Institute of Forest and Wildlife Research and Development

Hydrological SWAT Modelling incorporated with impact tool to Simulate Existing and Future Discharge, Ground Water Recharge and Soil Erosion Behaviour in Prek Thnot Watershed, Cambodia

Prepared by: Sopheap Lim

November 2018

ACKNOWLEDGEMENT

Institute of Forest and Wildlife Research and Development (IRD) under the Ministry of Agriculture, Forestry and Fisheries (MAFF) is currently implementing a project entitled "Landscape Approach to Sustainable Management of Forests in Prek Thnot Watershed". To fulfill this hydrologic assessment which consists of hydrological SWAT modelling tool incorporated with Spatial assessment for surface runoff, soil erosion and groundwater recharge, I would like to express my deepest gratitude and appreciation to Dr. Edward V. Maningo, Dr. Koy Ra and Mr. So bon for their provided data together with related information for this study; and their valuable contribution for suggestion as well as recommendation to complete this concrete report. The author wishes to thank IRD management team involving Dr. Sokh Heng and Dr. So Thea for their technical support and guidance. Also wish to thank to Ms. Kheav Channara for her constantly support in all arrangement to this study.

Abbreviations and Acronyms

DEM	Digital Elevation Model
DSF	Decision Support Framework
DWR	Department of Water Resources (Cambodia)
GW	Groundwater
HRU	Hydrologic Response Unit
IRD	Institute of Forest and Wildlife Research and Development
SWAT	Soil and Water Assessment Model (hydrological model)
MAFF	Ministry of Agriculture, Forestry and Fisheries
MOE	Ministry of the Environment
MOWRAM	Ministry of Water Resources and Meteorology
MQUAD	Mean
MRCS	Mekong River Commission Secretariat

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1 Introduction

1.1 Background

Land management activities including forest cover losses can have serious implications for water resources because during rainfall events, interception decreases and soil infiltration rates are exceeded. Such alterations have the potential to cause flashier flows and result in altered flow regimes (Calder, 1993).

The Institute of Forest and Wildlife Research and Development (IRD) is currently implementing the project entitled "Landscape Approach to Sustainable Management of Forests in Prek Thnot Watershed" funded by APFNet. This study aims to provide a watershed-based approach in planning the landscape which will provide a guide for land use planning (e.g. commune land use plans, Protected Areas Plan, etc.).

Prek Thnot River is one of major tributaries of Mekong River in Cambodia, whose watershed has high potential in water resources development to increase agricultural production. However, it is one of the watersheds that have high risk of impairment of its watershed function. The loss of forest cover can greatly diminish the protective role of the watershed and increase the vulnerability of the downstream communities. The ongoing deforestation in the uplands increasingly subjects the downstream communities including Phnom Penh to flooding. Prek Thnot is facing threats from: (1) Unabated logging of the forest areas, particularly those adjacent or within the Cardamom Mountains; (2) Fuelwood and charcoal industry; (3) Expansion of farms and agro-industries; (4) Settlers migrating from the nearby districts within Kampong Speu province and from other provinces; and (5) From 2002-2010, the forest losses were 20,722 hectares. Most of the areas are now being developed for agro-industries such as rice, sugar cane, corn, cassava and fruits.

The project has completed the land allocation of Prek Thnot watershed to different land uses. The land allocation will then be integrated in the development of the Integrated Watershed Management Plan (IWMP). However, in respect with recommendation made by Mid Term Evaluation Team, it is compulsory to conduct an impact evaluation of the proposed land use/land allocation of Prek Thnot watershed.

Then, Soil and Water Assessment Tool (SWAT) associated with Spatial assessment are chosen as a method to increase understanding of watershed response to land use change to determine whether land cover changes within the Prek Thnot watershed can be causally linked to hydrological alteration. Coupled with historical and proposed land cover and land use information, an assessment can then be presented as how soil erosion, surface water and groundwater have changed since 1985 and implications this may have negative environmental impact.

This report discusses all process of implementation and completion of hydrologic assessment for Prek Thnot Watershed. Specifically, it covers data requirement, model setup, calibration, validation and spatial assessment for both existing and future scenarios as required by the study.

1.2 *Study Area*

Prek Thnot watershed covers the provinces of Kampong Speu and Kandal and Phnom Penh, the Capital City of Cambodia. It covers a total land area 666,764 hectares, 77.8% of which are in Kampong Speu province. Most of the forest cover of Prek Thnot watershed is found in the northwestern part although few patches of forests could still found on the downstream part. The watershed provided ecosystem goods and services and support the livelihoods and production systems of the downstream communities. The surface runoffs of the watershed drain towards Phnom Penh via the streams and rivers (Figure 1.1).

