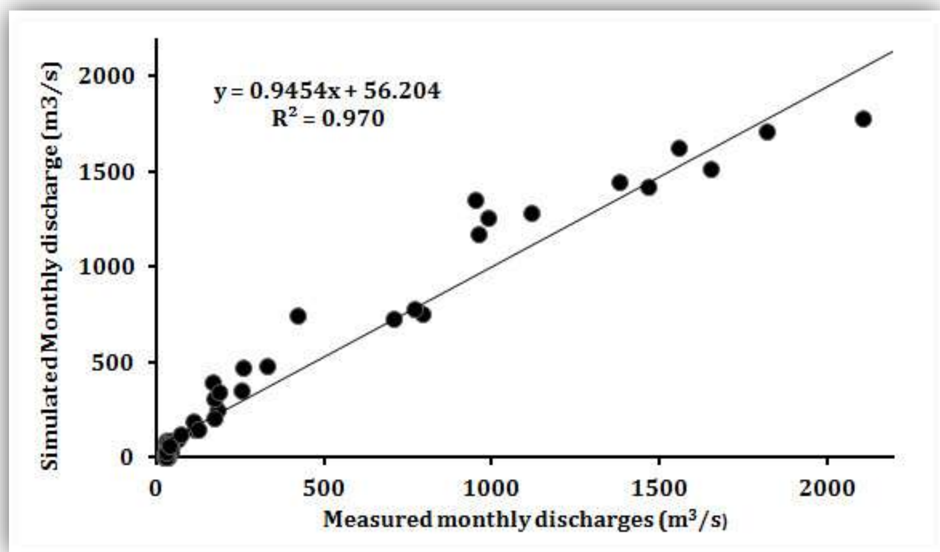


Figure 3.10 Scatter plot of the monthly discharges for the calibration period (2001-2005)

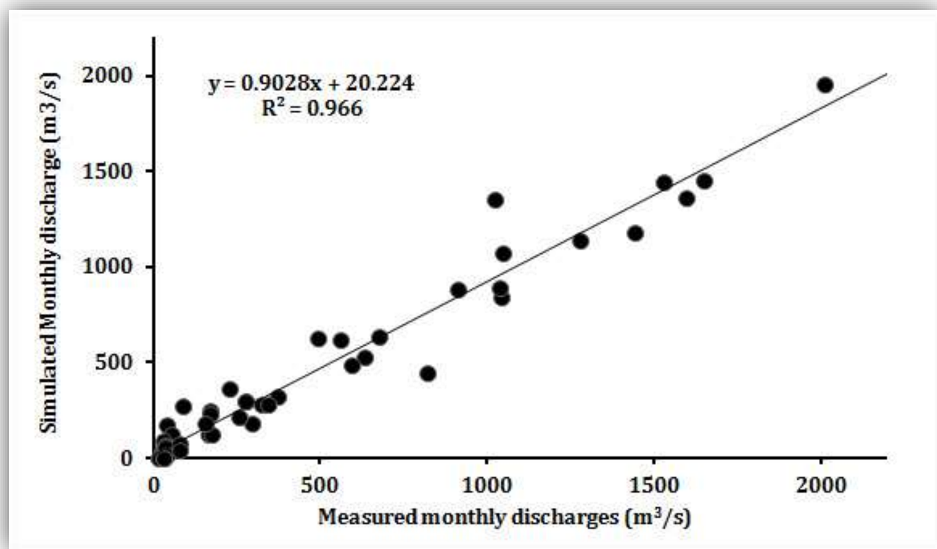


Figure 3.11 Scatter plot of the monthly discharges for the validation period (2006-2010)

From the scatter plots of the measured and simulated monthly flows of the Xebangfai@Bridge station between the periods of calibration model (2001-2005) and validation model (2006-2010) are addressed in Figure 3.10 and Figure 3.11, respectively. Both of the scatter plots represent relatively good R^2 values: 0.970 and 0.966, respectively.

From Table 3.9, the value of Nash-Sutcliffe efficiency (E_{NS}) commonly ranges from 0-1. In the previous research, Saleh *et al.* (2004), indicated that the better prediction of model should be greater than 0.65, whereas the lower (E_{NS}) value will be indicated as a poor model prediction. In addition to Moriasi *et al.* (2007) indicated that the simulations of SWAT model in term of monthly time are generally able to decided acceptable value when (E_{NS}) value is bigger than 0.5. According to these suggestions, the result of SWAT model in this study area is *very good* in the calibration period of (E_{NS}) value greater than 0.65, and less (E_{NS}) value is assumed that there possibly are some uncertainty in the data.

According to the goodness-of-fit method model assessment and suggestion, the above-indicated are satisfactory for baseline. The same is available to apply for the Xe Bang Fai river basin Scenarios.

3.4.3 Uncertainty Analysis

SUFI-2 stands for Sequential Uncertainty Fitting version 2 attached in SWAT-CUP, which is a good and also more smoothly calibrates and validate hydrological model by users. Consequently, this algorithm is considered for calibration and validation in the Xe Bang Fai River Basin. In the analysis procedure, such as sensitivity analysis, calibration, validation, and uncertainty analysis are carried out by SWAT-CUP, which SUFI-2 algorithm is provided numerous iterations to receive the optimized values with the acceptable result. Each of iterations gives the new values of distinct parameters supporting user use of those values for adjustment in the next iteration. Eventually, the process gives the acceptable result including the values of the Nash-Sutcliffe (E_{NS}), Coefficient of Determination (R^2) and others attached values in SWAT-CUP. Saleh *et al.* (2004) indicated that the better prediction of model should be greater than 0.65 and also Moriasi *et al.* (2007) indicated the common accomplishment ratings of the SWAT model for monthly time step simulations. According to these commendations, the SWAT model accomplishment for the Xe Bang Fai river basin is optimized value based on the calibration period with $E_{NS} > 0.80$ and the less value of E_{NS} suppose that there possibly are some uncertainty in the data. The uncertainty analysis represents that base-flow alpha factor for bank storage (ALPHA_BNK) and main channel alluvium (CH_K2) are effectually the parameters of hydraulic indication, which they have a significant roles for the SWAT model calibration and validation. In the previous study, as Luo *et al.* (2012) stated that both of parameters are important effect on the model calibration in SWAT Model, and the sampling scale additionally affect to the analysis of model sensitivity. In this paper, the model structure and the input data are not checked the uncertainty in the model, because of this model has only focused on Coefficient of Determination (R^2) and the Nash-Sutcliffe (E_{NS}) for accuracy assessment. According to this study, it is significant to do the furthermore research by concentrating on these topics of the uncertainty analysis.

3.5 Discussions

Hydrological model is simplified impersonation of the hydrological cycle part in real world system. It is mainly applied to predict hydrological cycle, in particular to comprehend its hydrological processes. Its functions are a mathematical model used to simulate fluvial flow for measuring their parameters of water quality (Kim *et al.*, 2007). The history of hydrological model has a long time. The hydrological model was firstly applied from Rational Method, which it was used a mathematic modeling in term of stream hydrology (Mulvany, 1850). In the 19^{th} century, hydrological model has started from the section of civil engineering to develop and improve the construction of canals, drainage systems, culverts, city sewers, dams and water supply systems. Until the middle of the 1960s, hydrologic modeling originally concerned the improvement of concepts, theories and models of unique elements of the hydrologic cycle, for instance water balance, channel flow, interception, sub-surface flow, infiltration, evaporation and base flow (Singh and

Woolhiser, 2002). Currently, it is widely distributed to be physically-meaningful models in a water resources management (Vivoni, 2003).

The most of models have some physical characteristics, but its sub-component consists of various parameters identifying the characteristics of the model which each model is mentioned to as its theoretical models. For instance of the previous models of conceptual hydrology, including the 2 models of USA as the model of SSARR (U.S Army Corps of Engineers Division, 1976) and the model of NWSRFS (Anderson, 1973); the model of British TOPMODEL (Beven & Kirkby, 1979); the model of Bangladesh MIKE 11 (Havnø *et al.*, 1995); the model of Danish MIKE-SHE (Refshaard *et al.*, 1995); the model of Canadian UBC (Quick & Pipes, 1976); the model of Swiss-American SRM (Rango & Martinec, 1979); the model of Italian ARNO model (Todini, 1996); the model of Japanese TANK (Sugawara, 1995); the model of Chinese Xinanjiang model (Ren-Jun, 1992) and the model of Danish NAM (Asger and Eggert, 1973). Therefore, hydrological model is simplified impersonation of the hydrological cycle part in real world system. Currently, hydrological models are widely accepted that they are significant and powerful tool for solving and management of water resources and environment (Wheater *et al.*, 2007) as well as SWAT model (Arnold *et al.,* 1998).

Soil and Water Assessment Tool (SWAT) (Arnold *et al.*, 1998) is assigned to use for studying climate change impact on hydrological response based on climate change scenarios in the future, because this hydrological model is the most broadly used model in the water sector (Shao and Chu, 2013). There are many previous hydrological research studies, for instance, Rosenthal *et al*., (1995) studied the stream flow volume in the Lower Colorado River basin of Texas by linking a geographic information system (GIS)-hydrological model to SWAT model, with no monthly simulation and calibration of river discharge amount. The research results found that the future upstream of urbanization will be main effects to river discharge change along downstream of Lower Colorado River basin. Borah & Bera (2004) simulated 11 basin-scale hydrological and nonpoint-source pollution models. These models were used for estimating long-term impacts of hydrological changes based on watershed management practices, particularly crop practices. The mathematical method of various model components was selected to use at the most accuracies for developing new approaches in the future. Gassman *et al*., (2007) reviewed using SWAT models, for instance river discharge calibration and associated hydrological analysis, climate change effects on hydrological response, pollutant load evaluations, comparisons with other hydrological models, and sensitivity analyses and calibration techniques.

In the past, there were hydrological research studies, especially a study on discharge of the Xe Bang Fai river basin tributaries to support information for water resources management policies in Lower Mekong Basin of Laos (NT2, 2003; MRC, 2010b;

LNMC, 2011b). These models are generalized hydrologic simulation package, which are capable for applying regulated and unregulated streams. The models are designed to be capable for addressing water quality and quantity and also environmental issues. Therefore, if there are any models that accurately study the effect of climate change on the hydrological system in the sub-basin of the Lower Mekong River (LMR), it will become a powerful tool for decision-marking, mitigation, measurement, planning for water resources management and controlling water quality. The outcome of study will support local human well-being for those who live along the downstream about water management.

3.6 Summary

As the results of this study based on hydrological modeling are successfully calibrated and validated by using the SWAT model in the Xe Bang Fai river basin. The results are represented with the possible gauging the calibration and validation model for two periods as follows: 2001-2005 and 2006-2010. In this study, the results of the monthly simulation R^2 and E_{NS} are 0.970 and 0.967 during the calibration periods and also 0.966 and 0.960 during the validation period. The sensitivity analysis of the model to sub-watershed delineation and HRU definition thresholds represents that the discharge is more sensitive to the thresholds of HRU definition than sub-watershed continuous affectation. The results of this study in the whole watershed area were discovered 716 HRUs, in which the

95PPU classifies very well with the measured data for the calibration and validation periods. The both of p-factor and r- factor were quantified by using SUFI-2 algorithm, which it provides good results by classifying value higher than 70% of the measured data. The technique of SUFI-2 algorithm is a powerful method which it has to need the process of additional iterations as well as the requirement for modification the parameter ranks. Notwithstanding the data uncertainty, the SWAT model can generate good simulation results of monthly time processes which they are valuable for water resources management in the Xe Bang Fai river basin as well as the whole sub-watershed in the Mekong River Basin. As results of this paper is able to be used for managing water and disaster protection. In addition to the SWAT model is able to be asked as the standard model for future study on sediment yield and water quality analysis. In addition, the study is able to conducted in the planning on hydropower dam constriction, irrigation system, levee and flood disaster risk management, which results of research are valuable for the sustainable country development.

Chapter 4. Climate Change Scenarios based Stream Flow Projection of the Xe Bang Fai River Basin.

4.1 Climate Change Impact on the Mekong Basin Hydrology

The impact of climate change has a potential on water resources, which it has become a subject debated in global for decades (Arnell, 1999). The variability of climate will effect to river runoff in the basin. Recently, IPCC's scientists study found that climate change has affected the operation and function of existent water foundation and water management (Parry, 2007). In previous researches has depended on historical precipitation and river discharge data for evaluating hydrological system at an observed site. Nevertheless, climatic variation in these data may be no longer reliable for forecasting future hydrological situation (Craig, 2010). In this chapter, we estimate the characteristic of river discharge with climate change scenarios in the Xe Bang Fai river basin, based on the feasible changes related to climate change evaluated in the previous chapter. In this study, we recognize gaps in knowledge regarding the effect of climate change on the river basin hydrology and the application of knowledge and experience acquired from other regions to the Xe Bang river basin.

The previous researches of IPCC-Intergovernmental Panel on Climate Change on estimation of climate change impact on water resources (Kundzewicz *et al.*, 2008), with also a technical paper on climate change and water (Bates *et al.*, 2008). According to several researches provide a significant basis to understand the climate change impact on river watersheds. In addition, numerous researches have studied variations in climate change, which associates with main hydrological system in the Mekong River Basin (Delgado *et al.*, 2012; Lacombe *et al.*, 2012; Räsänen *et al.*, 2012; Räsänen and Kummu, 2013) and modeled, moreover, the climate change impact on hydrological system of Mekong River (Snidvongs *et al.*, 2003; Center, 2008; Eastham *et al.*, 2008; Västilä *et al.*, 2010; Kingston *et al.* 2011; Lauri *et al.*, 2012; Piman *et al.*, 2013) under various suppositions regarding the future of the Mekong River Basin (MRB). The MRB region is classified into two categories, namely the Upper Mekong Basin (UMB) and the Lower Mekong Basin (LMB). The UMB characteristic is great mountains with deep gorges, steep slopes and small-scale catchment regions. In this part of Myanmar and China, the 24% of the total basin area are contains the Lancang2 Basin, the Three Rivers region and three physiographic regions-the Tibetan Plateau (Lauri *et al.*, 2012). For the LMB part includes Laos, Thailand, Cambodia, and Vietnam, which their 76% of total basin contains the Northern Highlands, Khorat Plateau, Tonle Sap Basin, and Mekong Delta physiographic areas (MRC, 2010b). The climatic characteristic in MRB is influenced by regional systems of tropical monsoon. The southwest monsoon generates a different rainy season which starts in middle May and extends over middle October, with that time the Mekong River Basin obtains 90% of annual precipitation. Cyclonic disruption may result in extensive rainfall of long-standing duration from July to September, which is able to bring about terrible flooding. The northeast monsoon starts from November to middle March, generating a cooler dry season with relatively low rainfall contribution. Middle March to middle May and late-October are periods of transition with unsteady wind speed and direction as shown in Table 4.1.

Table 4.1 Monsoon seasons and transitions in the Mekong River Basin

Cold Season			Summer Season		Rainy Season					Cold Season	
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Northeast Monsoon			Transition		Southwest Monsoon					Northeast Monsoon	

The characteristic of the UMB climate differs importantly from its headwaters origin or to mouth of lower reaches. The basin temperature fall down zero in Winter and average temperature in Summer maybe reach 13°C (MRC, 2005). As the high plateau region below, the climatic characteristic in summer becomes sub-tropical climate with average temperature (2-3°C) at the upstream of the hydrological boundary in the LMB, in which the temperature is lightly cooler than the Highlands of LMB Northern. Average annual evaporation in this basin ranges from 1000-2000mm, which the altitude and slope orientation are variable significantly (MRC, 2005). The most of the LMB region has a tropical climate as high humidity and temperature. The minimum average monthly temperature in this basin area is never lower than 20°C. Average annual evaporation in this basin area is approximately 1500 mm in the Northern Highlands in Laos. The variation in evaporation is low from year to year caused by the high relative humidity, and also the stable regional influence of the tropical monsoon in the UMB and LMB region, the seasonal distribution of rainfall is pretty homologous with different dry and rainy seasons. The peak annual rainfall in this basin region happens during June-October. The distribution of average annual rainfall over the LMB presents a different east to west gradient. The mountain areas in Laos get the highest rainfall more than 2500 mm/year, and the central part get the least rainfall less than 1000 mm/year. The largest contributions to mainstream discharges during the summer monsoon season, which occur within the large Mekong tributaries in Laos (MRC, 2010b).

Recently researches by the Institute for Water Management Institute propose that runoff of the UMB also offers most of the flooding during the year's majority. At Vientiane Capital of Laos, for instance mean contributions rank from over 75% during the low-discharge months in April-May, to over 50% during the peak-discharge months in July, August and September. Even though, contributions of year-to-year are highly alterable which the LMB contributes 75-80% of MRB annual discharge. The majority of runoff in Lower Mekong Basin is obtains from the Mekong Eastern riverside tributaries of Laos, in which drain the high-rainfall regions of the Northern Highlands (Adamson *et al.*, 2009). For instance as shown in Figure 4.1 represents the mean annual hydrographs for the Mekong River basin at different measuring stations (ICEM, 2010). Overall of the Laos watershed contributes 43% of LMB runoff (more than 35% of total MRB runoff), which they produce the most of the rainy season peak discharge and importantly supporting to downstream floodwater incidence (Adamson, 2006).

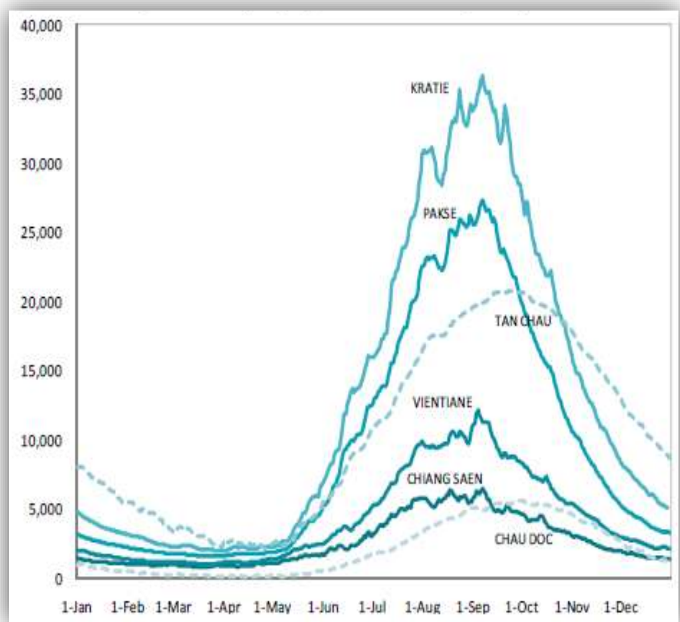


Figure 4.1 Mean annual hydrographs for Mekong River Basin with various observed station, source: ICEM, 2010.

The widespread monsoon climate influence in the Mekong river basin and altitude of the Mekong river watercourse increase a single-peaked hydrograph in large seasonal distinctions between low and high discharges. The determining the Mekong River hydrograph characteristics, especially associate with estimating the influence of hydrology and climate change in the basin, are the invariability in the timing of the starting and the ending of the rainy season, smooth rainy season peak of stable size and normality, and the observable low-discharge season (Adamson *et al.*, 2009; MRC, 2010b; ICEM, 2010). As shown in Figure 4.2, Adamson (2006) separated the hydrograph of the Mekong River into four variant seasons over the hydrological year. For example, at the Chiang Saen (observed station) in UMB and at the Kratie station (observed station) in LMB, the timing of the beginning and these seasons duration is practically similar pattern as shown in Figure 4.1. The annual minimum daily flow regularly takes place in early April. The doubling of this flow, normally in late May, determines the beginning of the first transition season (point 2). This finishes when the floodwater season occasions (point 3). The beginning of the floodwater season starts within a couple days each year at the end of June. The timing of peak floodwater is very steady over time, with a standard deviation of approximately 23 days. The 2^{th} transition season determines during the end of the floodwater season (point 4) and the beginning of the dry season (point 5), in which takes place when ranks of daily discharge reduce become pattern of "base-discharge" recession. Commonly, the beginning of the dry season is in late November. The floodwater season continues for only over 130 days. The substantiality regarding the beginning and late stage of the annual floodwater is able to be assured to take place within a period of just two weeks is a distinguished and determining qualification of the Mekong River system (Adamson *et al.*, 2009).

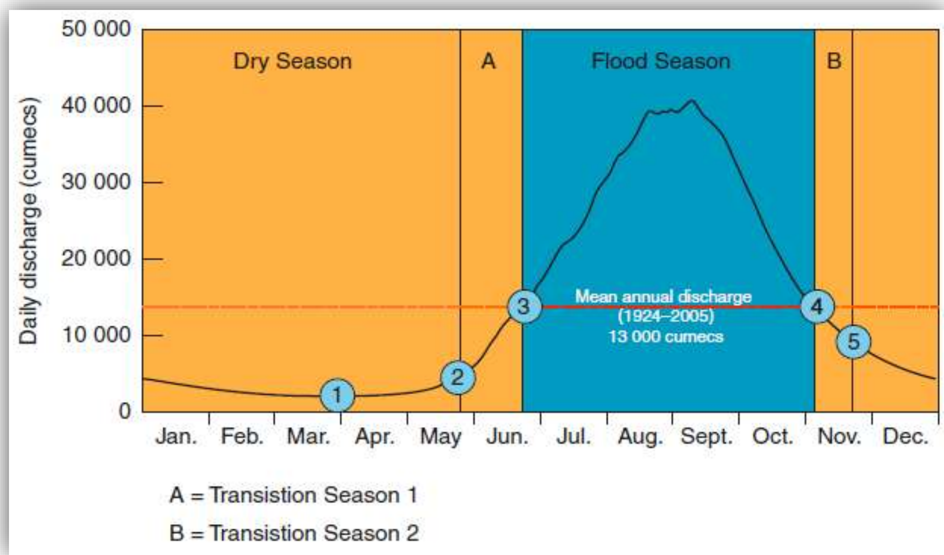


Figure 4.2 Mekong River mean annual hydrograph with major transition seasons, source: Adamson, 2006.

As history recorded, extreme tropical and cyclones storms have created the most important circumstance of Mekong River flooding. The greatest recorded floodwater happened in 1966 when Phyllis tropical storm attacked the UMB. At the end of basin downstream, extreme tropical storms joined with the Southwest monsoon to generate floods in the large region of LMB (Adamson *et al.*, 2009).

4.2 Characteristics of the Xe Bang Fai River Basin Climate

The climate of the Lao PDR is generally influenced by the tropical monsoon climate, with northeast monsoons and the seasonal southwest (Jasparro and Taylor, 2008; Keskinen *et al.*, 2010; MRC, 2010a), and also the shift of tropical cyclone disturbances and the Inter-tropical Convergence Zone (ITCZ) (ReliefWeb, 2016b). Consequently, the weather of the Xe Bang Fai river basin is affected from tropical storms and depressions.

The rainy season (May-October) is affected from the southwest monsoon, which it has predominant in particular atmospheric pressure is low over Asia. (Center, 2008; Chen and Chappell, 2009; Räsänen and Kummu, 2013; Giang *et al.*, 2014; Thompson *et al.*, 2014). The characteristics of the weather in this period are frequent and heavy rainfall. The rainy season, nevertheless, rainfall characteristic commonly has a bimodal distribution, with two weeks as a short dry period and during June to July. After this time, rainfall characteristic turns into more normal, containing tropical storms attacking the regime from the South China Sea (http://reliefweb.int/disasters) (ReliefWeb, 2016c; Manton, 2001; Holmes *et al.*, 2009) mostly during two month as September and November. Flooding disaster often happens when two patterns, as more of these storms happen in accession, or it will occur when ITCZ passes into one of its more active stages, with tropical storm ensuing shortly after that time.

A period of season transition, from the middle of October through early November, is attacked by the dry northeast monsoon (cool dry season), which commonly continues from October through February. The season characteristic is classified that its distribution is light, rather disrupted rainfall, and also its atmosphere pressure lower humidity and lower temperatures. The characteristic of northeast monsoon is followed by another period of transition to the hot dry season in March and April, and is classified based on raising humidity, rainfall and temperature. This season transition is slower than the transition from the rainy season through the cold dry season (MRC, 2014b; 2015).

According to the data collection and analysis in the Chapter 2, the notation of the long-term precipitation is obtainable in the Xe Bang Fai river basin and other close location of stations, in which is sited nearby the Xe Bang Fai river basin mouth side and the notation of the long-term precipitation note obtainable in southern basin area, for instance the Xeno, the Donghen and the Xepon stations.

4.3 Climate Change Scenarios

Climate change scenarios are reasonable and regularly clarified explanation of the future climate, based on an internally stable set of climatological relationships (IPCC, 2014). Scenarios are generated from distinction between future climate and a reference climate. IPCC is classified into two major distinct scenarios including A and B. Scenario “A” focuses on stronger economic values, and scenario “B” emphasizes stronger environmental values. Scenarios A and B, nonetheless, can be classified in future by expanding regionalization and globalization. Scenario 1 here is a connection between country or global. In addition to scenario 2 is a connection between countries in the regional scale as shown in Figure 4.3 that represents the international Panel on Climate Change Scenarios (IPCC) A1, A2, B1, and B2 scenarios.

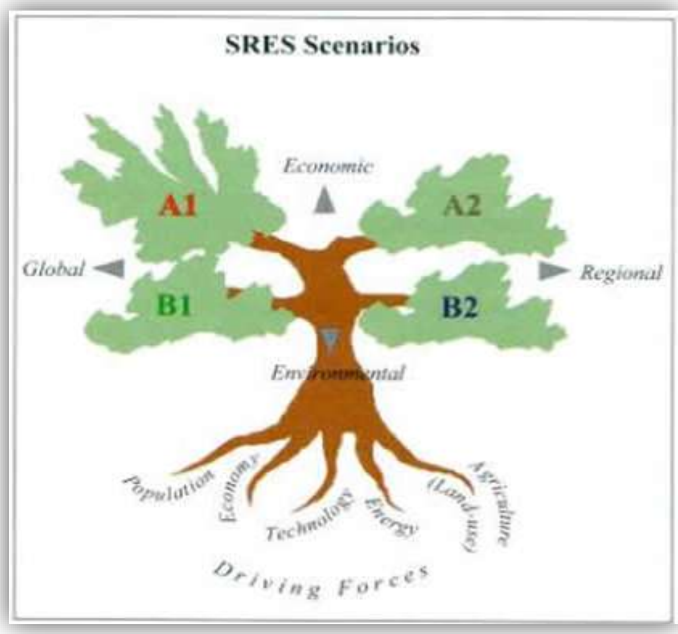


Figure 4.3 Schematic diagrams of the four SRES storylines, source: IPCC, 2014.

Meaning of A2 emphasizes strong economic in regional scale and B1 is more environment in global scale. Moreover, scenario

COMMIT indicates atmospheric environment burned of long-live greenhouse gasses.

4.4 Acquisitions of Climate Change Factors (CFs) Data

In the study on river discharge based on climate change scenarios in the Xe Bang Fai river basin. The projection of stream flow needs a set of exploratory climate change factors (CFs) from Mekong River Commission (MRC) (MRC, 2014a). These data requires the Flood Management and Mitigation Programme (FMMP) to use for imputing into Soil Water Assessment Tool (SWAT) model, This processing will be used to receive a final result regarding the appropriate range to use for stress test scenarios of Flood Management and Mitigation Programme (FMMP), which FMMP is one of various components in MRC for flooding disaster risk management in Lower Mekong Basin. The CFs data in change factors of SWAT model (RFINC) are given from 3 main institutes including Institute Pierre-Simon Laplace (IPSL), NASA Goddard Institute for Space Studies (GISS) and Geophysical Fluid Dynamics Laboratory (GFDL).

The concept of stress test scenarios is generated to develop a strong method that takes into consideration of uncertainty in climate variation projections in the LMB (Kingston, 2011), especially flooding disaster risk management of FMMP based on the cooperation between the MRC and Deutsche Gesellschaft für

Internationale Zusammenarbeit (GIZ) GmbH in 2012 under the initial program assessment of climate-sensitive flood management in the Lower Mekong Basin. In the study, the stress test scenarios relates to applying MRC's basin hydrological models (SWAT model) based on various configurations to evaluate how watershed hydrology is forecasted to respond for providing variations in climate powering variables (MRC, 2011b). As discussed and approved with the CCAI teams and the MRC's FMMP divisions with technical cooperation in 2013, the data of change factors generated in the project were acquired in a feature that is agreeable with the clarification of change factors usable for SWAT models in MRC (MRC, 2014a). The hydrological model (SWAT model) imposes these change factors as monthly resolution in tabular form. Consequently, the current work values for each hydrological model based on SWAT model, sub-watershed has been given as a final method stage. The SWAT sub-watersheds were assigned by the MRC Tool in the features of Geographic Information System (GIS) files.

In the Lower Mekong Basin as the Xe Bang Fai river basin is located in the Mekong River Catchment as shown in the part of Lao PDR illustrated in the Figure 4.5. The configuration of the Xe Bang Fai Sub-basin is identically from MRC SWAT sub-basin, thus the climate change factors from the regional model is able to be applied for the SWAT model scenarios of the Xe Bang Fai river basin. In this study, the factor change which is applied for the Xe Bang Fai river basin scenarios is shown in Table 4.2, 4.3, 4.4 and 4.5. In the tables, overall of the factors are received from the line-agency as Lao National Mekong Committees (LNMCs) working with Mekong River Commission. These data will be used to compute the climate change factors in each sub-basin of Xe Bang Fai river basin. Furthermore detail will be indicated in the simulation of climate change scenarios as shown below.

Table 4.2 The change factors of SWAT model.

Variable Name	Definition	Units
RFINC (month)	Monthly precipitation is adjusted by the specified percentage. i.e. RFINC= 10 will make rainfall equal to 110%.	%
TMPINC (month)	Monthly maximum and minimum temperatures within the month are increased or decreased by the specified amount	°C
RADINC (month)	Monthly radiation within the month is increased or decreased by the specified amount	MJ m2-day
HUMINC (month)	Monthly values for relative humidity within the month are increased or decreased by the specified amount	Fraction

Where, RFINC is rainfall adjustment; TMPINC is temperature adjustment; RADINC is radiation adjustment; and HUMINC is humidity adjustment. The climate model was generated by RCP6.0 simulations from 4th intergovernmental Panel on Climate Change (IPCC) (IPCC, 2014) assessment to test how the climate is likely to change in the Xe Bang Fai river basin, and also the effect of change on water resources in basin.