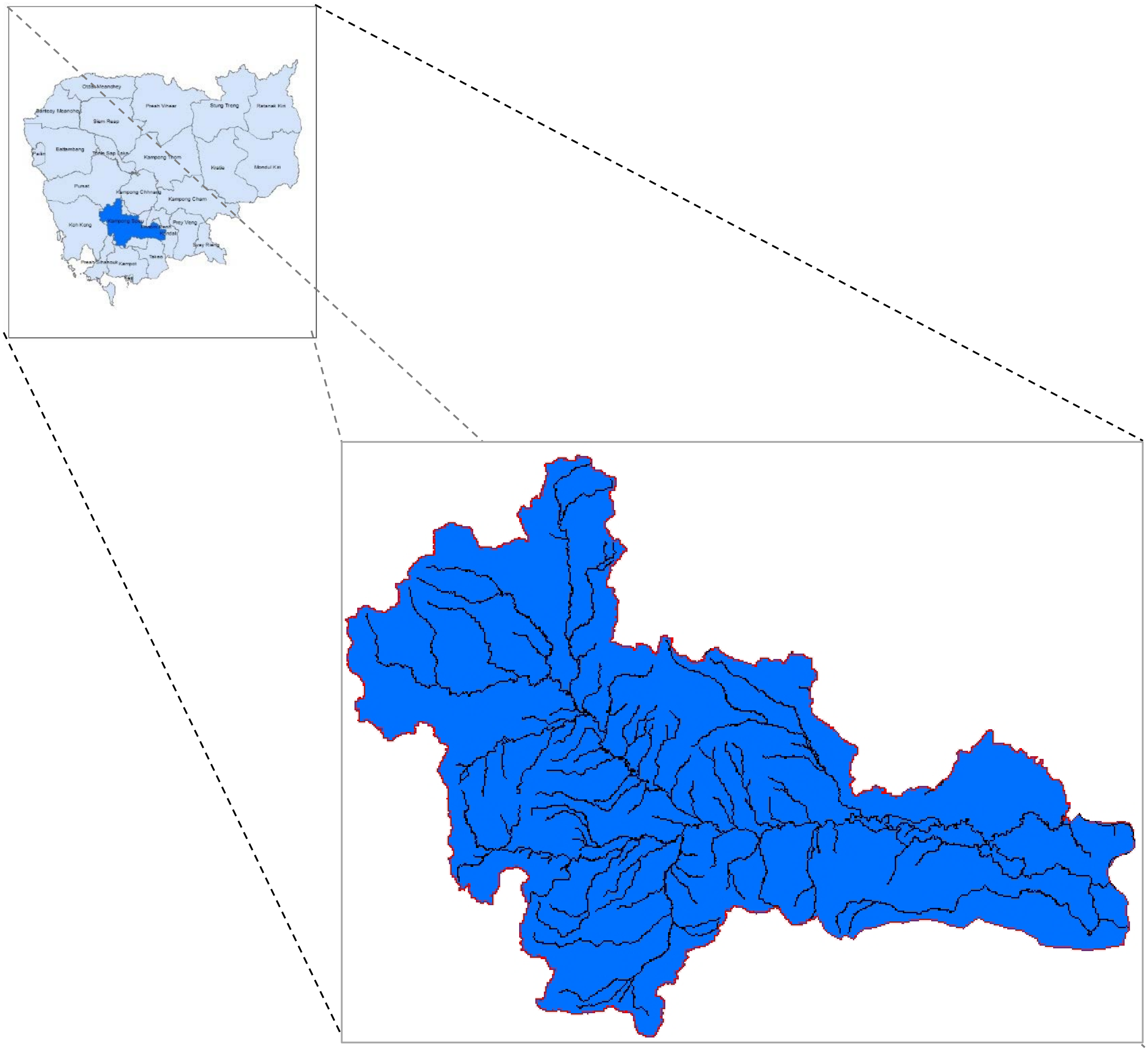


Figure 1-1: Location of Prek Thnot Watershed

2 Soil and Water Assessment Tool Modelling Approach

2.1 Soil and Water Assessment Tool Model Application

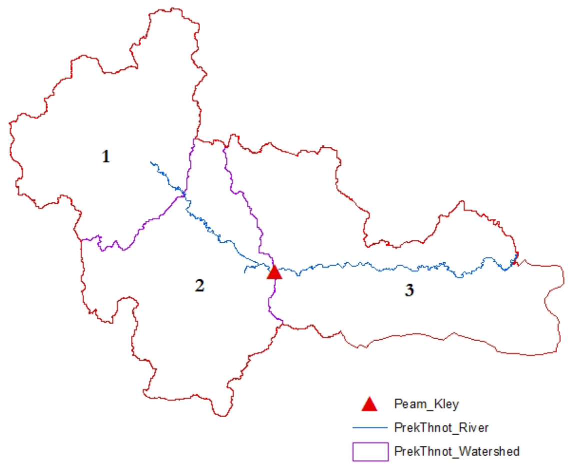
For this study, the SWAT2012 model is used which is linked to a GIS interface (ArcGIS) to simulate hydrologic assessment in the Prek Thnot watershed over a 30-year period beginning in 1985 up to 2014.

The Soil and Water Assessment Tool (SWAT) is a public domain model jointly developed by USDA Agricultural Research Service (USDA-ARS) and Texas A&M AgriLife Research, part of The Texas A&M University System. The SWAT has been developed in order to predict the impact of land management practices on water, sediments and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions (Neitsch et al. 2011; Arnold et al. 2012). SWAT is a physically based semi-distributed hydrologic model operating on a daily time step and uses a modified Soil Conservation Service-Curve Number (SCS CN) method to calculate runoff. It is a physically based model which computes readily available data (e.g. weather, soil, vegetation, land management practices), and allows the study of short to long-term impacts, processing data on a continuous time mode as it receives continuous meteorological time series (Neitsch et al. 2011).

This section provides an overview of the workflow of SWAT model application for Prek Thnot watershed.

2.2 SWAT Model Schematization and Model Set up

The SWAT model is set up and calibrated using SWAT 2012 and weather data covering period 1985-2014. (30 years). Prek Thnot Watershed is delineated into 3 sub basin in SWAT model and Peam Khley gauge station is available for calibration (Figure 2.1).
- Warm up model : 1980 – 1984
- Calibration period : 1996 – 2008 (13 years)
- Validation period : 2009 – 2014 (6 years)



SUBBASIN	Area (km2)
1	180,259
2	191,512
3	249,269

Figure 2-1: Prek Thnot Watershed delineation in SWAT model

2.3 Data Requirement for model set up

The data for set-up SWAT model for Prek Thnot watershed are listed below:

a. Spatial Data

Three main data are required for SWAT model application Figure 2.2.

- **Digital Elevation Model (DEM)**: The data source is the 1:50,0000 scale American topographic maps and available on 50 m grid.
- **Land cover/landuse map**: Basically, there are 44 land use types covering the entire Prek Thnot Basin. Then, land use types are grouped and presented into one type; finally a total number of 4 land use types are obtained as seen in Table 2.1.

Table 2-1: Detail of Land use in Prek Thnot Watershed

GRIDCODE	Field	Detail of Landuse
12	EMLD	Evergreen,medium-low cover den
20	DECD	Deciduous
63	BAMB	Bamboo Forest
64	WSDR	Shrubland
65	WSIN	Wood- and shrubland, inundated
92	BRNL	Barren land
94	URBN	Urban or built-over area
95	WATR	Water
97	WETD	Wetland
103	PDDY	Paddy field
104	FCRP	Field Crop
108	ORCD	Orchard
224	PAST	Grassland
420	PNFR	Forest Plantation

- **Soil map**: Based on MRC soil classification map, 18 soil types are classified covering the entire Prek Thnot (Table 2.2). There are 3 major soil classes in the basin including SC, Aoand N

Table 2-2: Soil types in Prek Thnot Watershed

Soil Name	TEXTURE
ACf	Loamy
ACh/LPd	Clay
ACha	Loamy
ACp	Clay
ACpg	Clay
Ag	Clay
Ao	Clay
ARl/ARh	Sandy
CMef	Clay
CMg	Clay
FLe	Loamy
GLu	Clay
LPd	Loamy
LPd/CMd	Loamy
PLd/ACg	Sandy
PTd	Clay
Reside	Sandy
W	Clay

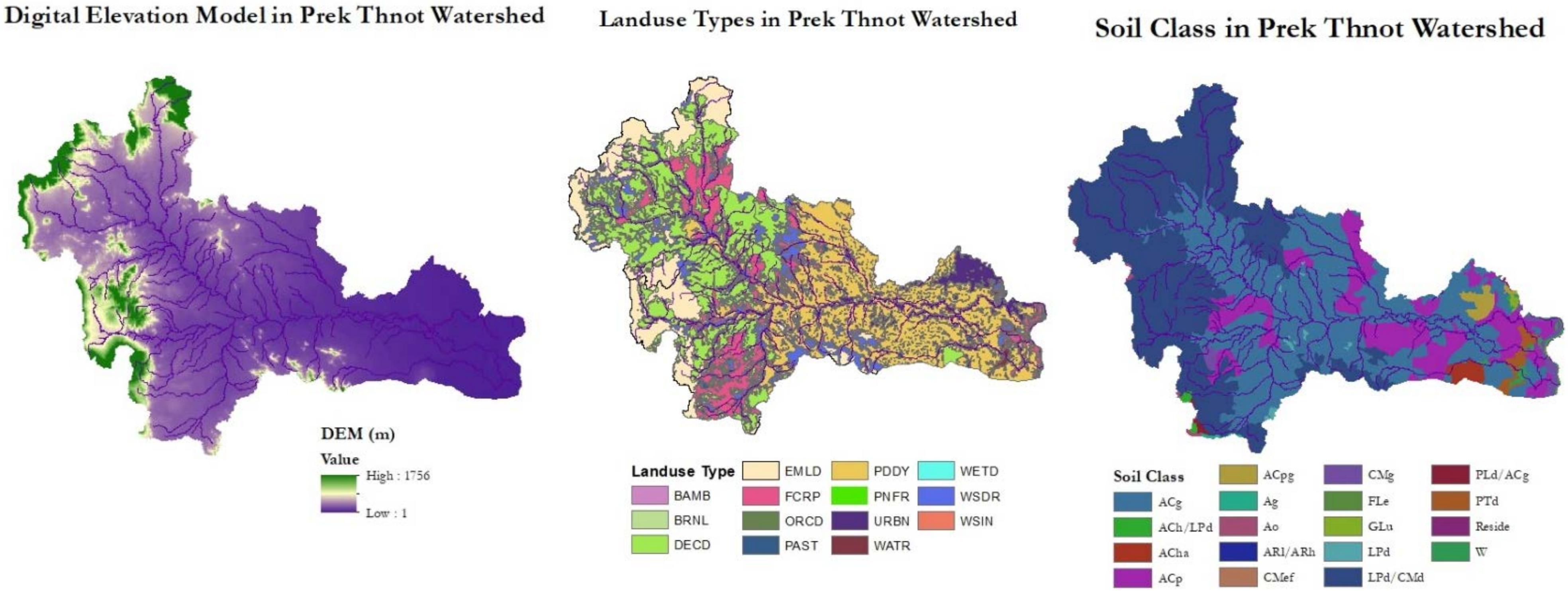


Figure 2-2: Topographic data, Land use and Soil in Prek Thnot for SWAT Model

b. Time Series Data

Timeseries data for setting-up SWAT model include rainfall, discharge and climatic data. Climatic components consists of maximum and minimum temperature (Tmp), relative humidity (Hmd), Solar radiation (Slr) and Wind speed (Wnd). The weather data used to set-up SWAT model of the Prek Thnot Watershet were obtained from various line agencies in Cambodia such as Department of Water Resources (DWR), Ministry of Water Resource and Meteorology (MOWRAM), Department of Plantation Development and Forest Private, Forestry Administration, Ministry of Agriculture, Forestry and Fisheries (MAFF).

- ✓ **Climatic data**: This data contains Minimum and Maximum Temperature, Relative Humidity, Solar Radiation and Wind speed from year 1985 – 2014 (Table 2.3) and (Figure 2.3).

Table 2-3: List of Climatic stations used for updated SWAT model

N^0	Station ID	Station Name	*Latitude*	*Longitude*	*Hmd*	*Slr*	*Tmp*	*Wnd*
1	110425	Pochentong	11.55	104.9167	x	x	x	x
2	110514	Prey Veng	11.4667	105.15	x	x	x	x

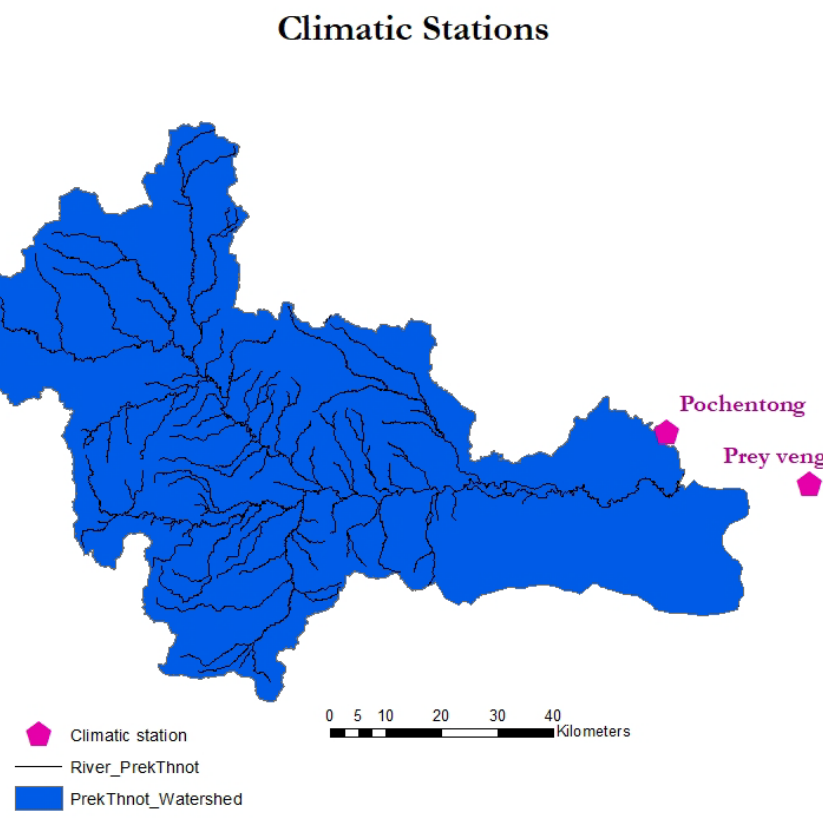


Figure 2-3: Location of climatic stations used in SWAT model setup at Prek Thnot Watershed

- ✓ **Daily Rainfall data**: All stations are available from year 1985 – 2014. Totally, there are 16 rainfall stations are chosen to determine the average rainfall per sub-basin of SWAT model (Table 2.4) and (Figure 2.4).

Table 2-4: List of Rainfall stations used for updated SWAT model

N^0	Station ID	Station Name	Porovince	*Latitude*	*Longitude*
1	110411	Phnom Penh (Bassac)	Phnom Penh	11.37	104.53
2	110425	Pochentong	Phnom Penh	11.55	104.92
3	110414	Tuol khpos	Kampong Chhnang	11.95	104.38
4	110437	Sdock	Kampong Speu	11.26	104.52
5	110431	Baset	Kampong Speu	11.15	104.54
6	110404	Kampong Speu	Kampong Speu	11.34	104.06
7	110432	Kong Pisey	Kampong Speu	11.30	104.63
8	110433	Oral	Kampong Speu	11.69	104.14
9	110415	Oudong	Kampong Speu	11.78	104.73
10	110413	Phnom Srouch	Kampong Speu	11.38	104.38
11	110434	O Taroat	Kampong Speu	11.54	104.42
12	640103	Peam Khley-Dam Site	Kampong Speu	11.47	104.37
13	110436	Prey Dop	Kampong Speu	11.22	104.56
14	110446	Prey Lvear	Takeo	11.17	104.95
15	110416	Sre Khlong	Kampong Speu	11.33	104.29
16	110445	Trapeang Chor	Kampong Speu	11.82	104.14

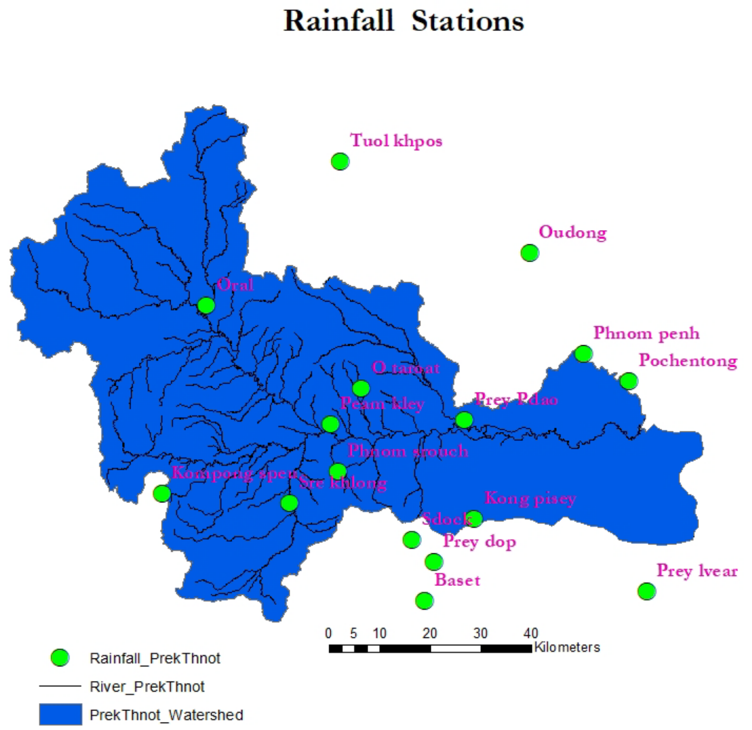


Figure 2-4: Location of rainfall stations used in SWAT model setup at Prek Thnot Watershed

The daily time-series of rainfall data was used to generate the daily time-series of average subbasin rainfall for each of the SWAT sub-basins using the MQUAD inside MRC Decision Support Framework (DSF).This is done by fitting a multi-quadratic surface to the daily rainfall data at all relevant locations in and around the study area and then integrating over each sub-basin area to obtain the average daily rainfall for the sub-basin (a series of smaller basin which is generated by a larger basin/watershed). Consequently, the average monthly rainfall/precipitation for entire Prek Thnot watershed is shown in Figure 2.5.