Table 4.3 RFINC of Institute Pierre-Simon Laplace (IPSL CM5A-MR)

MRC SWAT Sub-basin	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
04A089	5.67	-9.78	-18.81	-17.34	-1.67	4.14	0.55	3.65	6.34	28.96	5.04	26.42
04A094	6.41	-11.24	-19.55	-17.21	-1.37	4.25	0.28	3.89	5.97	27.84	5.79	27.95
04A097	5.89	-11.86	-20.25	-17.00	-1.33	4.42	-1.40	3.32	5.67	28.62	5.44	30.41
04A101	1.02	4.42	19.51	-6.41	4.73	1.60	-3.40	4.08	11.06	1.60	12.14	5.31
04A104	5.24	-12.08	-20.40	-16.83	-1.36	4.31	-1.27	3.17	5.31	27.17	5.66	29.52
04A106	5.83	-12.27	-20.39	-16.99	-1.29	4.53	-1.96	2.88	5.85	31.16	4.91	33.75
04A109	4.32	-13.08	-21.37	-16.67	-1.34	4.36	-3.19	2.20	4.76	29.03	5.11	33.98
04A110	4.00	-12.88	-21.50	-16.57	-1.38	4.29	-2.97	2.28	4.58	27.43	5.37	32.20
04A111	4.33	-12.42	-21.12	-16.60	-1.40	4.22	-1.91	2.81	4.86	26.05	5.73	29.35

Table 4.4 RFINC of NASA Goddard Institute for Space Studies (GISS E2-R-CC)

MRC SWAT Sub-basin	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
04A089	-11.45	-2.73	-6.38	0.21	-0.83	2.27	0.17	5.15	2.37	-11.02	0.66	-4.41
04A094	-10.52	-2.75	-4.89	-1.32	-1.53	2.07	2.30	5.94	2.65	-10.30	-0.31	-4.30
04A097	-10.58	-3.64	-6.82	-2.96	-3.18	2.22	-0.34	4.79	2.16	-9.67	0.45	-4.47
04A101	-10.34	-2.47	-4.63	-1.23	-1.41	1.46	3.31	6.08	2.87	-9.84	0.40	-4.24
04A104	-10.36	-3.55	-6.87	-3.13	-3.29	1.75	0.34	4.81	2351	-9.09	0.70	-4.41
04A106	-11.12	-4.59	-8.80	-4.19	-4.71	2.69	-3.40	3.54	1.44	-9.91	0.99	-4.75
04A109	-10.79	-5.20	-10.41	-5.29	-5.80	2.14	-3.72	2.94	1.32	-8.60	1.82	-4.69
04A110	-10.52	-4.77	-9.72	-4.93	-5.30	1.71	-2.23	3356	1.66	-8.21	1.74	-4.58
04A111	-10.24	-3.75	-7.67	-3792	-3.89	1.32	0.47	4.42	2.27	-8.37	1.20	-4.42

Table 4.5 RFINC of Geophysical Fluid Dynamics Laboratory (GFDL CM3)

MRC SWAT Sub-basin	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
04A089	0.83	4.17	19.84	-6.13	5.06	1.47	-3.43	4.42	11.73	1.49	12.59	5.4
04A094	0.75	4.42	20.1	-6.34	4.84	1.61	-3.49	4.27	11.49	1.5	12.28	5.37
04A097	1.19	4.27	21.09	-6.38	4.69	1.69	-3.44	4.33	11.55	1.53	12.72	5.42
04A101	1.47	4.26	20.66	-6.5	4.57	1.7	-3.32	4.16	11.14	1.63	12.63	5.36
04A104	1.61	4.02	22.56	-6.12	4.68	1.74	-3.57	4.54	12.09	1.5	13.34	5.61
04A106	2.54	3.85	22.46	-6.32	4.38	1.85	-3.3	4.32	11.44	1.7	13.57	5.64
04A109	2.47	3.94	21.69	-6.48	4.33	1.83	-3.19	4.16	11.04	1.76	13.29	5.51
04A110	1.94	4.17	20.55	-6.59	4.4	1.74	-3.19	4.02	10.77	1.75	12.72	5.33
04A111	0.83	4.17	19.84	-6.13	5.06	1.47	-3.43	4.42	11.73	1.49	12.59	5.4

4.5 Methods

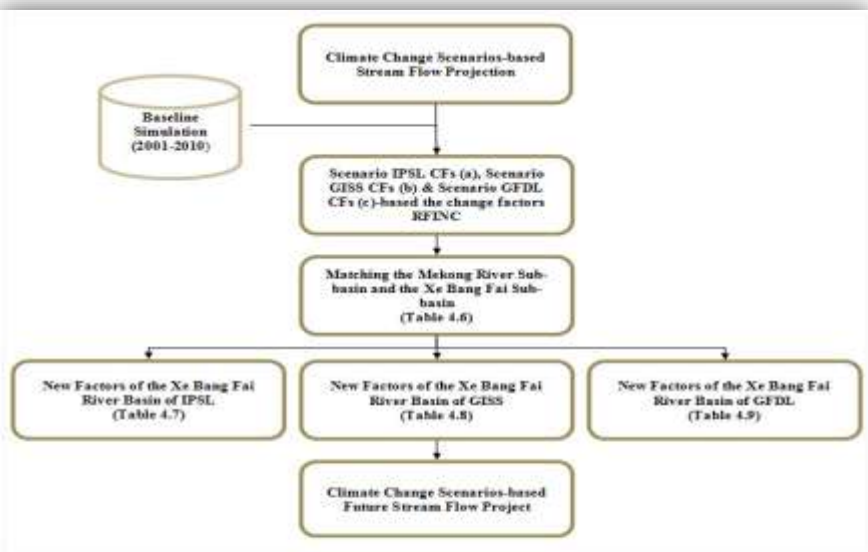


Figure 4.4 The flow chart of climate change scenarios

To study the climate change impact on hydrological response, especially the change of river discharge in the Xe Bang Fai river basin, first data needs to be collected including the baseline of river discharge simulation from the available dataset of the Xe Bang Fai river basin and the future climate change scenarios within this basin region. The baseline of river discharge simulation of the Xe Bang Fai river basin is given from the river discharge simulation in the Chapter 3 during 2001-2010, with good results of the model calibration periods (2001-2005) and validation periods (2006-2010) as shown in Table 3.9. For climate change scenarios, the three climate model are selected for studying river discharge change based on the climate change model in 2030, namely IPSL, GISS and GFDL, which they are the last climate model under the Intergovernmental Panel on Climate Change (IPCC). The climate model was generated by RCP6.0 simulations from 4^{th} intergovernmental Panel on Climate Change (IPCC) (IPCC, 2014), which they were corrected by using the MRC's hydrological tool under the cooperation between the MRC and Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH in 2012 under the initial program assessment of climate-sensitive flood management in the Lower Mekong Basin (IPSL CM5A-MR 2030, GISS E2-R-CC 2030 and GFDL CM3 2030). Therefore, the study on river discharge based on three climate change scenarios is processed by using SWAT model (Arnold *et al.*, 2012). The main analysis procedure is carried out as following below.

4.6 Preparing Baseline Simulation for Scenario Simulation

(1) River Discharge Baseline

To study on future changing river discharge in the Xe Bang Fai river basin, climate change scenarios was used to study on changing river discharge in this region. The baseline scenario was obtained from river discharge simulation of the Xe Bang Fai river basin as shown in Chapter 3. The baseline simulation period (2001-2010), the monthly of measured and simulated flow data for the Xebangfai@bridge station has been portrayed in the hydrograph for calibration period (2001-2005) and validation period (2006-2010) individually, which the identical hydrograph were represented in Chapter 3 (Figures 3.8, 3.9, 3.10, 3.11). According to the statistical analysis of monthly-simulated flow at the Xebangfai@bridge station during the calibration period (2001-2005) is shown in Chapter 3 (Table 3.7, 3.8, 3.9). The high values of Coefficient of Determination (R^2) and Nash-Sutcliffe Efficiency (E_{NS}) demonstrates acceptable modeling performance for runoff simulation during the monthly calibration period (monthly) for the Xebangfai@bridge station. Therefore, the result of the baseline data of river discharge of the Xe Bang Fai river basin will be used to compare with the river discharge obtained from the analysis of climate change model in 2030, namely IPSL, GISS and GFDL), which they were used to simulate river discharge change in 2030 (IPSL CM5A-MR 2030, GISS E2-R-CC 2030 and GFDL CM3 2030). For comparison of river discharge in 2030, the overall river discharge is in term of monthly as shown in Figure 4.8 and Figure 4.9.

4.7 Climate Change Scenarios-based Stream Flow Projection

(1) Correcting Sub-basin Spatial Data

A large number of problems were recognized with the SWAT model, sub-basin explanations provide by the related line-agency working with MRC for this study. These involve to the spatial feature of the SWAT sun-basins in the form of shape files as shown in Figure 4.5.

Overall problems were corrected based on the method of standard ArcGIS spatial tool. Mostly, the result has affected to little transform in the area of sub-basin slightly which it is suitable for analysis. Figure 4.6 displays the amounts of MRC SWAT sub-basins are larger than the Xe Bang Fai sub-basins. An instance of sub-basin number 04A101 of MRC SWAT sub-basins are contained 4 sub-basins of the Xe Bang Fai sub-basins including No. 2, 3, 4 and 5, as the homogeneous site. It shows that the Xe Bang Fai sub-basin is able to utilize the homogeneous monthly factors change values of the MRC SWAT sub-basin.

In the study, scenarios of climate change were simulated using change factors of climate acquired from the FMMP/MRC modeling team to input into the time series of the SWAT model scenarios. The change factors of climate characteristic were produced from the three sources of global data, as (a) IPSL CM5A-MR 2030, (b) GISS E2-R-CC 2030 and (c) GFDL CM3 2030. In this study, precipitation is the only one parameter of time series, which is significant condition to the CFs of climate. The scenario of climate change is able to be used for inputting into the SWAT model, for instance rainfall as change factor as shown in Tables 4.3, 4.4 and 4.5. The climate CFs were super-assigned from the sub-basins of regional SWAT Mekong model region 4 (Nakornpanom-Thakhek) to sub-basins of the new updated model for the Xe Bang Fai river basin.

Figure 4.5 The configuration of the Mekong SWAT sub-basins with the Xe Bang Fai area

Figure 4.6 Overlaying the Xe Bang Fai river basin with the Mekong SWAT sub-basins

Table 4.6 Matching between the Mekong River sub-basin and Xe Bag Fai sub-basin

MRC SWAT Sub-basin	Xe Bang Fai Sub-Basin Numbers
04A089	5
04A094	4
04A097	1, 3, 6, 8
04A101	2, 3, 4, 5
04A104	6
04A106	7, 9, 10
04A109	14
04A110	12, 15
04A111	5

Table 4.7 Climate change factors RFINC of Institute Pierre-Simon Laplace (IPSL CM5A-MR 2030)

Sub-basin	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	1.059	0.900	0.810	0.825	0.981	1.043	1.008	1.039	1.065	1.292	1.052	1.266
2	1.061	0.879	0.795	0.828	0.985	1.046	0.988	1.035	1.059	1.288	1.056	1.306
3	1.066	0.886	0.803	0.826	0.984	1.045	1.001	1.041	1.062	1.280	1.060	1.282
4	1.061	0.879	0.795	0.828	0.985	1.046	0.988	1.035	1.059	1.288	1.056	1.306
5	1.012	1.046	1.197	0.934	1.049	1.018	0.964	1.043	1.113	1.018	1.123	1.055
6	1.012	1.046	1.197	0.934	1.049	1.018	0.964	1.043	1.113	1.018	1.123	1.055
7	1.012	1.046	1.197	0.934	1.049	1.018	0.964	1.043	1.113	1.018	1.123	1.055
8	1.060	0.875	0.794	0.828	0.985	1.047	0.978	1.031	1.061	1.314	1.051	1.339
9	1.060	0.875	0.794	0.828	0.985	1.047	0.978	1.031	1.061	1.314	1.051	1.339
10	1.060	0.875	0.794	0.828	0.985	1.047	0.978	1.031	1.061	1.314	1.051	1.339
11	1.012	1.046	1.197	0.934	1.049	1.018	0.964	1.043	1.113	1.018	1.123	1.055
12	1.060	0.875	0.794	0.828	0.985	1.047	0.978	1.031	1.061	1.314	1.051	1.339
13	1.045	0.869	0.784	0.831	0.985	1.046	0.966	1.024	1.050	1.292	1.053	1.342
14	1.045	0.874	0.787	0.832	0.984	1.044	0.979	1.030	1.051	1.262	1.059	1.296
15	1.042	0.870	0.783	0.832	0.984	1.045	0.968	1.025	1.048	1.276	1.056	1.324

Table 4.8 Climate change factors RFINC of NASA Goddard Institute for Space Studies (GISS E2-R-CC 2030)

Sub-basin	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.886	0.973	0.936	1.002	0.992	1.027	1.006	1.056	1.028	0.890	1.011	0.956
2	0.894	0.964	0.932	0.970	0.968	1.026	1.001	1.052	1.026	0.903	1.004	0.955
3	0.895	0.973	0.951	0.987	0.985	1.025	1.027	1.063	1.031	0.897	1.001	0.957
4	0.894	0.964	0.932	0.970	0.968	1.026	1.001	1.052	1.026	0.903	1.004	0.955
5	0.897	0.975	0.954	0.988	0.986	1.019	1.037	1.065	1.033	0.902	1.004	0.958
6	0.897	0.975	0.954	0.988	0.986	1.019	1.037	1.065	1.033	0.902	1.004	0.958
7	0.897	0.975	0.954	0.988	0.986	1.019	1.037	1.065	1.033	0.902	1.004	0.958
8	0.889	0.954	0.912	0.958	0.953	1.031	0.966	1.039	1.018	0.901	1.010	0.953
9	0.889	0.954	0.912	0.958	0.953	1.031	0.966	1.039	1.018	0.901	1.010	0.953
10	0.889	0.954	0.912	0.958	0.953	1.031	0.966	1.039	1.018	0.901	1.010	0.953
11	0.897	0.975	0.954	0.988	0.986	1.019	1.037	1.065	1.033	0.902	1.004	0.958
12	0.889	0.954	0.912	0.958	0.953	1.031	0.966	1.039	1.018	0.901	1.010	0.953
13	0.892	0.948	0.896	0.947	0.942	1.025	0.963	1.033	1.017	0.914	1.018	0.953
14	0.898	0.962	0.922	0.963	0.961	1.017	1.005	1.048	1.027	0.916	1.012	0.956
15	0.892	0.948	0.896	0.947	0.942	1.025	0.963	1.033	1.017	0.914	1.018	0.953

Table 4.9 Climate change factors RFINC of Geophysical Fluid Dynamics Laboratory (GFDL CM3 2030)

Sub-basin	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	1.014	1.048	1.204	0.941	1.057	1.021	0.968	1.050	1.123	1.021	1.132	1.060
2	1.018	1.049	1.217	0.938	1.053	1.023	0.968	1.049	1.122	1.021	1.133	1.060
3	1.014	1.050	1.207	0.939	1.054	1.022	0.967	1.049	1.121	1.021	1.129	1.060
4	1.018	1.049	1.217	0.938	1.053	1.023	0.968	1.049	1.122	1.021	1.132	1.060
5	1.016	1.050	1.201	0.938	1.053	1.022	0.968	1.047	1.117	1.021	1.127	1.059
6	1.016	1.050	1.201	0.938	1.053	1.022	0.968	1.047	1.117	1.022	1.127	1.059
7	1.016	1.050	1.201	0.938	1.053	1.022	0.968	1.047	1.117	1.022	1.127	1.059
8	1.022	1.046	1.232	0.941	1.053	1.023	0.966	1.051	1.127	1.021	1.137	1.062
9	1.022	1.046	1.232	0.941	1.053	1.023	0.966	1.051	1.127	1.021	1.137	1.062
10	1.022	1.044	1.232	0.941	1.053	1.023	0.966	1.051	1.127	1.021	1.137	1.062
11	1.016	1.046	1.201	0.938	1.053	1.022	0.966	1.047	1.117	1.022	1.127	1.059
12	1.022	1.046	1.232	0.941	1.053	1.023	0.966	1.051	1.127	1.021	1.139	1.062
13	1.031	1.045	1.231	0.939	1.050	1.024	0.969	1.049	1.120	1.023	1.142	1.062
14	1.025	1.048	1.211	0.936	1.050	1.023	0.970	1.046	1.114	1.023	1.133	1.059
15	1.031	1.045	1.222	0.937	1.049	1.024	0.968	1.048	1.116	1.024	1.139	1.061

4.8 Results

According to the results of three simulation of stream flow in the Xe Bang Fai river basin based on the scenarios of climate change were evaluated by running the calibrated hydrological model in the period 2001-2010, and applying the climate change factors of (IPSL CM5A-MR 2030), (GISS E2-R-CC 2030) and (GFDL CM3 2030).

In this study, the main spatial dataset and whole parameters as shown in (Chapter 3 including the land use/cover map, DEM, slope map and soil map) were preserved to use for forecasting surface runoff for the year 2030, which differences institutes studied the factors of climate change as shown in the results of Table 4.10, for instance as the monthly average changes in the Percentage Differenced rank of climate change factor are (-13.29 to 12.55) for IPSL CM5A-MR 2030 scenarios, the monthly average change of GISS E2-R-CC 2030 scenarios is generated in Percentage Differenced rank is (-2.28 to 13.95) and GFDL CM3 2030 scenario is as Percentage Differenced rank (1.18 to 20.75) respectively.

As the results as shown in Figure 4.8, the comparison of the monthly baseline and monthly scenarios flows in the Xebangfai@bridge station is observed that overall of the flows of hydrological scenario has increased at the middle of July until to the middle of September.