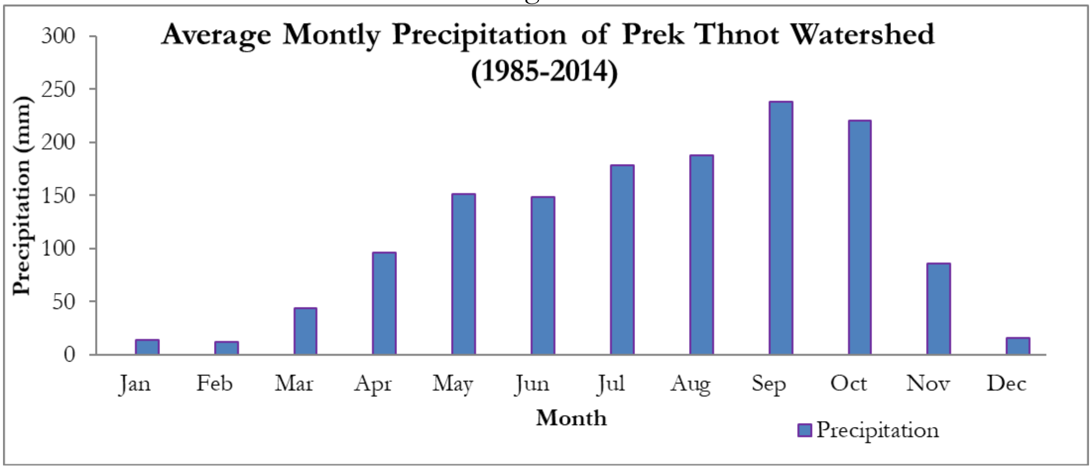


Figure 2-5: Average Monthly Precipitation of Prek Thnot basin

- ✓ **Daily Hydrological data** at Peam Khey station is chosen from year 1985 – 2014 for calibration and validation of performance model simulation as seen in Table 2.5 and Figure 2.6.

Table 2-5: List of Discharge stations used for updated SWAT model calibration and validation

N^0	Station ID	Station Name	River	Latitude	Longitude
1	640103	PeamKhley	St. Prek Thnot	11.4705	105.369

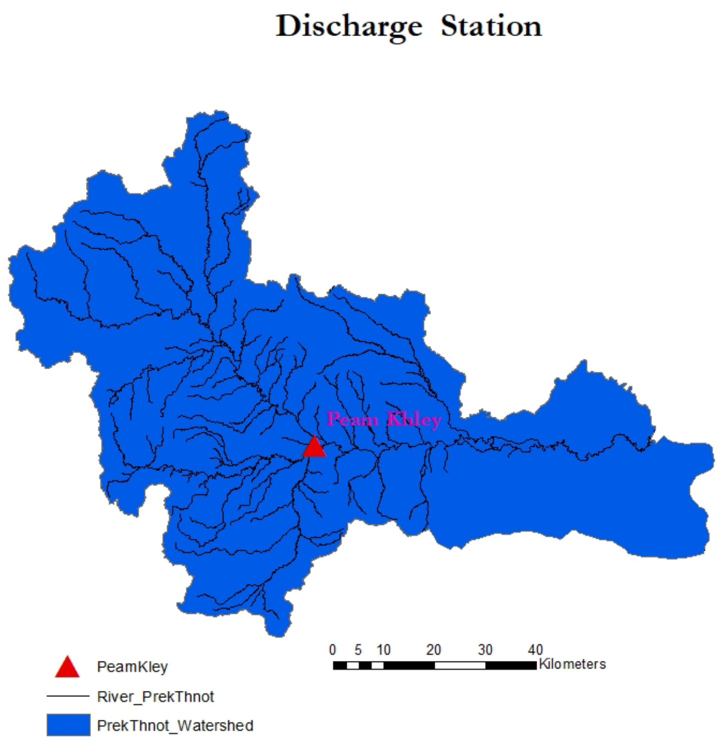


Figure 2-6: Location of discharge stations used in SWAT model setup at Prek Thnot Watershed

2.4 SWAT Model Calibration and Validation

Model Simulation Period is from year 1985-2014 while year 1980-1984 is set as warm up period for the model. With limit of data during year 1985 -1996, therefore model calibration divided to be 2 part (a) Calibration Period from year 1996-2008(13 years- 43 % of Simulation period) (b) Validation Period from year 2009-2014 (8 years – 27% of Simulation period).

2.4.1 Parameters Sensitivity in SWAT model calibration

The first step in the calibration and validation process in SWAT is the determination of the most sensitive parameters for a given watershed or subwatershed. Sensitivity analysis is the process of determining the rate of change in model output with respect to changes in model inputs (parameters). It is necessary to identify key parameters and the parameter precision required for calibration (Ma et al., 2000). The SWAT model is calibrated based on relevant parameter in Hydrological Balance in the basin such as management parameter, Ground Water, HRU, Reach and SUB. Only relevant parameters that were modified during the calibration process have been reported. Parameter for Flow calibration as follow:

1. Land and Water Management (Mgt): to ensure of the land and water management practices taking place within the system; data for planting, harvest, irrigation applications, nutrient applications, pesticide application and tillage operation have to put in part of management. The pattern between Forest land use and Agriculture land use is different and user should put the correct pattern otherwise it cannot estimated reasonable water use and finally effect to runoff. Parameters that can adjust for each type of Land use is CN.

CN2 : Initial SCS runoff for moisture condition II.

2. The ground water (GW): SWAT partition groundwater into 2 systems; a shallow, unconfined aquifer which contributors return flow to streams within watershed and a deep, confined aquifer which contributes no return flow to streams inside the watershed.

GW_DELAY: Groundwater delay time (days)
ALPHA_BF: Baseflow alpha factor (1/days)
GWQMN: Threshold depth of water in the shallow aquifer required for return flow to occur (mmH2O)
GW_REVAP: Groundwater "revap" coefficient.
REVAPMN: Threshold depth of water in the shallow aquifer for "revap" or precipitation to the deep aquifer to occur (mmH2O)
RCHRG_DP: Deep aquifer percolation fraction

3. Hydrologic Response Unit (HRU): information related to a diversity of feature within HRU, topographic characteristics, water flow, erosion, land cover and depression storage area.

SLSOIL: Slope length for the lateral subsurface flow (m)
LAT_TTIME: Lateral flow travel time (days)
CANMX: Maximum canopy storage (mm H2O)
ESCO: Soil evaporation compensation factor (define for specific HRU)

4. The main Channel (RTE): information on the physical characteristics of the main channel within each sub-basin.

CH_N2: *Manning's "n" value for the main channel.*
CH_K2: *Effective hydraulic conductivity in main channel alluvium (mm/hr)*
ALPHA_BNK: *Baseflow alpha factor for bank storage (days)*

5. The sub-basin (Sub): contains sub-basin size and location, specification of climate data used within the sub-basin, the amount of topographic relief within the sub-basin, properties of tributary channel within sub-basin, variables related to climate change.

CH_N: Manning's "n" value for the tributary channels.
CH_K: Effective hydraulic conductivity in tributary channels alluvium (mm/hr)

6. Basin (BSN): contain information of general watershed attribute.

ESCO: Soil evaporation compensation factor.