While in the middle of August in hydrograph is highest, which this peak nearly gives more than 1500 m^3/s (monthly mean) after middle of September of the hydrograph is fall down as shown in Figure 4.8. In hydrograph of three scenarios (IPSL CM5A-MR 2030, GISS E2-R-CC 2030 and GFDL CM3 2030), their scenarios are higher than baseline in rainy season. With the discharges result of the (IPSL CM5A-MR 2030) obtained is lower in the dry season (Feb-May), which it is lower than baseline and during the wet season is above than the baseline as shown in Figure 4.9.

The results of the three climate change scenarios are compared with baseline scenario processed by SWAT model, which contained factors of climate change by applying the original input baseline data are shown in Figures 4.7 and 4.8.

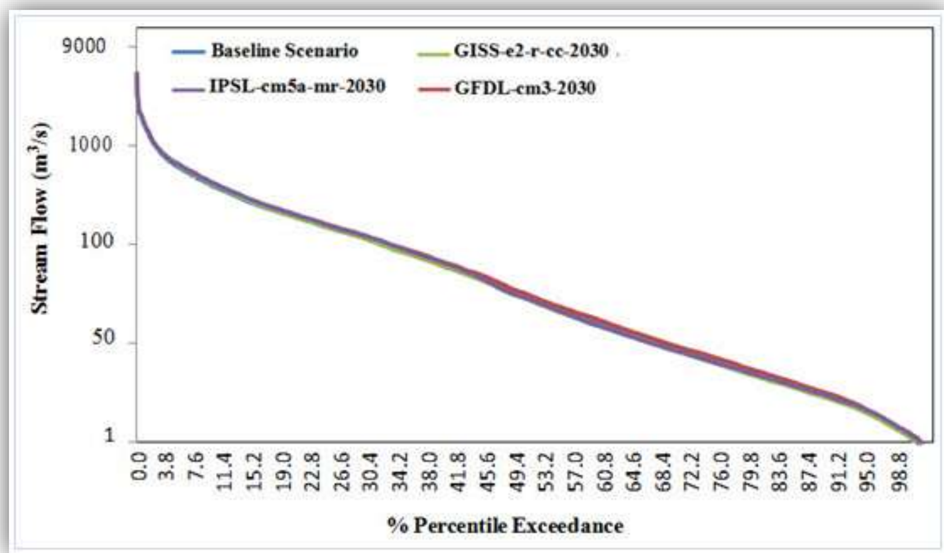


Figure 4.7 Comparing discharges of the climate change scenarios with baseline

The scenarios of (IPSL CM5A-MR 2030), (GISS E2-R-CC 2030) and (GFDL CM3 2030) were represented in the discharge of both wet and dry seasons. While the result of three scenarios, the (IPSL-CM5A-MR 2030) has provided lower discharges in the dry season (Feb-May) than the baseline scenario, as the end of the wet season is above the baseline scenario. The flow of climate change scenarios generated more than 800 m^3/s of the monthly (July, August, and September) with comparing the baseline scenario at Xebangfai@bridge station as shown in Table 4.10 and Figure 4.8. As the results, the cause of peak discharge during these months due to this area commonly is influenced from the southwest monsoon (wet season) in the middle of May to early October, which this is a dominant phenomena when air pressure is low-down beyond Asia. In addition to Lao PDR is influenced from heavy rainfall by citing some researches: Snidvongs *et al.* (2003); Eastham *et al.* (2008) and Västilä *et al.* (2010); SONNASINH (2009); MRC (2015). The severe change scenario is overall of three scenario as (IPSL CM5A-MR 2030), (GISS E2-R-CC 2030) and (GFDL CM3 2030), while the amount of monthly high surface runoff which the duration of the monthly high surface runoff also increases and expand until the first week of September. The stream flow comparison is given in Table 4.10 and Figure 4.8.

Table 4.10 Climate change scenarios, which effected in surface runoff.

Months	Monthly Scenarios Flow				Percentage Differences Compared to Baseline		
	Baseline Flow (m^3/s)	IPSL 2030 flow (m^3/s)	GISS 2030 flow (m^3/s)	GFDL 2030 flow (m^3/s)	% Difference of IPSL 2030	% Difference of GISS 2030	% Difference of GDFL 2030
Jan	18.72	19.15	18.63	18.94	2.30	-0.48	1.18
Feb	19.43	19.03	19.28	19.79	-2.06	-0.77	1.85
Mar	21.75	20.29	23.32	25.57	-6.71	7.22	17.56
Apr	29.43	25.52	28.67	29.72	-13.29	-2.28	0.99
May	95.53	88.65	98.85	105.79	-7.20	3.84	10.74
Jun	270.64	277.91	282.24	278.87	2.69	4.29	3.04
Jul	742.35	835.52	825.34	822.58	12.55	11.18	10.81
Aug	1463.23	1582.87	1518.9	1585.78	8.18	3.80	8.38
Sep	1263.19	1398.89	1338.08	1320.78	10.74	5.93	4.56
Oct	452.39	493.82	444.89	459.39	9.16	-1.66	1.55
Nov	57.36	58.54	65.36	69.26	2.06	13.95	20.75
Dec	23.25	24.05	23.37	23.75	3.44	0.52	2.15
	Annually Scenarios Flow				**% Annually Change**		
Annually	371.43	403.68	390.57	396.68	1.82	3.74	6.96

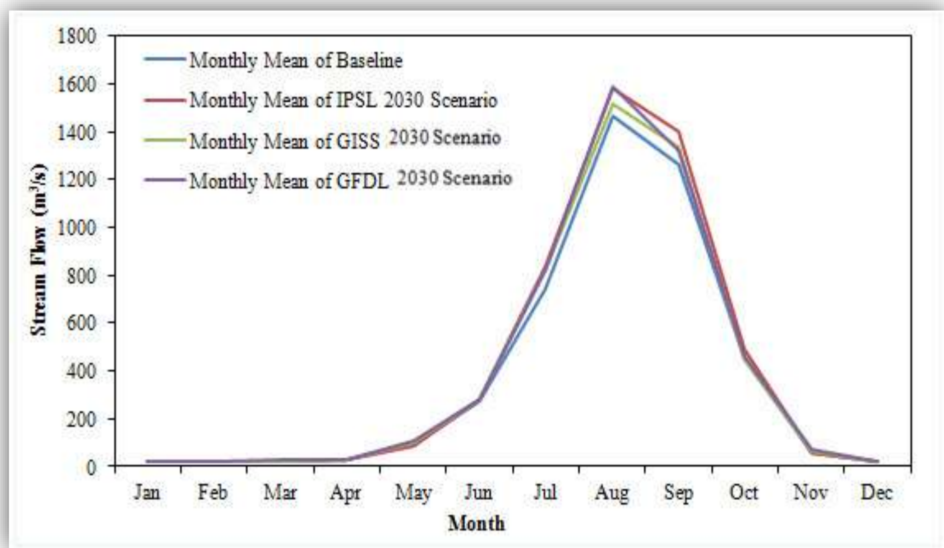


Figure 4.8 Comparing monthly changes in discharge of the Xebangfai@bridge station of the climate change scenarios with baseline scenario.

According to the results of Table 4.11 and Figure 4.9, they are found that in the starting point they response the information, and during the water resources availability in the dry season is very little throughout the years, which discharge lower than 20 m^3/s, which is able to extreme drought in this southern part of region, but during the wet season this region is under water.

As the Table 4.10 showed the stream flow of the Xe Bang Fai river basin for the year 2030 based on the future climate change factor of three institutes recommended river discharge taking into account the climate change is resulted in as well as in normal conditional distribution.

Table 4.11 Monthly averages of scenarios 2030 in the dry season of the Xebangfai@bridge station.

Dry Season	Monthly Mean of Baseline (m^3/s)	Monthly Mean of IPSL 2030 (m^3/s)	Monthly Mean of GISS (m^3/s)	Monthly Mean of GFDL (m^3/s)
Nov	57.36	58.54	65.36	69.26
Dec	23.25	24.05	23.37	23.75
Jan	18.72	19.15	18.63	18.94
Feb	19.43	19.03	19.28	19.79
Mar	21.75	20.29	23.32	25.57
Apr	29.43	25.52	28.67	29.72

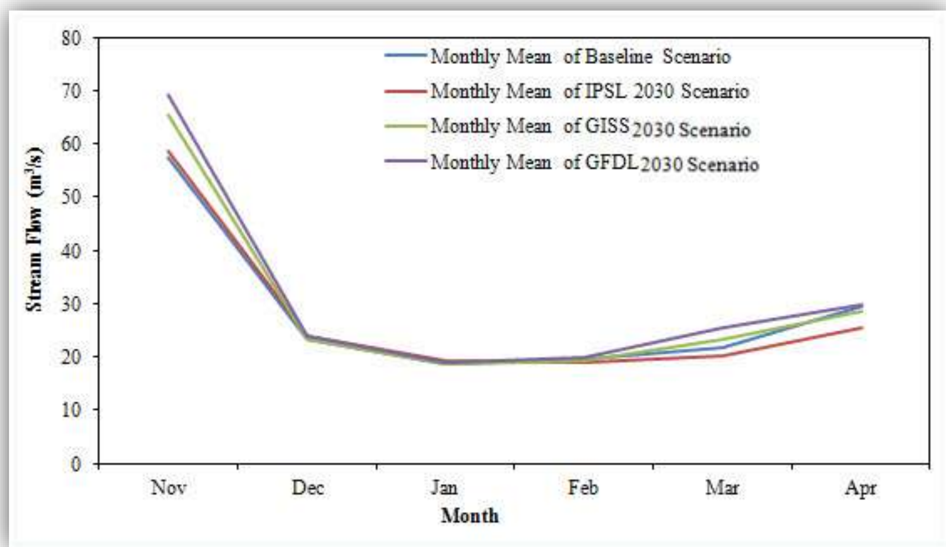


Figure 4.9 Monthly mean plots in the dry Season of overall scenarios and baseline.

4.9 Discussions

The impact of future climate change has a potential threat on water resources, which has become a subject debated globally for decades (Arnell, 1999). The variability of climate will effect to river runoff in the basin. Recently, IPCC's scientists study found that climate change has affected the operation and function of existent water foundation and water management (Parry, 2007). The previous researches of IPCC-Intergovernmental Panel on Climate Change on estimation of climate change impact on water resources (Bates *et al.*, 2008), with also a technical paper on climate change and water (Kundzewicz *et al.*, 2008). According to several researches provide a significant basis to understand the climate change impact on river watersheds. This research is the river discharge simulation based on the climate change scenarios in the Xe Bang Fai river basin by 2030, and estimates the uncertainty of future climate projections. The climate model was generated by RCP6.0 simulations from 4th intergovernmental Panel on Climate Change (IPCC) (IPCC, 2014) assessment to test how the climate is likely to change in the Xe Bang Fai river basin, and also the effect of change on water resources in basin. The model provides primary evaluation of the potential impact of these changes on water resources (Eastham *et al.*, 2008).

For comparing the river discharge change based on three climate change scenarios, the climate change model of three institutes, namely Institute Pierre-Simon Laplace (IPSL), NASA

Goddard Institute for Space Studies (GISS) and Geophysical Fluid Dynamics Laboratory (GFDL) were used for estimating river discharge change in 2030 (IPSL CM5A-MR 2030, GISS E2-R-CC 2030 and GFDL CM3 2030) (Sperber *et al.*, 2013). In this study, the three climate models (IPSL CM5A-MR 2030, GISS E2-R-CC 2030 and GFDL CM3 2030) were generated by RCP6.0 scenario based on cooperating between Mekong River Commission (MRC) and Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. The configuration of the Xe Bang Fai Sub-basin is identically from MRC SWAT sub-basin, which the climate change factors from the regional model were applied to the SWAT model of the Xe Bang Fai river basin. The data of change factors generated in the project were acquired in a feature that is agreeable with the clarification of change factors usable for SWAT models in MRC (MRC, 2014a). In these tables, overall of the factors were given by the Lao National Mekong Committees (LNMCs) working with Mekong River Commission. In this research indicates that the amount of river discharge in the Xe Bang Fai river basin is increase under 2030 climate change scenarios (IPSL CM5A-MR 2030, GISS E2-R-CC 2030 and GFDL CM3 2030). However, since the basin area and volume of water in the basin is small, the impact on river discharge and water availability in the Xe Bang Fai river basin downstream is probably to be significant for both during the period of rainy and dry season. Based on the three climate change scenarios in 2030, total annual runoff from the Xe Bang Fai river basin is likely to doubled increase more than 315 m^3/s of river discharges since before the NT2 began operating (Baird *et al.*, 2015). According to the three climate change scenarios, runoff increase of the Xe Bang Fai river is estimated for overall catchments, generally resulting from increased runoff during the rainy season. Runoff in dry season is predicted to remain the same or doubled its previous dry season discharge that has trended dramatic impacts, changing the stream's ecology and basically altering its relationship to local communities (Descloux *et al.*, 2016).

Therefore, this study on climate change impacts on hydrological response can be used as important information for quantifying sediment transportation and water quality analysis. In addition, the hydrological model can be used for water resources management and natural disaster protection, those of which are valuable for the sustainable development of the Lao PDR in the future.

4.10 Summary

In this study, the future three climate change scenarios (IPSL CM5A-MR 2030, GISS E2-R-CC 2030 and GFDL CM3 2030) are estimated the hydrological response in the Xe Bang Fai river basin in 2030 based on the set of exploratory climate change factors from Mekong River Commission (MRC) (MRC, 2014a). The statistical data of climate change is input to the SWAT model of the Xe Bang Fai river basin. The present-day monthly hydrographs are successfully calibrated and validated by using the SWAT model in the Xe Bang Fai river basin. The results are represented with the possible gauging the calibration and validation model for two periods as follows: 2001-2005 for calibration periods and 2006-2010 for validation periods. In this study, the results of the monthly baseline simulation R^2 and E_{NS} of river discharge in the Xe Bang Fai river basin are more than 0.9 during both of the calibration and validation period respectively.

The scenarios of climate change in this study are prosperously evaluated by applying the dataset of exploratory climate change factors from the related line-agency (LNMCs) working with Mekong River Commission supported. As MRC (2014a), the statistical data of climate change is applied to intake for the SWAT model in the Xe Bang Fai river basin. In the study, the results of the climate change scenarios were estimated under the calibrated hydrological model for the period 2001-2010, and also used the climate change factors of (IPSL CM5A-MR 2030), (GISS E2-R-CC 2030) and (GFDL CM3 2030) for forecasting surface runoff in the year 2030. Differences institutes studied climate change factor, for instance the average monthly changes in the Percentage differenced rank of climate change factor are (-13.29 to 12.55) for IPSL CM5A-MR 2030 scenarios, the monthly average change of GISS E2-R-CC 2030 scenarios is generated in Percentage Differenced rank is (-2.28 to 13.95) and GFDL CM3 2030 scenario is as Percentage Differenced rank (1.18 to 20.75) respectively. According to these results of climate change scenarios, the model will be used as preferable information for water resources management and natural disaster protection. In addition, the model is able to be applied as the standard for future studies on sediment yield estimation and water quality analysis. It also is able to be carried out to plan for flood disaster risk prevent, which is valuable for the sustainable development of the Lao PDR in the future.

Chapter 5. Conclusions

The effect of climate alteration on hydrological characteristic in the Xe Bang Fai river basin of Lao PDR was evaluated by applying hydrological data based on modeling. The study showed in distinct chapters which use statistical analysis at the inter-annual, season and situation-based time series, and continual long-term hydrological simulation.

In chapter 1 represents the hydrological background of the Xe Bang Fai river basin based on climate variation in Lao PDR, and suggests the study objectives etc.

In chapter 2 represents the study on trend analysis of climate change, especially focusing on precipitation and temperature in the Xe Bang Fai river basin of Lao PDR, in which it was implemented with annual and seasonal precipitation and temperature series data by applying the statistical analysis as Mann-Kendall test and Sen's Slope estimates method (MAKESENS). The study objective was to look for the effect of climate change and try to analyze an interaction between a trend of climate change and the current increase of natural disasters in particular flooding disaster. The increased trend of precipitation scales as shown in Figure 3.6 (a), (b), (c) and (d) was discovered in northern part of the Xe Bang Fai river basin at Signo, Thakhkek and Mahaxay station. In addition to the decreased trend of annual precipitation related to drought risk was discovered in the southern part of the Xe Bang Fai river basin at Ban Veun, Donghen and Xepon station. As the analysis results offer significant information for water resources management in the basin area.

In chapter 3 represents the study of hydrological modeling simulation in the sub-basin of the Mekong River Basin by using SWAT Model. The hydrological model was successfully calibrated and validated in the Xe Bang Fai river basin by applying SUFI-2 algorithm. In the SWAT model, the sensitivity analysis of the hydrological model, the discharge parameter is not sensitive, but also the parameter of HRUs delineation thresholds followed by sub-watershed continuous affectation. The result of study indicated that 716 HRUs are suitable in this basin, in which the represented SUFI-2 algorithm is be modified while simulating flow in the Xe Bang Fai river basin. The calibration and validation model are implemented in the two periods: 2001-2006 and 2007-2010. In this study, the results of the monthly simulation R^2 and E_{NS} are 0.970 and 0.967 during the calibration periods and also 0.966 and 0.960 during the validation period. The SWAT model can generate good simulation results of monthly time processes which they are valuable for water resources management in the Xe Bang Fai river basin as well as the whole sub-watershed in the Mekong River Basin. The model was already calibrated successfully. It can be applied for more analysis of climate variation and land use changes as well as other distinct management models on the hydrology.

In chapter 4 represents the calibration model was proceed by climate variation supported by the Mekong River Commission Tool (MRC Tool). In the study, three scenarios of climate change were selected to run the model during the period: 1993-2008 with the factors of climate change (IPSL CM5A-MR 2030, GISS E2-R-CC 2030 and GFDL CM3 2030) to set the surface runoff for the 2030-year periods. Various research institutes studied the factors of climate variation, for instance IPSL CM5A-MR 2030, GISS E2-R-CC 2030 and GFDL CM3 2030, which represented the discharge in both dry season and wet season. In the study, the results of IPSL 2030, the discharges in the dry season (Feb-May) are lower than the baseline, while the end of the wet season is above the baseline. The scenarios of climate variation produced more 800 m^3/s for the months including July, August and September as baseline of the Xebanfai@bridge station. The cause of the peak discharge in these months is the effect of southwest monsoon, commonly affects the watersheds from middle of May to early October (wet season). This situation is predominant when air pressure is low through Laos and result in heavy rainfall (Snidvongs *et al.*, 2003; Eastham *et al.*, 2008) and (Västilä *et al.*, 2010; SONNASINH, 2009; MRC, 2015). The severe variation was found with the overall scenario of (IPSL CM5A-MR 2030), (GISS E2-R-CC 2030) and (GFDL CM3 2030), which causes the high volume monthly runoff, raises the large monthly runoff duration and expands the large runoff season until the first week on September. The results of climate variation model's scenarios can be used for better information in future researches.

With overall of the results given in this study improve knowledge of climate change effects on hydrological system in Laos. These results in this study can be applied to plan on water resources management and national disaster protection and mitigation in the future. Moreover, the study offers valuable information to plan for developing hydropower project and flood disaster risk reduction, which it is essential for the sustainable development in this country. Now, Lao's government has focused on the reduction of severe events from disaster dangers, especially floods and droughts. Due to Lao's government understands the potential impact of climate change as intimately associated with disaster management and also the emergence of server happens such as floodwaters and drought. Mostly emphasizing with disaster management, it is one of the key policies of Laos' government for dealing with climate change, due to relationship between climate and disaster is absolute situation, which the neglecting to increase effects of climate change is serious.

For results of this study on effects of climate change on hydrological response, the model obtained will be contributed to local and national level framework based on Lao's government strategy in 2016-2020 regarding to adaptation on climate change as itemized in the Appendix 2. The Lao's government in 1995 ratified the UNFCCC and Laos also succeeded the Initial National

Communication (INC) in 2011 and in 2013 Laos ratified the Kyoto Protocol. According to the National Adaptation Plan of Action (NAPA) of Laos consists of 45 priority projects, which has total budget (US$ 85 million) within 4 main sectors for climate change adaptation, including forestry, water resources, agriculture and health (WREA, 2010).In addition to Laos approved a National Strategy on Climate Change (NSCC) in 2010. There are seven priority sectors in Laos's infrastructure for mitigation and adaptation under the Laos NSCC including water resources, forestry and land use change, agriculture and food security, urban development, industry, energy and transportation and public health (Nam, 2011). The National Adaptation Programmes of Action (NAPAs) was established to become a central part of the Laos NSCC. The overall purpose of the Laos NSCC is to assure that climate change will be approved into Lao's 7th National Social-Economic Development Plan (2011-2015) and 8th National Social-Economic Development Plan (2016-2020).

Commonly, the technology requires estimation for climate variation mitigation was carried out even though associated process with the criteria application, scoring and approaches of stakeholders consultation. Overall, the estimation is subdivided into two main steps; sector selection and prioritization of mitigation technology in the elected sectors. In assessment process, the selection of sector was implemented throughout the selection of initial sector; the situation reviews and emissions trend and then checked out with workshop on the consultation of sector selection. The selection of initial sector as well as the emissions review and trends mostly emphasized on reconsider and summary of the emissions and trends illustrated in the Second National Communication on Climate Change-SNC and the Strategy on the Climate Change of the Lao PDR-SCC (MONRE, 2012) and National Socioeconomic Development Plan of the Lao PDR 2011-2015 (MPI, 2011) along with plans on sectoral development and the results of the review is key documentations for stakeholders and intakes for sector selection. The sector selection fundamentally purposes to select two priority sectors for the estimation. In the process, multi-criteria and scoring were used with consultation approach to understand the priority sector, especially water resource. In addition to the prioritization of advanced technology in the water sector was implemented throughout the review of available mitigation technologies in the workshop on technology prioritization. The review of the mitigation technologies emphasized on the advanced technologies that were specifically assigned in the Strategy on the Climate Change of the Lao PDR (SCC) and the Initial and Second National Communication on Climate Change (MONRE, 2010). Recently, Laos' government conducted the strategy on the climate change adaptation, especially climate change impact on water resources based on multi-criteria and available mitigation technologies with supporting from international organizations. The adaptation technologies for water sector were implemented, including Early Warning System, Disaster Impact Reduction Fund and River Basin or Watershed Management.

(1) *Early Warning System* is mainly pre-requirement for flood protection. It related to installation on weather forecast system, modeling of river discharge, water observations and dissemination tools information for providing the information to people in Laos. In addition improvement of preparedness and recovery plan for reducing effects that would be caused by severe occurrence, especially flood. The technology of warning system is used in Laos by numerous stakeholders, but this technology could not systematically operated, because of lacking financial support, skill and knowledge on this system in particular tools and equipments. Nonetheless, this is the country priority as assigned on the Strategy on Climate Change of the Lao PDR (MONRE, 2010) based on National Disaster Management Master Plan, the Social Economic Development Plan (2011-2015) (MPI, 2011) etc. With the warning system efficiently, the government is expected that the effects caused from disasters, especially flood, for instance flash flood could be decreased that lead to protection of people life and properties from losses.

(2) *Disaster Impact Reduction Fund* is to support to the early warning system, impact reduction or disaster management fund was be set up by Laos' government. In the past, the recovery fund after natural disasters were inadequate, because of the fund mobilization was on specific purpose and also lacked a management mechanism,

which lead to be the big problem when the disaster happened. Therefore, the particular fund is required for adding the protection effectiveness and disaster management in well-timed method. The management of natural disaster has to consist of increasing fund and management mechanism, indubitable networks and organizations in overall rank as from central to local level. With the efficient fund and mechanism, we are expected that natural disaster effects in particular flood can be mostly decreased while the adaptable capability is able to be improved in the future.

(3) *River Basin or Watershed Management* is an important for social economic and environment development, along with climate change adaptation. To ensure that water resource and social economic and environment development are sustainable, the implemented tools have to be efficient. Lately, Integrated Water Resources Management (IWRM) that contained associated techniques and multi-disciplinary is generated as a key tool for understanding such sustainability, especially climate change adaptation. Likewise, the strategy on water resources management in Laos as well assigned to use IWRM for overall watershed and river basin management. Currently, there are some pilot project initiatives on the usage of IWRM for Nam Theun-Kading and Nam Ngum river basin. Currently, by 2015, there are at least 5 river basins, namely Nam Ou, Sebangfai, Sebanghieng, Sedone and Sekong will be succeeded their IWRM and management committee. Consequently, the prioritization of technology identifications

supports implementation of water resources policy, including nutrition and food security, misuse reduction, renewable energy development, environmental, climate change adaptation and mitigation.

In conclusion, however, Lao PDR already have strategies and national policies associated with adaptation on climate change, but almost overall of this framework are relatively new and they remain in the procedure of being assigned and refined, especially an elaborated analysis regarding setting adaptation policy is practically impossible in the moment. Moreover, national strategies of adaptation, regional initiatives and programmes for adapting climate change in the whole Mekong River existence. For instance, more regional initiative is the Adaptation Initiative on Climate Change in the Mekong River Commission, which it was established on 2008. The distinct regional methods and programmes were argued in more detail in the Interim Report of this project (TKK and SEA START RC 2008). Currently, overall countries in Lower Mekong Basin have ratified both of the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol. Each country has a fundamental policy document which designs its strategy and responses to climate change. Recently, Lao's government has pointed to disaster management which it is a responsibility of the Department of Climate Change and Disaster Management under Ministry of Natural Resources and Environment (MoNRE). Thus, the Department of Climate Change and Disaster Management is in charge of the formulation and implementation of climate change policy in Lao PDR. For the agreement on Laos Climate Change Action Plan, MoNRE has already submitted to the United Nations Framework Convention on Climate Change in 2015 (Appendix 2), which it is the responsibility regarding constant concentrations of greenhouse gas (GHG) in the atmosphere to against serious human intervention with the climate system of earth.

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국문 초록

보정된 수문모델은 기후변화와 지표피복변화가 하천의 유량과 수질, 그리고 하천퇴적물의 양에 미치는 영향을 정량적으로 파악할 수 있는 수단이 된다. 라오스 중부에 위치한 시방파이(Xe Bang Fai) 유역(10,064 km^2)은 태풍의 영향권에 놓여 있으며, 여름철은 높은 강우강도로 인해 매년 주기적인 범람의 위험을 안고 있다. 특히 현재 진행되고 있는 기후변화로 인해 태풍의 빈도와 강도가 크게 변할 것으로 예상되기 때문에 홍수로 인한 피해의 위험성은 점차 높아지고 있다. 이 연구의 목적은 Soil and Water Assessment Tool (SWAT) 모델을 이용하여 예상되는 기후변화 시나리오에 따라 하천유량에 미치는 영향을 예측하는 것이다. 이 연구에서 SWAT 모델은 2001 년과 2005 년 사이 기후 및 유량자료를 통해 보정하였으며, 2006 년과 2010 년의 예측치와 실측치 비교를 통해 검증하였다. 모의한 월별 유량과 실제 측정된 유량간의 일치도는 R^2 값이 0.9 (E_{NS} > 0.9)를 넘어 모델의 예측력이 높은 것으로 나타났다. 세 개의 기후모델(IPSL CM5A-MR 2030, GISS E2-R-CC 2030 and GFDL CM3 2030)은 현재 진행되고 있는 기후변화로 인해 가까운 미래인 2030 년에는 여름 몬순기간 동안 강우량이 약 10% 증가할 것으로 예측된다. 이 경우 우기인 7 월과 9 월 사이 시방파이 다리 부근에서 관측되는 하천의 유량은 현재보다 약 800 m^3/s 정도 증가할 것으로 예측되었다. 이 연구에서 보정된 SWAT 모델은 향후 홍수저감과 라오스의 지속가능한 발전정책의 수립에 효과적으로 사용될 것으로 기대된다.

주요어: 기후변화, 수문모델, SWAT 모델, 시방파이 유역(Xe Bang Fai), Mann-Kendall and Sen's Slope, 추세분석, IPCC.

학 번: 2013-31271

Appendix 1

Results of Mann-Kendall Test and Sen's Slope Estimates.

Itemization of Results

The statistical computations of trend are itemized on the result tables. The results are given for each time series data as shown in the table below:

1. **Mann-Kendall test Z:**

- **Time series**: the names of the time series are derived (from the Annual data).
- **First year**: starting year of each time series (from the Annual data).
- **Last year**: ending year of each time series (from the Annual data).
- **n**: the number of annual values in the calculation excluding missing values (from the Annual data).
- **Test S**: If n is 9 or less, the test statistic S is displayed. The absolute value of S is compared to the probabilities of the Mann-Kendall non-parametric test for trend to define if there is a monotonic trend or not at the level α of significance. A positive (negative) value of S indicates an upward (downward) trend. In n is larger than 9, this cell is empty.
- **Test Z**: If n is at least 10, the test statistic Z is displayed. The absolute value of Z is compared to the standard normal

cumulative distribution to define if there is a trend or not at the selected level α of significance. A positive (negative) value of Z indicates an upward (downward) trend. If n is 9 or less, this cell is empty.

– **Signific**: the smallest significance level α with which the test shows that the null hypothesis of no trend should be rejected. If n is 9 or less, the test is based to the S statistic and if n is at least 10, the test is based to the Z statistic (normal approximation).

For the four tested significance levels the following symbols are used in the template:

***	if trend at α = 0.001 level of significance
**	if trend at α = 0.01 level of significance
*	if trend at α = 0.05 level of significance
+	if trend at α = 0.1 level of significance

In case the cell is empty, the significance level is greater than 0.1.

2. Sen's slope estimate Q:

The Sen's estimator for the true slope of linear trend i.e. change per unit time period (in this case a year)

– ***Qmin99***: the lower limit of the 99 % confidence interval of Q (α = 0.1)

– ***Qmax99***: the upper limit of the 99 % confidence interval of Q (α = 0.1)

– ***Qmin95***: the lower limit of the 95 % confidence interval of Q (α = 0.05)

- *Qmax95*: the upper limit of the 95 % confidence interval of Q (α = 0.05)

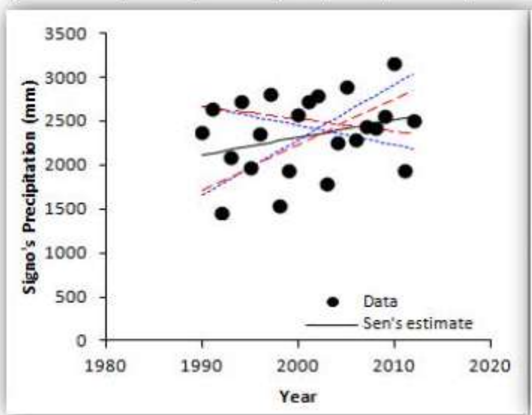
3. *B*: estimate of the constant *B* in equation "*f*(year)=*Q*∗(year-firstYear)+ *B*" for a linear trend

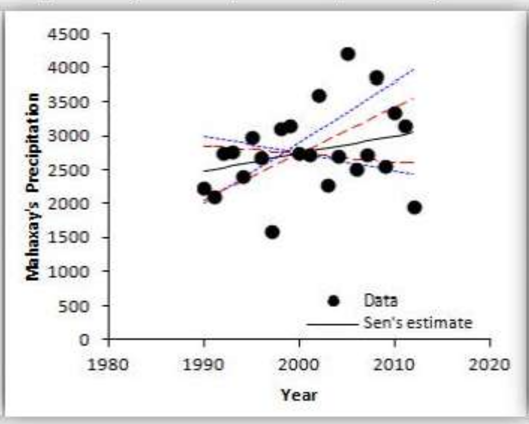
- *Bmin99*: estimate of the constant *Bmin99* in equation "*f*(year)=*Qmin99*∗(year-firstYear)+ *Bmin99*" for 99% confidence level of linear trend
- *Bmax99*: estimate of the constant *Bmax99* in equation "*f*(year)=*Qmax99*∗(year-firstYear)+ *Bmax99*" for 99% confidence level of linear trend:
- Bmin95: estimate of the constant Bmin95 in equation "*f*(year)=*Qmin95*∗(year-firstYear)+ *Bmin95*" for 95% confidence level of a linear trend:
- *Bmax95*: estimate of the constant *Bmax95* in equation "*f*(year)=*Qmax95*∗(year-firstYear)+ *Bmax95*" for 95% confidence level of a linear trend