The value for selected parameter at calibration point is presented in Table 2.6.

Table 2-6: Parameter of SWAT Model calibration in Prek Thnot Watershed

Total number of basin : 3

BSN

SURLAG	ESCO
4	0.95

N^{0}	Name	Sub Outlet	Subbasin Inside	Number of subbasin	GW						HRU				RTE			SUB	Calibration (1996-2008)		Validation (2009-2014)	
					GW_DELAY	ALPHA_BF	GWQMN	GW_REVAP	REVAPMN	RCHRG_DP	LT_TIME	SLSOIL	CANMX	ESCO	CH_N2	CH_K2	CH_N1	CH_K1	COE	Vol	COE	Vol
1	Peam Khley	2	1,2	2	150	0.11	100	0.2	500	0.4	150	0	20	0.7	0.2	10	0.2	10	0.63	115	0.67	106

2.4.2 Model Calibration and Validation Performance

To evaluate "goodness-of-fit" of model performance, the Nash–Sutcliffe coefficient (NSE; Nash and Sutcliffe, 1970) is chosen as the most suitable method for judging goodness-of-fit for calibration results with observed data. The Nash-Sutcliffe coefficient is used on a daily basis for both high and low flows to assess the model calibration. NSE or it is so-called Coefficient of Efficiency "CE" is calculated using the following equation:

$$CE = 1 - \frac{\sum_{i=1}^{n} (O_i - S_i)^2}{\sum_{i=1}^{n} (O_i - \overline{O})^2}$$

$O_i = Observed\ \ flow\ at\ day\ i$
$S_i = Simulated\ \ flow\ at\ day\ i$
$i = Day\ no.\ i$
$n = Number\ of\ \ days$
$\overline{O} = Mean\ of\ observed\ \ flows$

It is important to preserve the time series of flow and to have a measure that assesses how well the model performs over time.

To ensure that the model is robust through the calibration, preservation of mass (Volume Ratio) is used in the model evaluation to asses over estimation or underestimation of the streamflow. Volume Ratio is calculated using the following equation:

$$V_r = \left(1 - \frac{\sum_{i=1}^{n} S_i}{\sum_{i=1}^{n} O_i}\right) * 100\%$$

$O_i = Observed\ \ flow\ at\ day\ i$
$S_i = Simulated\ \ flow\ at\ day\ i$
$i = Day\ no.\ i$
$n = Number\ of\ \ days$
$\overline{O} = Mean\ of\ \ observed\ \ flows$

The calibration (1996-2008) and validation model performance (2000-2014) at Peam Kley station is presented in table 2.6. This station indicates COE higher than 0.5 and Volume ratio different is between 106 – 115. Therefore, the model can use for further assessment including the future change of climate and land use change. The figure 2.7 illustrates the daily comparison between observed and simulation at Peam Kley station.

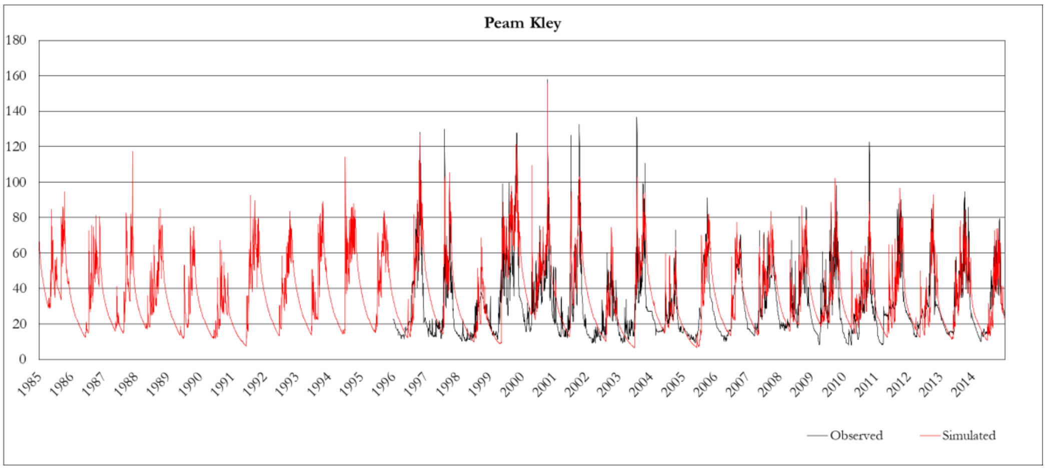


Figure 2-7: Calibration and Validation performance at Peam Kley station

After calibration, overall hydrological condition of Prek Thnot is shown in Appendix A including hydrological phenomena due to climate change and land use change (land allocation) which are extracted from SWAT- Check. Actually, the hydrology in SWAT-Check summarized the water balance both graphically and numerically. It provides the ratios of different water balance components for instance, return flow, lateral flow, surface flow, recharge to deep aquifer so on and so forth.

3 Soil and Water Assessment Tool Modelling Approach

To facilitating in assessing the impact under different development condition including the future change of climate on water quantity, ground water recharge and soil erosion, the following scenarios are taken into account in scenario formulation.

3.1 Land use Change scenarios (Proposed land allocation)

Landuse change is made as in accordance with the proposed land per selected district within Prek Thnot watershed (Figure 3.1). Number of landuse types such as fruit orchard, high value crops, conservation, industrial plantation and other plantation area are allocated for better management which will also be given emphasis for development as seen in Figure 3.2 and Table 3.1. The information taken from this data combining with existing landuse types is added into to the SWAT model to determine the impact of land use change.