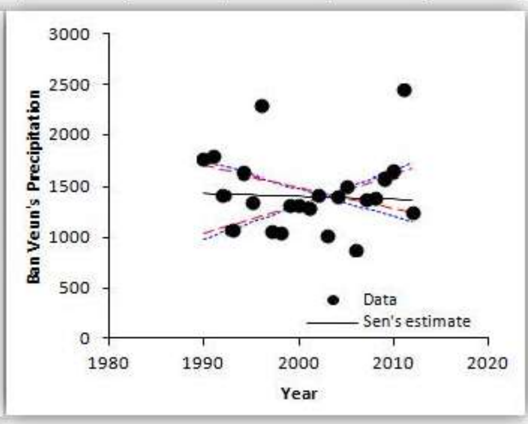
A.1 Mann-Kendall Test and Sen's Slope Estimates of Total Annual Precipitation

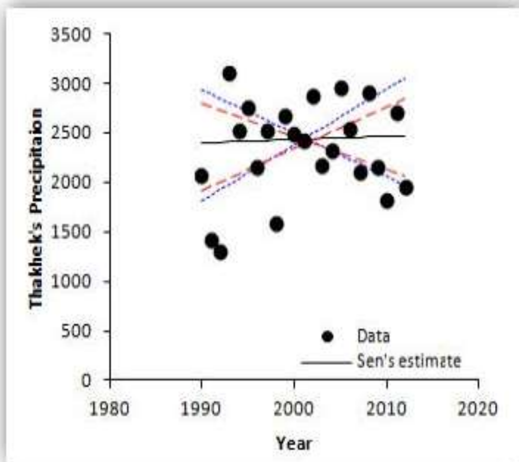
Mann-Kendal Trend test   Sen's Slope estimate

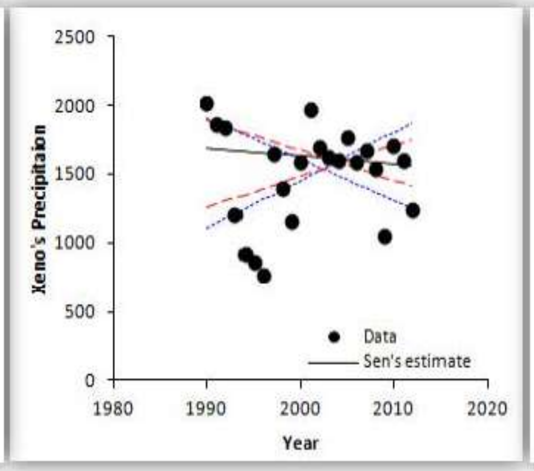
Time series	First year	Last year	n	Test S	Test Z	Signific.	Q	Qmin99	Qmax99	Qmin95	Qmax95	B	Bmin99	Bmax99	Bmin95	Bmax95
Signo	1990	2012	23		1.06		19.688	-22.034	62.736	-13.864	52.057	2055.55	2736.14	1468.12	2703.45	1553.54
Mahaxay	1990	2012	23		1.16		25.820	-25.840	88.886	-12.122	68.509	2404.33	3082.76	1745.45	2890.71	1849.38
Ban Veun	1990	2012	23		-0.21		-2.850	-26.833	33.726	-20.690	28.656	1440.95	1824.59	876.86	1759.33	947.47
Thakhek	1990	2012	23		0.21		3.311	-43.981	56.603	-33.440	42.126	2386.64	3068.75	1640.55	2900.19	1791.87
Xeno	1990	2012	23		-0.48		-5.831	-29.789	34.891	-21.621	22.421	1704.31	1993.03	998.66	1952.10	1189.91
Donghen	1990	2012	23		-0.66		-6.856	-28.142	24.044	-23.411	14.507	1844.28	2046.42	1472.21	1971.64	1597.93
Xepon	1990	2012	23		-1.90	+	-1.902	-57.546	18.786	-50.437	1.240	2074.13	2699.92	1572.71	2566.94	1754.50

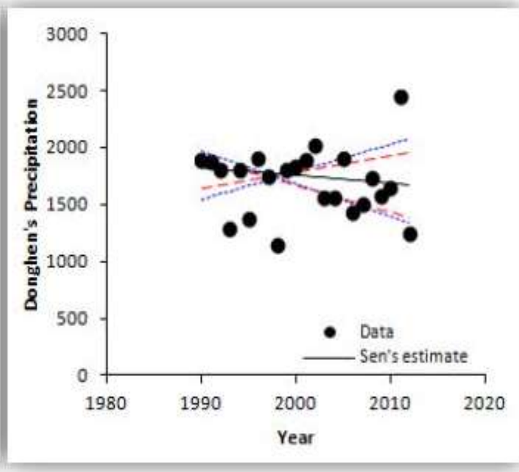


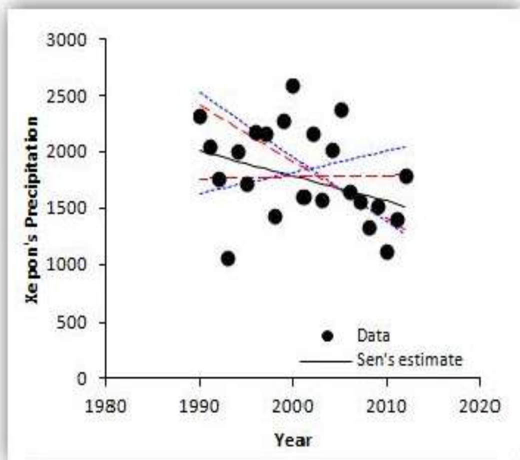





Thakhek's Precipitaion
3500
3000
2500
2000
1500
1000
500
0
1980
1990
2000
2010
2020
Year
Data
Sen's estimate


Xeno's Precipitaion
2500
2000
1500
1000
500
0
1980
1990
2000
2010
2020
Year
Data
Sen's estimate

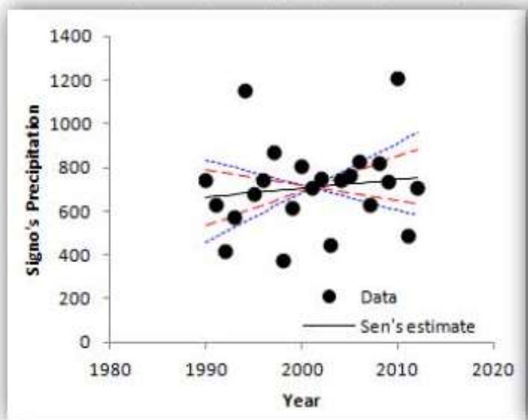

Donghen's Precipitation
3000
2500
2000
1500
1000
500
0
1980
1990
2000
2010
2020
Year
Data
Sen's estimate

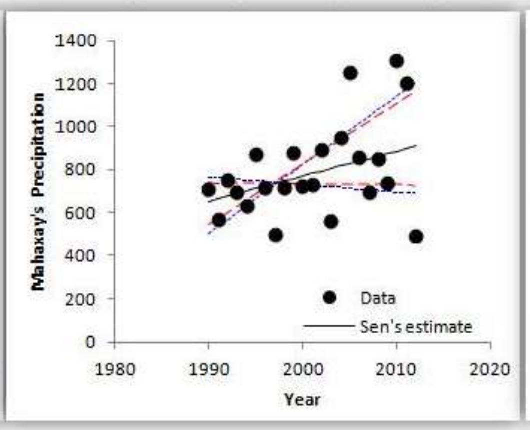

Xepon's Precipitation
3000
2500
2000
1500
1000
500
0
1980
1990
2000
2010
2020
Year
Data
Sen's estimate

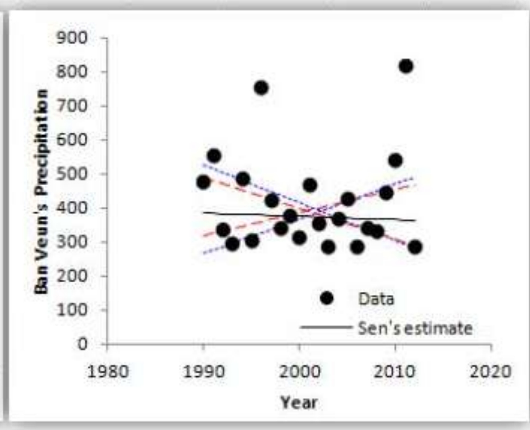
A.2 Mann-Kendall Test and Sen's Slope Estimates of Annual Maximum Monthly Precipitation

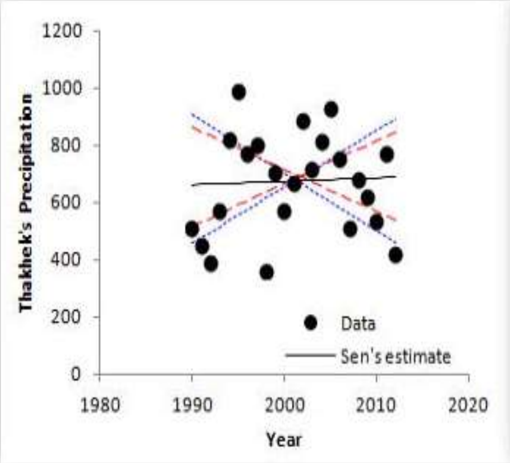
Mann-Kendal Trend test **Sen's Slope estimate**

Time series	First year	Last year	n	Test S	Test Z	Signific.	Q	Qmin99	Qmax99	Qmin95	Qmax95	B	Bmin99	Bmax99	Bmin95	Bmax95
Signo	1990	2012	23		0.85		4.000	-11.523	22.675	-6.954	16.043	653.00	870.32	391.55	810.58	484.40
Mahaxay	1990	2012	23		1.85	+	11.667	-3.539	32.027	-0.516	28.434	617.00	774.01	406.81	739.23	454.26
Ban Veun	1990	2012	23		-0.45		-1.000	-11.112	10.305	-9.040	6.811	388.00	559.90	234.17	515.40	297.16
Thakhek	1990	2012	23		0.11		1.250	-20.270	19.784	-14.667	14.972	657.75	967.89	397.02	907.00	472.08
Xeno	1990	2012	23		0.08		0.333	-10.046	12.929	-7.699	9.919	432.67	543.14	214.50	524.98	268.06
Donghen	1990	2012	23		-0.16		-2.000	-16.451	13.125	-11.976	9.440	502.00	735.06	350.25	677.69	392.68
Xepon	1990	2012	23		-1.29		-6.190	-24.126	8.252	-18.000	3.822	585.95	902.77	398.22	787.00	482.38

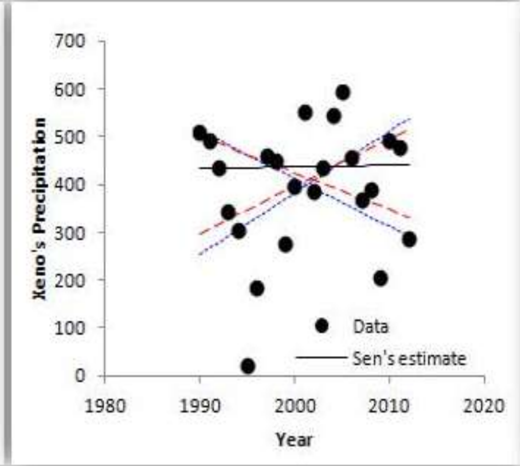




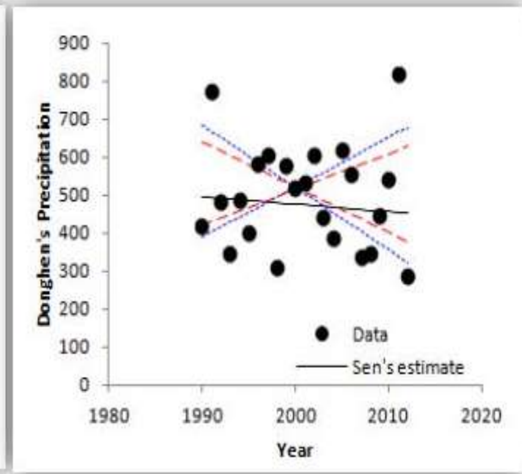




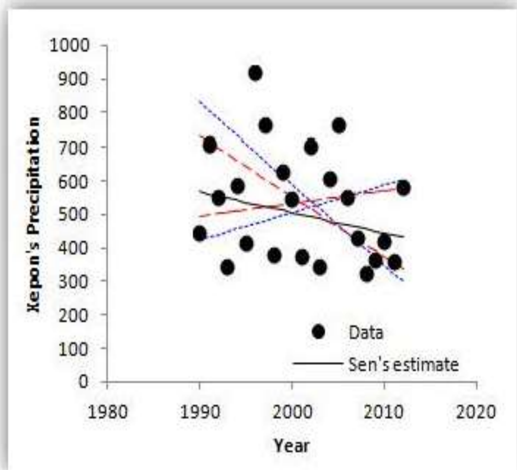
Thakhek's Precipitation
Data
Sen's estimate
Year



Xeno's Precipitation
Data
Sen's estimate
Year



Donghen's Precipitation
Data
Sen's estimate
Year

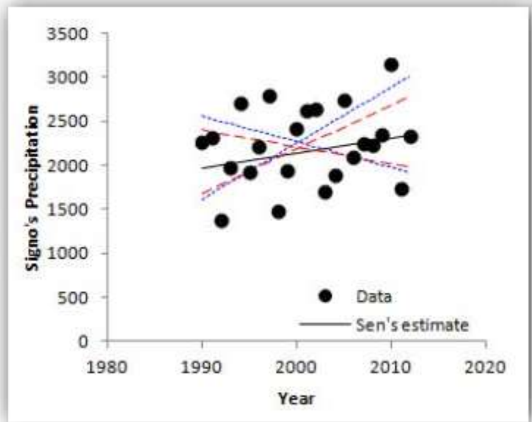


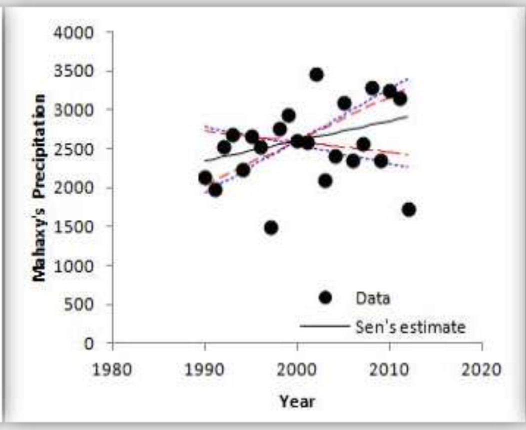
Xepon's Precipitation
Data
Sen's estimate
Year

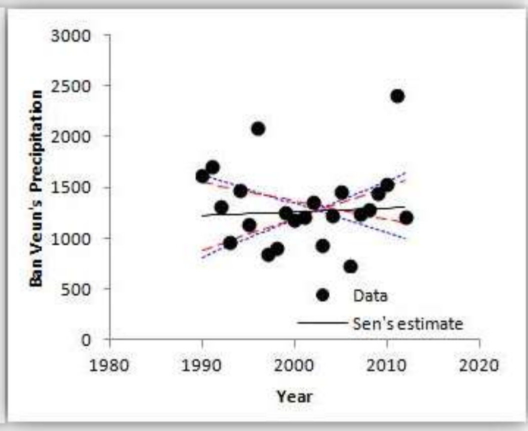
A.3 Mann-Kendall Test and Sen's Slope Estimates of Total Annual Precipitation in Wet Season

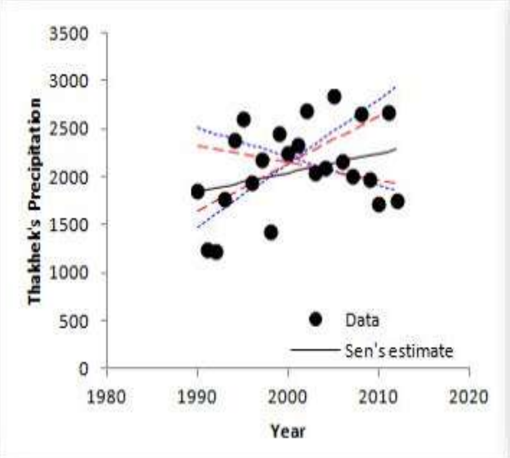
Mann-Kendal Trend test **Sen's Slope estimate**

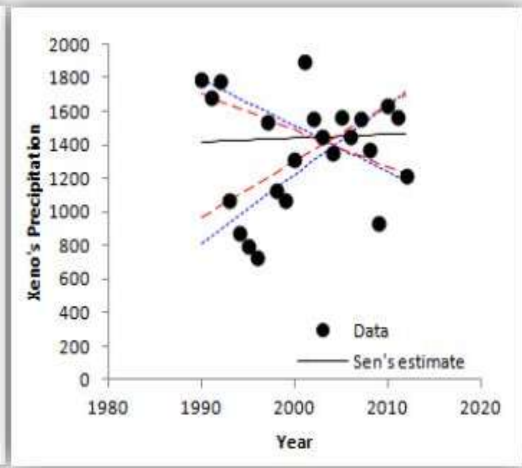
Time series	First year	Last year	n	Test S	Test Z	Signific.	Q	Qmin99	Qmax99	Qmin95	Qmax95	B	Bmin99	Bmax99	Bmin95	Bmax95
Signo	1990	2012	23		0.79		17.000	-29.041	63.495	-19.144	50.113	1913.40	2647.59	1424.04	2459.53	1531.09
Mahaxay	1990	2012	23		1.21		25.489	-23.606	66.387	-13.381	56.764	2270.64	2854.85	1738.97	2766.28	1864.07
Ban Veun	1990	2012	23		0.21		3.775	-28.638	37.190	-18.295	31.193	1211.43	1714.81	704.65	1607.80	788.60
Thakhek	1990	2012	23		1.06		20.100	-29.611	66.304	-18.120	49.739	1781.50	2598.48	1276.01	2384.35	1489.27
Xeno	1990	2012	23		0.26		2.190	-27.389	41.248	-21.729	33.451	1411.39	1872.17	686.89	1771.92	866.22
Donghen	1990	2012	23		-0.26		-1.208	-22.824	28.894	-21.088	20.562	1607.46	1859.41	1254.06	1843.79	1337.38
Xepon	1990	2012	23		-1.48		-20.143	-51.258	13.951	-43.692	3.234	1833.44	2347.58	1463.39	2256.46	1599.34

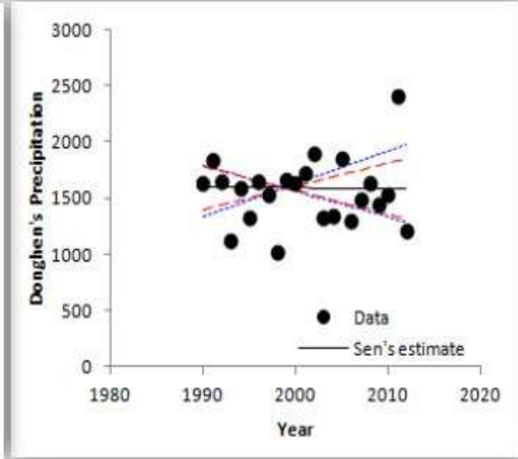


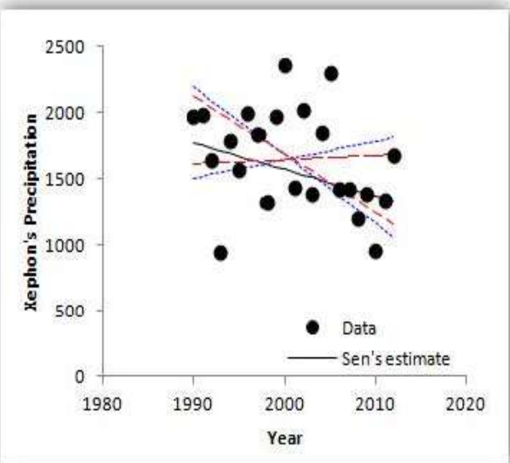





Thakhek's Precipitation
Year
Data
Sen's estimate


Xeno's Precipitation
Year
Data
Sen's estimate

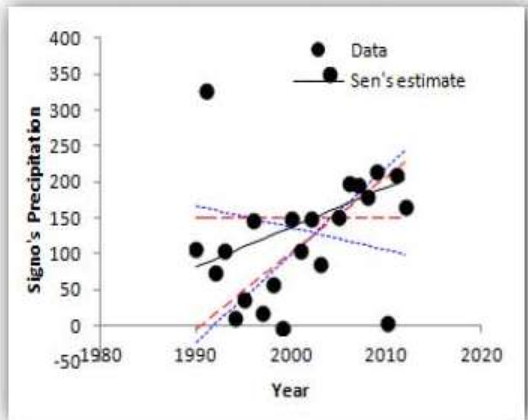

Donghen's Precipitation
Year
Data
Sen's estimate

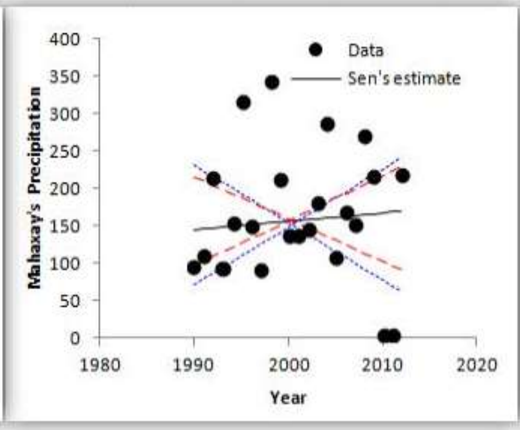

Xephon's Precipitation
Year
Data
Sen's estimate

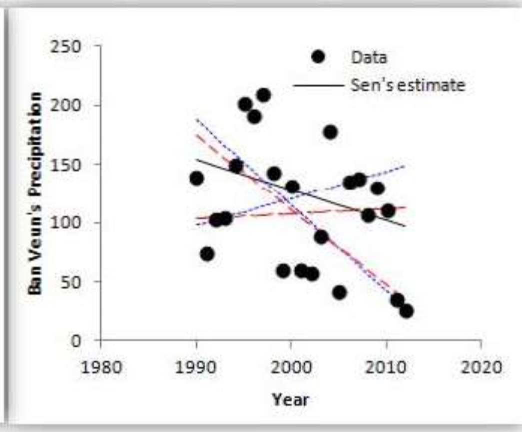
A.4 Mann-Kendall Test and Sen's Slope Estimates of Total Annual Precipitation in Dry Season

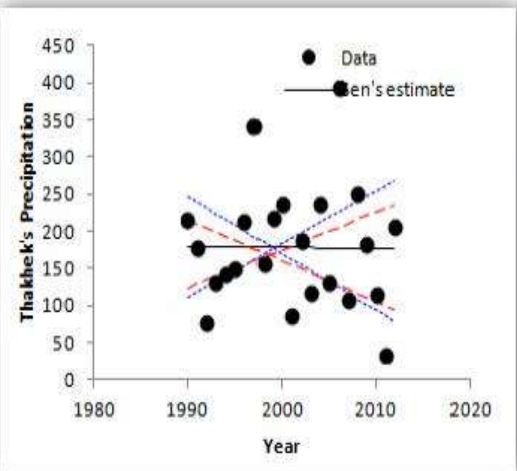
Mann-Kendal Trend test   Sen's Slope estimate

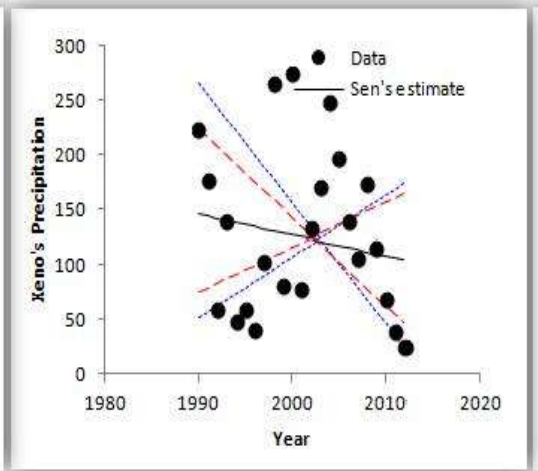
Time series	First year	Last year	n	Test S	Test Z	Signific.	Q	Qmin99	Qmax99	Qmin95	Qmax95	B	Bmin99	Bmax99	Bmin95	Bmax95
Signo	1990	2012	23		1.93	+	5.536	-3.082	12.130	-0.054	10.580	64.94	176.74	-59.04	149.49	-36.33
Mahaxay	1990	2012	23		0.37		1.109	-7.682	7.731	-5.645	6.021	142.02	254.41	48.62	232.87	78.94
Ban Veun	1990	2012	23		-1.74	+	-2.600	-7.296	2.318	-6.386	0.439	161.70	210.21	90.59	194.20	101.86
Thakhek	1990	2012	23		-0.05		-0.167	-7.624	7.154	-5.510	5.096	180.67	269.92	89.87	232.53	108.33
Xeno	1990	2012	23		-0.79		-1.850	-10.898	5.538	-8.053	4.066	151.10	298.54	35.07	248.16	63.05
Donghen	1990	2012	23		-2.17	*	-5.200	-11.661	1.115	-9.921	-0.657	209.00	314.96	107.73	274.13	140.49
Xepon	1990	2012	23		-1.43		-3.208	-11.622	3.009	-9.264	1.125	200.38	361.04	106.96	313.88	125.42

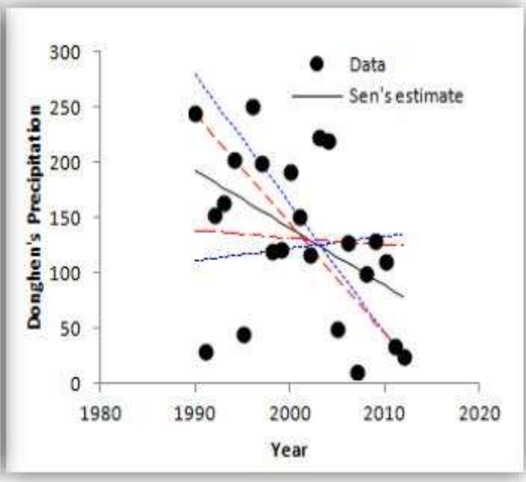


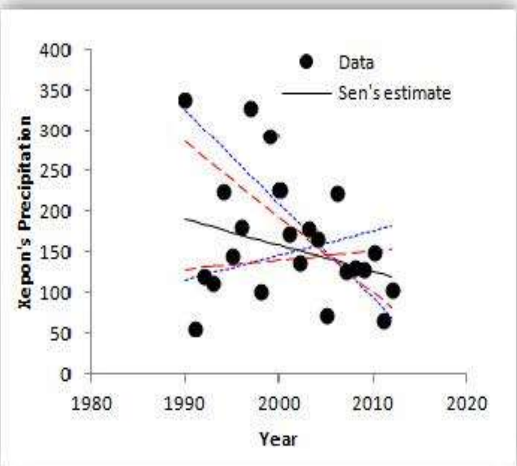





Data
Sen's estimate
Thakhek's Precipitation
Year


Data
Sen's estimate
Xeno's Precipitation
Year

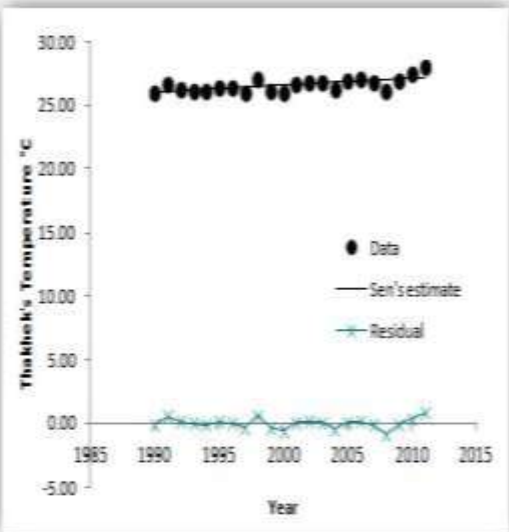

Data
Sen's estimate
Donghen's Precipitation
Year

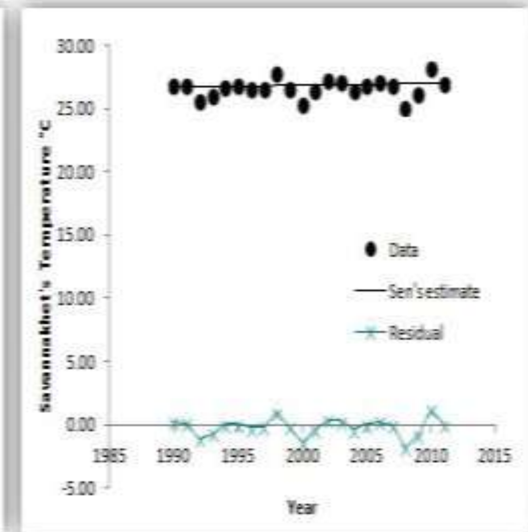

Data
Sen's estimate
Xepon's Precipitation
Year

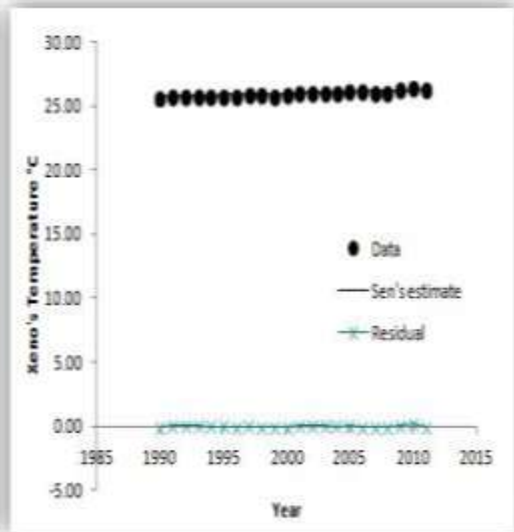
A.5 Mann-Kendall Test and Sen's Slope Estimates of Annual Mean Temperature

Mann-Kendal Trend test   Sen's Slope estimate

Time series	First year	Last year	n	Test S	Test Z	Signific.	Q	Qmin99	Qmax99	Qmin95	Qmax95	B	Bmin99	Bmax99	Bmin95	Bmax95
Thakhek	1990	2011	22		2.876	**	0.054	0.011	0.085	0.020	0.077	25.88	26.44	25.51	26.32	25.61
Savannakhet	1990	2011	22		0.790		0.014	-0.039	0.087	-0.030	0.063	26.64	27.07	25.55	26.99	25.91
Xeno	1990	2011	22		5.470	***	0.027	0.020	0.034	0.022	0.032	25.61	25.68	25.54	25.66	25.56