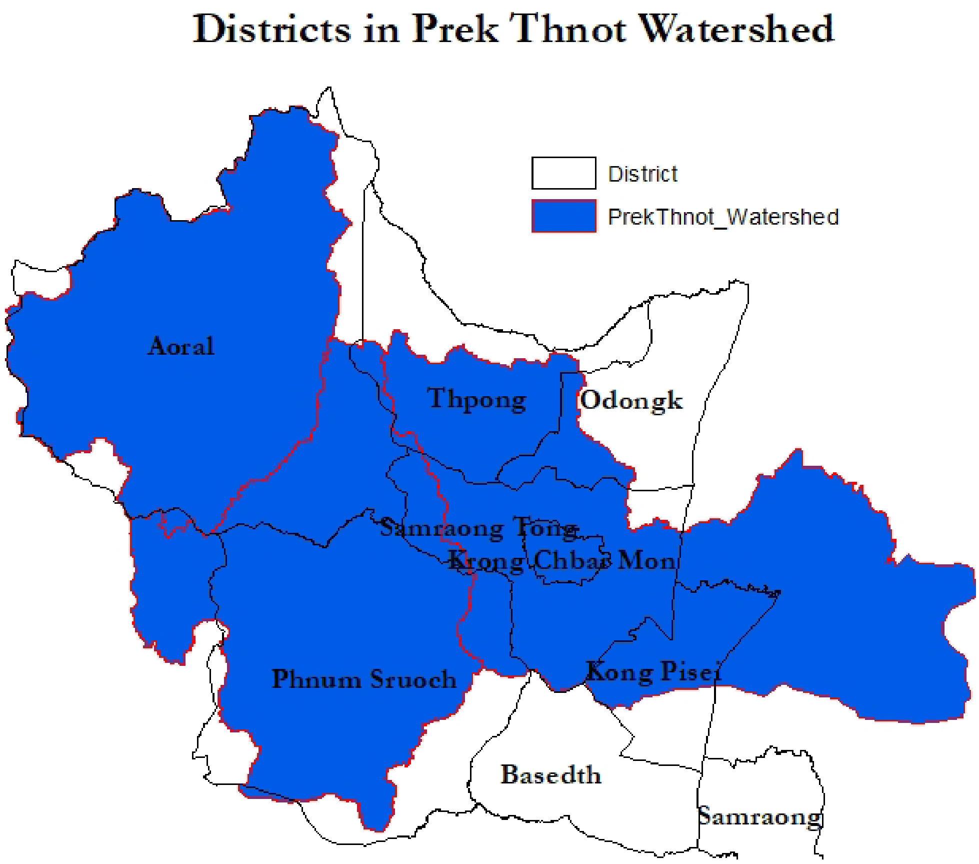


Figure 3-1: Location of district located within Prek Thnot watershed

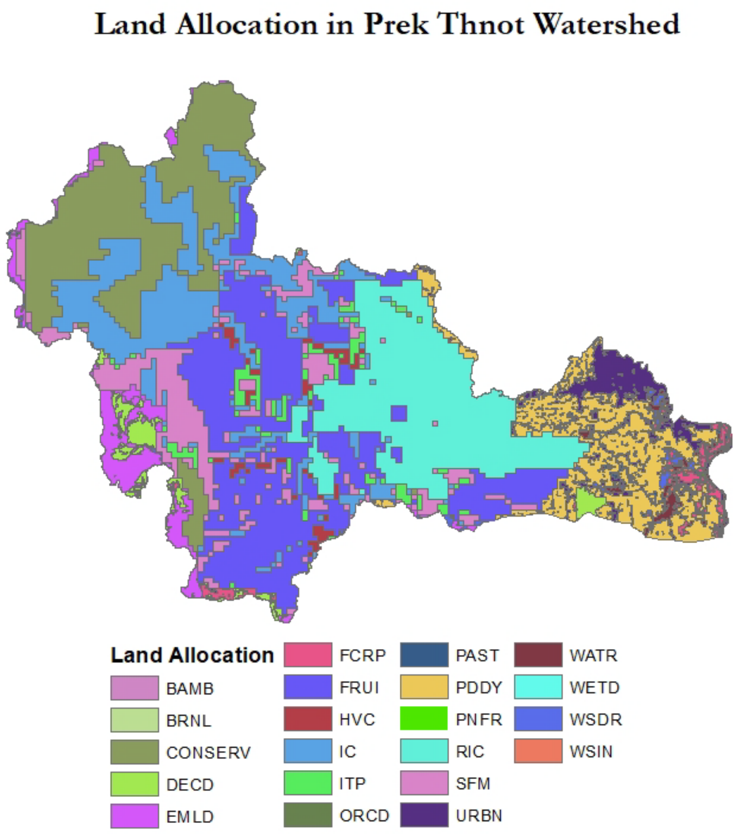


Figure 3-2: Land Allocation for Landuse Scenario Formulation in Prek Thnot watershed

Table 3-1: Land allocation combining with exiting landuse in Prek Thnot Watershed used for landuse scenario formulation

GRIDCODE	Field	Detail of Landuse
12	EMLD	Evergreen,medium-low cover density
20	DECD	Deciduous
63	BAMB	Bamboo Forest
64	WSDR	Shrubland
65	WSIN	Wood- and shrubland, inundated
92	BRNL	Barren land
94	URBN	Urban or built-over area
95	WATR	Water
97	WETD	Wetland
103	PDDY	Paddy field
104	FCRP	Field Crop
108	ORCD	Orchard
224	PAST	Grassland
420	PNFR	Forest Plantation
1	CONSERV	Conservation
2	FRUI	FRUITS
3	HVC	High Value Crops
4	IC	Industrial Crops
5	ITP	Industrial Tree Plantations
6	RIC	RICE
7	SFM	Sustainable Forest Management

3.2 Climate Change scenarios

Climate change is extracted from the SIMCLIM software, which provides statistical downscaling the outputs of a set of global circulation models driven with assumptions of intermediate levels of greenhouse gas emissions (RCP4.5). The climate change scenario IPSL which represents mean seasonal changes involving mean monthly change of humidity, solar radiation, wind speed, precipitation and temperature change is chosen for this study as seen in Figure 3.3 and 3.4. This seasonal climate change dataset is employed to adjust the reference 1985-2014 climate.

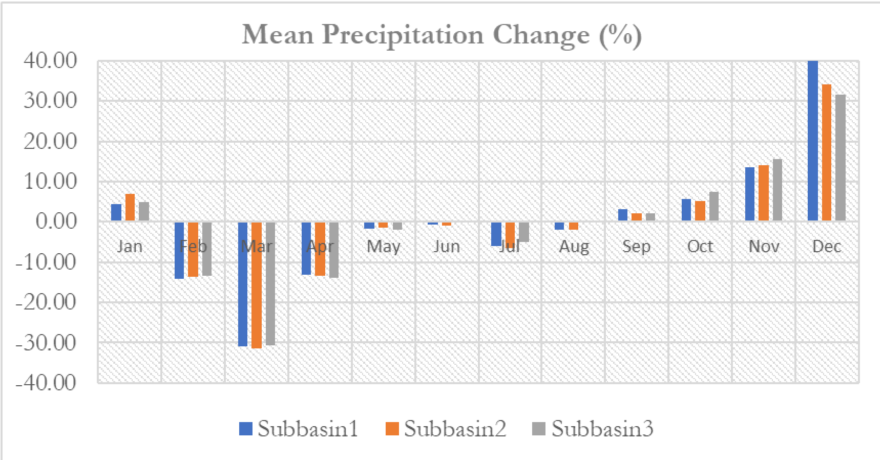


Figure 3-3: Mean Monthly Precipitation Change (%)

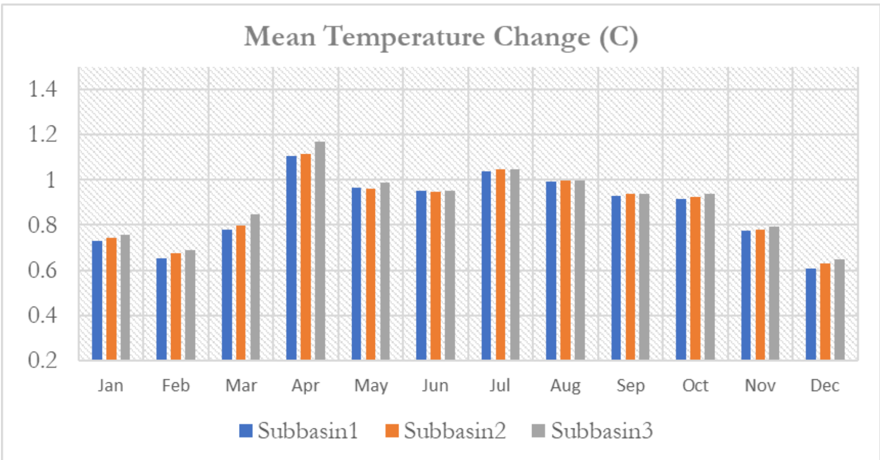


Figure 3-4: Mean monthly Temperature Change °C in each catchment within Prek Thnot watershed

4 Result Analysis from Different Scenarios

4.1 100 Years Return Period

To fulfil in the planning and design of water resource projects, estimation of Peak Flood discharge for a desired return period (average numbers of years between two exceedances based on the probability and the given event) will be equalled or exceeded in any given year is a pre-requisite. In this study, to see effect from Landuse change and climate change by comparing with result of Baseline, 100 years return period (statistically a flood event that has 1 percent chance of occurrence in any given year) is carried out at analysis the frequency of Prek Thnot watershed using the Gumbel's distribution method which is one of the probability distribution methods applicable for streamflow. The maximum discharge result is considered as flood peak when applied 100 –year flood event (Table 4.1).

On average, when applied 100-year flood event on Prek Thnot watershed, particularly at Peam Kley station, it is found that the impact of streamflow made the peak of river change from Baseline by decrease from 194 cms to 172 cms (Land use change), this clearly shows that there is no significant change between the baseline and Land use change. However, it is observed that there is a significantly increase from 194 cms to 210 cms (Climate Change) as seen in Figure 4.1

Table 4-1: Computation of expected flood in Prek Thnot watershed

Return period	Probability	f(x)	X (Gumbel) Baseline (cms)	X (Gumbel) Landuse Change (cms)	X (Gumbel) Climate Change (cms)
2.3	0.4	0.6	102.1	93.9	102.9
5.0	0.2	0.8	123.3	111.9	127.5
10.0	0.1	0.9	140.6	126.6	147.5
50.0	0.0	1.0	178.6	158.9	191.5
100.0	**0.0**	**1.0**	**194.7**	**172.5**	**210.2**

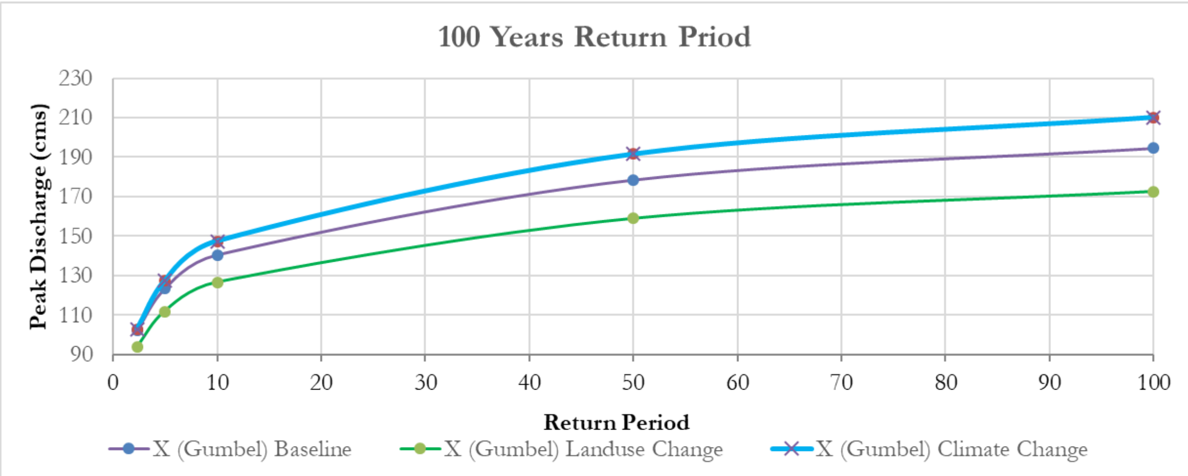


Figure 4-1: 100 years Return Period resulted from Baseline, Landuse change and climate Change

4.2 Annual and Seasonal Change at Peam Kley station

For the three scenarios, the differences in total flow volumes are subtle (Figure 4.2). At Peam Kley, for example, the change in average annual flows relative to the Baseline scenario is -2 % and +3% for the landuse change and climate change scenarios, respectively.

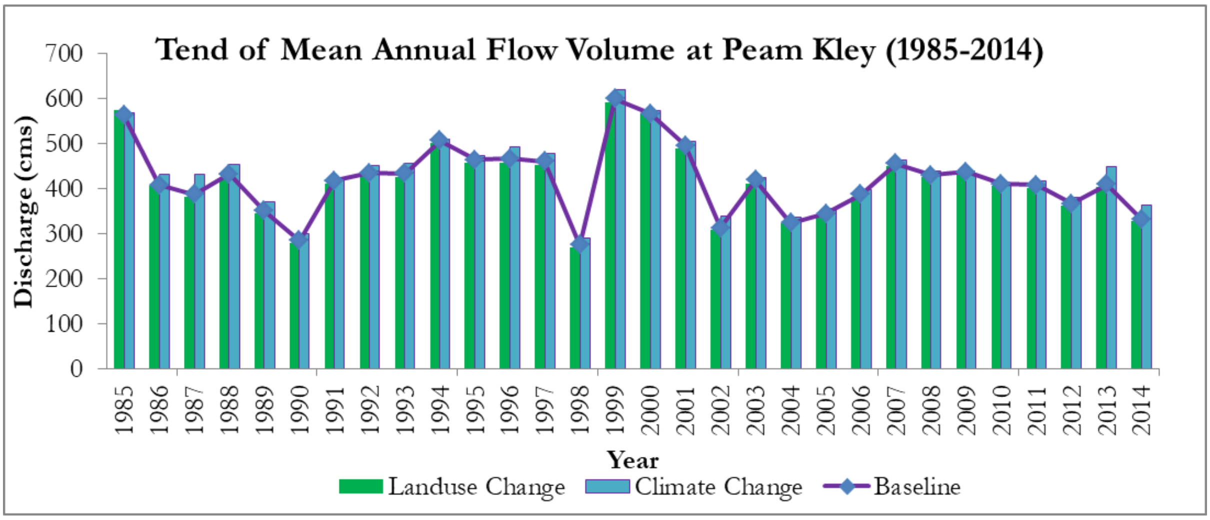


Figure 4-2: Mean Annual Discharge at Peam Kley resulted from Baseline, Climate Change and Land Use Change

However, the change in seasonal flow patterns between baseline and climate change is significant. The climate scenario changes the timing of the of the wet season flows, with peak flows occurring later in the year (Figure 4.3).

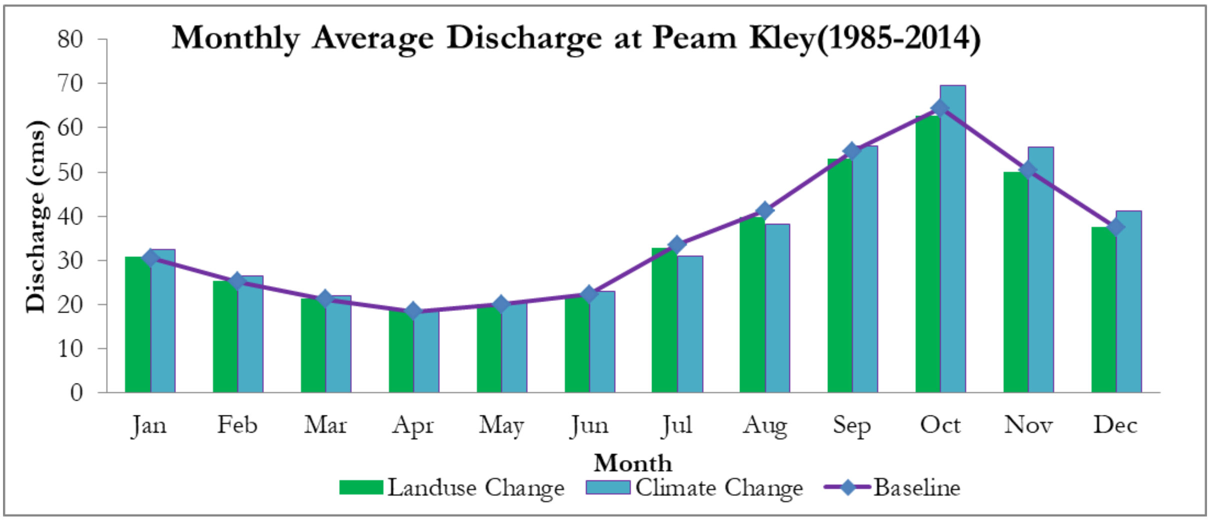


Figure 4-3 : Monthly Average Discharge at Peam Kley resulted from Baseline, Climate Change and Land Use Change

4.3 Spatial Analysis between Baseline and Scenarios Results

The SWAT model is used to assess the impacts of different scenarios including landuse change and climate change on hydrological processes in the Prek Thnot watershed. The Landuse change scenario, which represents increasing the forest land areas, preserving crop production and reduction of certain landuse types *(detail can be found in proposed land allocation in section 3.1)* results in slightly reduction in surface runoff and significant reduction in soil erosion in the Prek Thnot watershed but increase in groundwater recharge (Figure 4.4-4.6). In response to an expected future change of climate, the result in the hydrological components is predicted to increase in surface runoff, soil erosion as well as groundwater recharge relative to baseline (Figure 4.4-4.6).