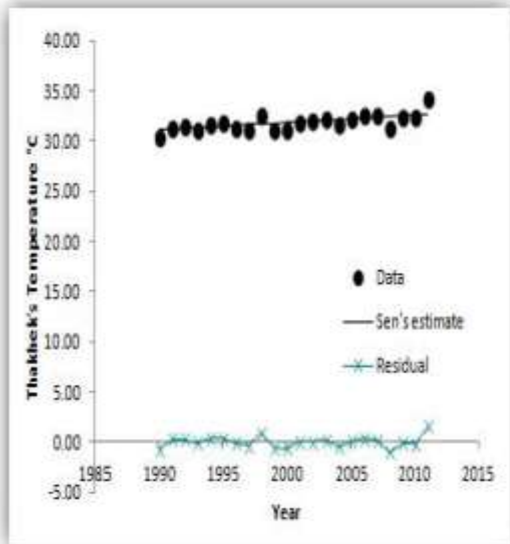


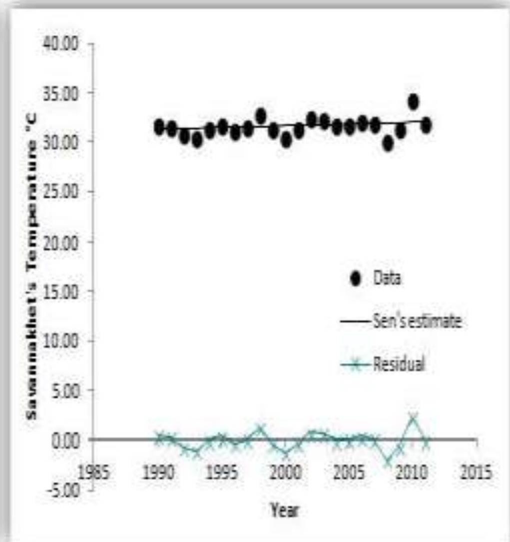


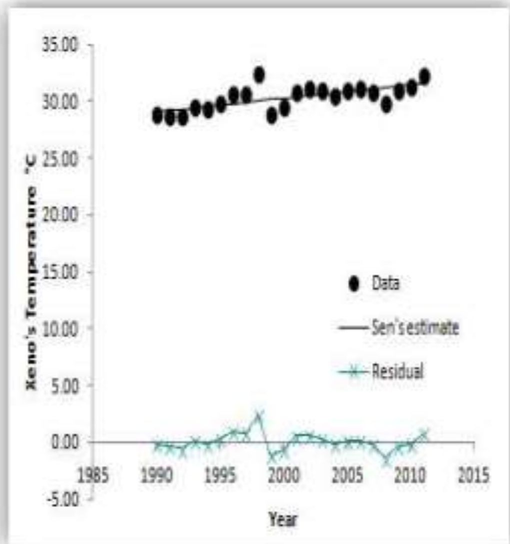
A.6 Mann-Kendall Test and Sen's Slope Estimates of Annual Monthly Maximum Temperature

Mann-Kendal Trend test Sen's Slope estimate

Time series	First year	Last year	n	Test S	Test Z	Signific.	Q	Qmin99	Qmax99	Qmin95	Qmax95	B	Bmin99	Bmax99	Bmin95	Bmax95
Thakhek	1990	2011	22		3.271	**	0.075	0.026	0.138	0.041	0.123	30.86	31.54	29.97	31.36	30.18
Savannakhet	1990	2011	22		1.523		0.035	-0.046	0.120	-0.017	0.088	31.18	32.13	30.03	31.78	30.37
Xeno	1990	2011	22		3.553	***	0.119	0.035	0.190	0.044	0.174	28.71	30.16	27.88	29.97	28.14



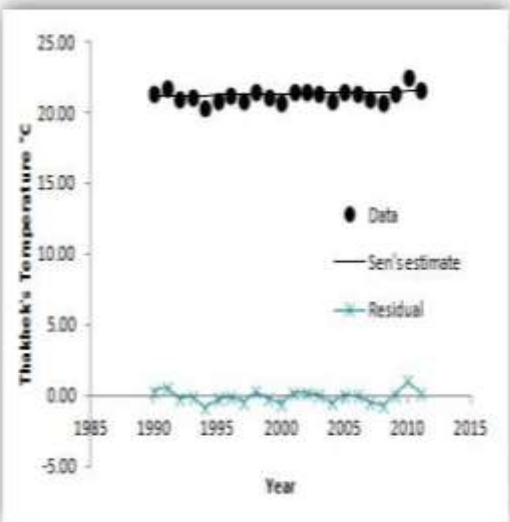


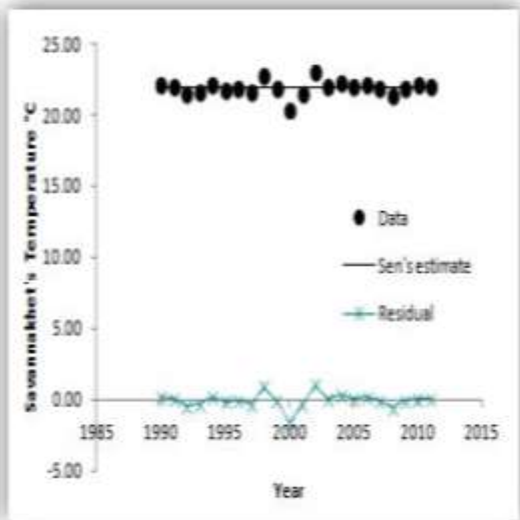


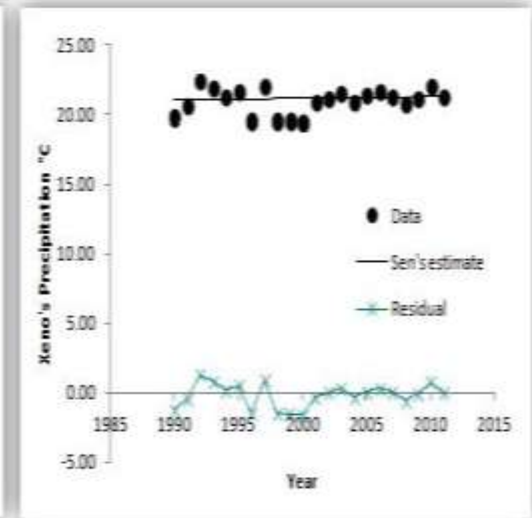
A.7 Mann-Kendall Test and Sen's Slope Estimates of Annual Monthly Minimum Temperature

Mann-Kendal Trend test   Sen's Slope estimate

Time series	First year	Last year	n	Test S	Test Z	Signific.	Q	Qmin99	Qmax99	Qmin95	Qmax95	B	Bmin99	Bmax99	Bmin95	Bmax95
Thakhek	1990	2011	22		0.846		0.016	-0.025	0.061	-0.017	0.051	21.09	21.53	20.41	21.45	20.55
Savannakhet	1990	2011	22		0.678		0.005	-0.036	0.037	-0.016	0.028	21.86	22.33	21.39	22.16	21.52
Xeno	1990	2011	22		0.423		0.012	-0.059	0.133	-0.041	0.108	20.95	22.02	18.93	21.82	19.38







Appendix 2

Lao People's Democratic Republic
Peace Independence Democracy Unity Prosperity

Ministry of Natural Resources and Environment (MoNRE)

Vientiane, 01 October 2015

Ms. Christiana Figueres
Executive Secretary
UN Climate Change Secretariat
Bonn
Germany

Subject: Submission of INDC of the Lao PDR.

Excellency,

On behalf of the government of Lao PDR, in my capacity as a UNFCCC Focal Point, we are pleased to submit the INDC of Lao PDR, which has been approved in principle by our government Cabinet and is pending the final approval. In case that the Cabinet adopts the INDC that is different in content to the submitted copy, the new version will be submitted immediately. For the time being, this INDC is our official document and we hope to be featured in the global synthesis report.

We would like to express our appreciation and sincere thanks to the UNFCCC for continued support in the preparation of our INDC. We would like to ensure you of our commitment to work together with our development partners towards the implementation of the Convention in Lao PDR.

We would like to thank you for your kind consideration and cooperation on this matter.

Yours sincerely,

Mr.Syamphone SENGCHANDALA
National Focal Point of the UNFCCC
Ministry of Natural Resources and Environment

Attachment: INDC of the Lao PDR.

Appendix 3

Table 1: Table of the Standard Normal Cumulative Distribution Function $\Phi(z)$

z	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
-3.4	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0002
-3.3	0.0005	0.0005	0.0005	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0003
-3.2	0.0007	0.0007	0.0006	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005
-3.1	0.0010	0.0009	0.0009	0.0009	0.0008	0.0008	0.0008	0.0008	0.0007	0.0007
-3.0	0.0013	0.0013	0.0013	0.0012	0.0012	0.0011	0.0011	0.0011	0.0010	0.0010
-2.9	0.0019	0.0018	0.0018	0.0017	0.0016	0.0016	0.0015	0.0015	0.0014	0.0014
-2.8	0.0026	0.0025	0.0024	0.0023	0.0023	0.0022	0.0021	0.0021	0.0020	0.0019
-2.7	0.0035	0.0034	0.0033	0.0032	0.0031	0.0030	0.0029	0.0028	0.0027	0.0026
-2.6	0.0047	0.0045	0.0044	0.0043	0.0041	0.0040	0.0039	0.0038	0.0037	0.0036
-2.5	0.0062	0.0060	0.0059	0.0057	0.0055	0.0054	0.0052	0.0051	0.0049	0.0048
-2.4	0.0082	0.0080	0.0078	0.0075	0.0073	0.0071	0.0069	0.0068	0.0066	0.0064
-2.3	0.0107	0.0104	0.0102	0.0099	0.0096	0.0094	0.0091	0.0089	0.0087	0.0084
-2.2	0.0139	0.0136	0.0132	0.0129	0.0125	0.0122	0.0119	0.0116	0.0113	0.0110
-2.1	0.0179	0.0174	0.0170	0.0166	0.0162	0.0158	0.0154	0.0150	0.0146	0.0143
-2.0	0.0228	0.0222	0.0217	0.0212	0.0207	0.0202	0.0197	0.0192	0.0188	0.0183
-1.9	0.0287	0.0281	0.0274	0.0268	0.0262	0.0256	0.0250	0.0244	0.0239	0.0233
-1.8	0.0359	0.0351	0.0344	0.0336	0.0329	0.0322	0.0314	0.0307	0.0301	0.0294
-1.7	0.0446	0.0436	0.0427	0.0418	0.0409	0.0401	0.0392	0.0384	0.0375	0.0367
-1.6	0.0548	0.0537	0.0526	0.0516	0.0505	0.0495	0.0485	0.0475	0.0465	0.0455
-1.5	0.0668	0.0655	0.0643	0.0630	0.0618	0.0606	0.0594	0.0582	0.0571	0.0559
-1.4	0.0808	0.0793	0.0778	0.0764	0.0749	0.0735	0.0721	0.0708	0.0694	0.0681
-1.3	0.0968	0.0951	0.0934	0.0918	0.0901	0.0885	0.0869	0.0853	0.0838	0.0823
-1.2	0.1151	0.1131	0.1112	0.1093	0.1075	0.1056	0.1038	0.1020	0.1003	0.0985
-1.1	0.1357	0.1335	0.1314	0.1292	0.1271	0.1251	0.1230	0.1210	0.1190	0.1170
-1.0	0.1587	0.1562	0.1539	0.1515	0.1492	0.1469	0.1446	0.1423	0.1401	0.1379
-0.9	0.1841	0.1814	0.1788	0.1762	0.1736	0.1711	0.1685	0.1660	0.1635	0.1611
-0.8	0.2119	0.2090	0.2061	0.2033	0.2005	0.1977	0.1949	0.1922	0.1894	0.1867
-0.7	0.2420	0.2389	0.2358	0.2327	0.2296	0.2266	0.2236	0.2206	0.2177	0.2148
-0.6	0.2743	0.2709	0.2676	0.2643	0.2611	0.2578	0.2546	0.2514	0.2483	0.2451
-0.5	0.3085	0.3050	0.3015	0.2981	0.2946	0.2912	0.2877	0.2843	0.2810	0.2776
-0.4	0.3446	0.3409	0.3372	0.3336	0.3300	0.3264	0.3228	0.3192	0.3156	0.3121
-0.3	0.3821	0.3783	0.3745	0.3707	0.3669	0.3632	0.3594	0.3557	0.3520	0.3483
-0.2	0.4207	0.4168	0.4129	0.4090	0.4052	0.4013	0.3974	0.3936	0.3897	0.3859
-0.1	0.4602	0.4562	0.4522	0.4483	0.4443	0.4404	0.4364	0.4325	0.4286	0.4247
-0.0	0.5000	0.4960	0.4920	0.4880	0.4840	0.4801	0.4761	0.4721	0.4681	0.4641
0.0	0.5000	0.5040	0.5080	0.5120	0.5160	0.5199	0.5239	0.5279	0.5319	0.5359
0.1	0.5398	0.5438	0.5478	0.5517	0.5557	0.5596	0.5636	0.5675	0.5714	0.5753
0.2	0.5793	0.5832	0.5871	0.5910	0.5948	0.5987	0.6026	0.6064	0.6103	0.6141
0.3	0.6179	0.6217	0.6255	0.6293	0.6331	0.6368	0.6406	0.6443	0.6480	0.6517
0.4	0.6554	0.6591	0.6628	0.6664	0.6700	0.6736	0.6772	0.6808	0.6844	0.6879
0.5	0.6915	0.6950	0.6985	0.7019	0.7054	0.7088	0.7123	0.7157	0.7190	0.7224
0.6	0.7257	0.7291	0.7324	0.7357	0.7389	0.7422	0.7454	0.7486	0.7517	0.7549
0.7	0.7580	0.7611	0.7642	0.7673	0.7704	0.7734	0.7764	0.7794	0.7823	0.7852
0.8	0.7881	0.7910	0.7939	0.7967	0.7995	0.8023	0.8051	0.8078	0.8106	0.8133
0.9	0.8159	0.8186	0.8212	0.8238	0.8264	0.8289	0.8315	0.8340	0.8365	0.8389
1.0	0.8413	0.8438	0.8461	0.8485	0.8508	0.8531	0.8554	0.8577	0.8599	0.8621
1.1	0.8643	0.8665	0.8686	0.8708	0.8729	0.8749	0.8770	0.8790	0.8810	0.8830
1.2	0.8849	0.8869	0.8888	0.8907	0.8925	0.8944	0.8962	0.8980	0.8997	0.9015
1.3	0.9032	0.9049	0.9066	0.9082	0.9099	0.9115	0.9131	0.9147	0.9162	0.9177
1.4	0.9192	0.9207	0.9222	0.9236	0.9251	0.9265	0.9279	0.9292	0.9306	0.9319
1.5	0.9332	0.9345	0.9357	0.9370	0.9382	0.9394	0.9406	0.9418	0.9429	0.9441
1.6	0.9452	0.9463	0.9474	0.9484	0.9495	0.9505	0.9515	0.9525	0.9535	0.9545
1.7	0.9554	0.9564	0.9573	0.9582	0.9591	0.9599	0.9608	0.9616	0.9625	0.9633
1.8	0.9641	0.9649	0.9656	0.9664	0.9671	0.9678	0.9686	0.9693	0.9699	0.9706
1.9	0.9713	0.9719	0.9726	0.9732	0.9738	0.9744	0.9750	0.9756	0.9761	0.9767
2.0	0.9772	0.9778	0.9783	0.9788	0.9793	0.9798	0.9803	0.9808	0.9812	0.9817
2.1	0.9821	0.9826	0.9830	0.9834	0.9838	0.9842	0.9846	0.9850	0.9854	0.9857
2.2	0.9861	0.9864	0.9868	0.9871	0.9875	0.9878	0.9881	0.9884	0.9887	0.9890
2.3	0.9893	0.9896	0.9898	0.9901	0.9904	0.9906	0.9909	0.9911	0.9913	0.9916
2.4	0.9918	0.9920	0.9922	0.9925	0.9927	0.9929	0.9931	0.9932	0.9934	0.9936
2.5	0.9938	0.9940	0.9941	0.9943	0.9945	0.9946	0.9948	0.9949	0.9951	0.9952
2.6	0.9953	0.9955	0.9956	0.9957	0.9959	0.9960	0.9961	0.9962	0.9963	0.9964
2.7	0.9965	0.9966	0.9967	0.9968	0.9969	0.9970	0.9971	0.9972	0.9973	0.9974
2.8	0.9974	0.9975	0.9976	0.9977	0.9977	0.9978	0.9979	0.9979	0.9980	0.9981
2.9	0.9981	0.9982	0.9982	0.9983	0.9984	0.9984	0.9985	0.9985	0.9986	0.9986
3.0	0.9987	0.9987	0.9987	0.9988	0.9988	0.9989	0.9989	0.9989	0.9990	0.9990
3.1	0.9990	0.9991	0.9991	0.9991	0.9992	0.9992	0.9992	0.9992	0.9993	0.9993
3.2	0.9993	0.9993	0.9994	0.9994	0.9994	0.9994	0.9994	0.9995	0.9995	0.9995
3.3	0.9995	0.9995	0.9995	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9997
3.4	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9998