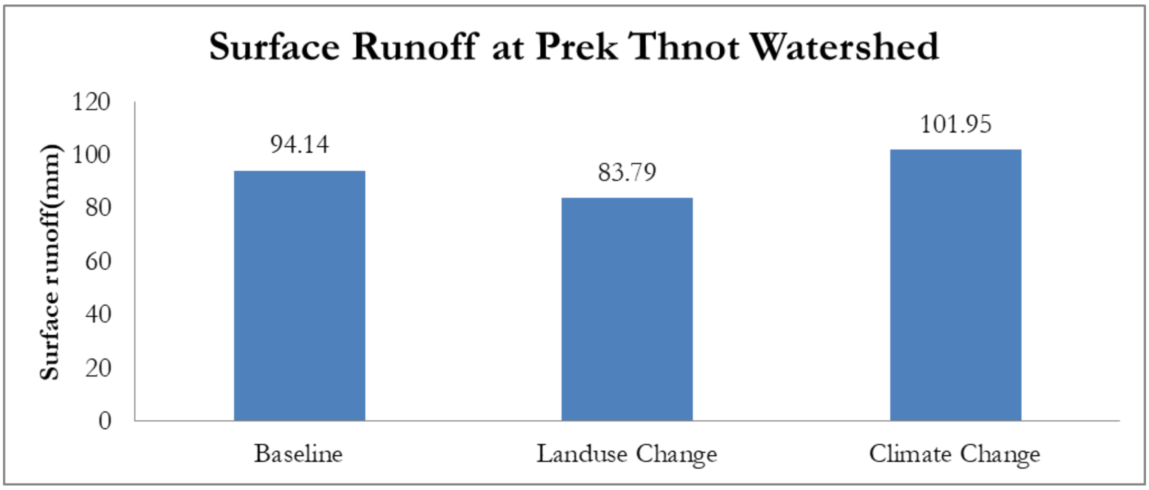


Figure 4-4: Surface Runoff under three scenarios development such as Baseline, Land use change and Climate Change

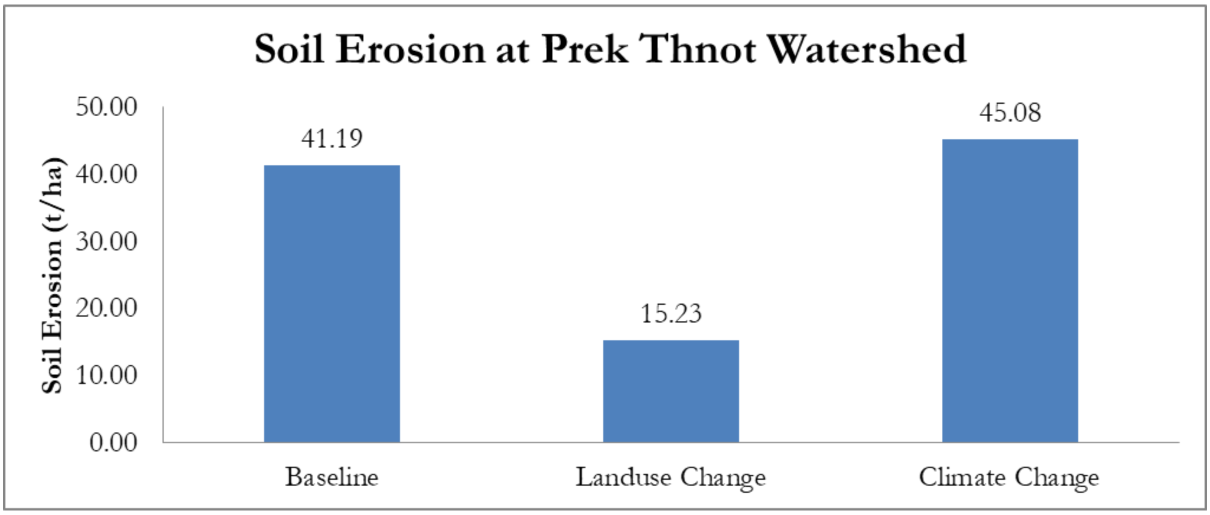


Figure 4-5: Soil Erosion under three scenarios development such as Baseline, Landuse change and Climate Change

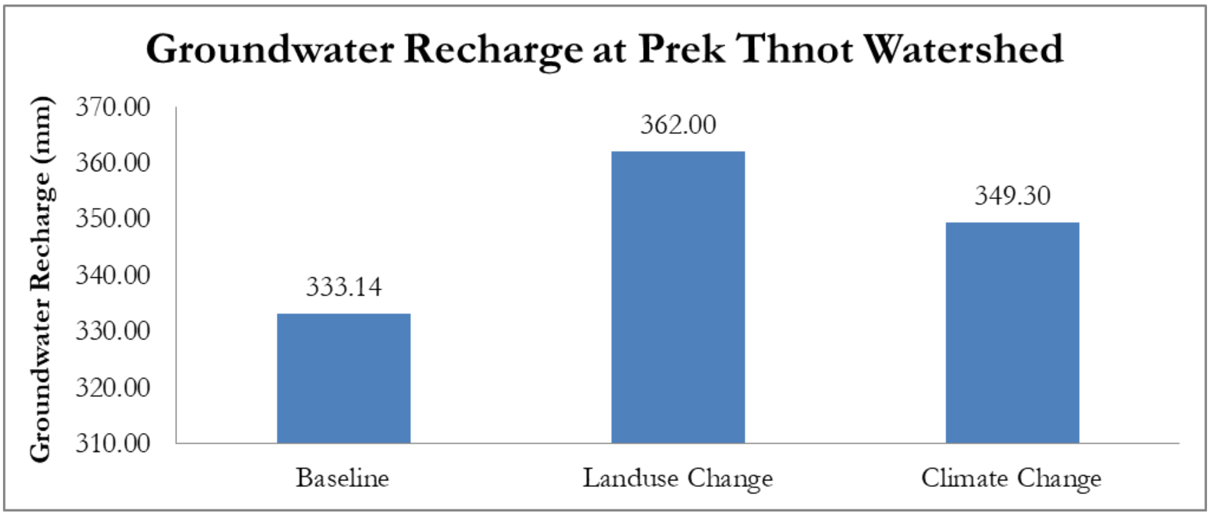


Figure 4-6: Groundwater Recharge under three scenarios development such as Baseline, Landuse change and Climate Change

For landuse change, the results of hypothetical scenario simulation has the effect of declining the surface runoff while climate change scenario, the model predicts an overall increase in surface runoff (Figure 4.7).

Despite decrease in the surface runoff in the Prek Thnot Watershed under the landuse change scenario, there is a drastic reduction in the soil erosion. In contrast, the climate change scenario results in an increasing in soil erosion (Figure 4.8).

For groundwater recharge, landuse change scenario results in a large increase in groundwater recharge within the Prek Thnot watershed while climate change scenario results in a slightly increase(Figure4.9)

➢ **Water Yield**

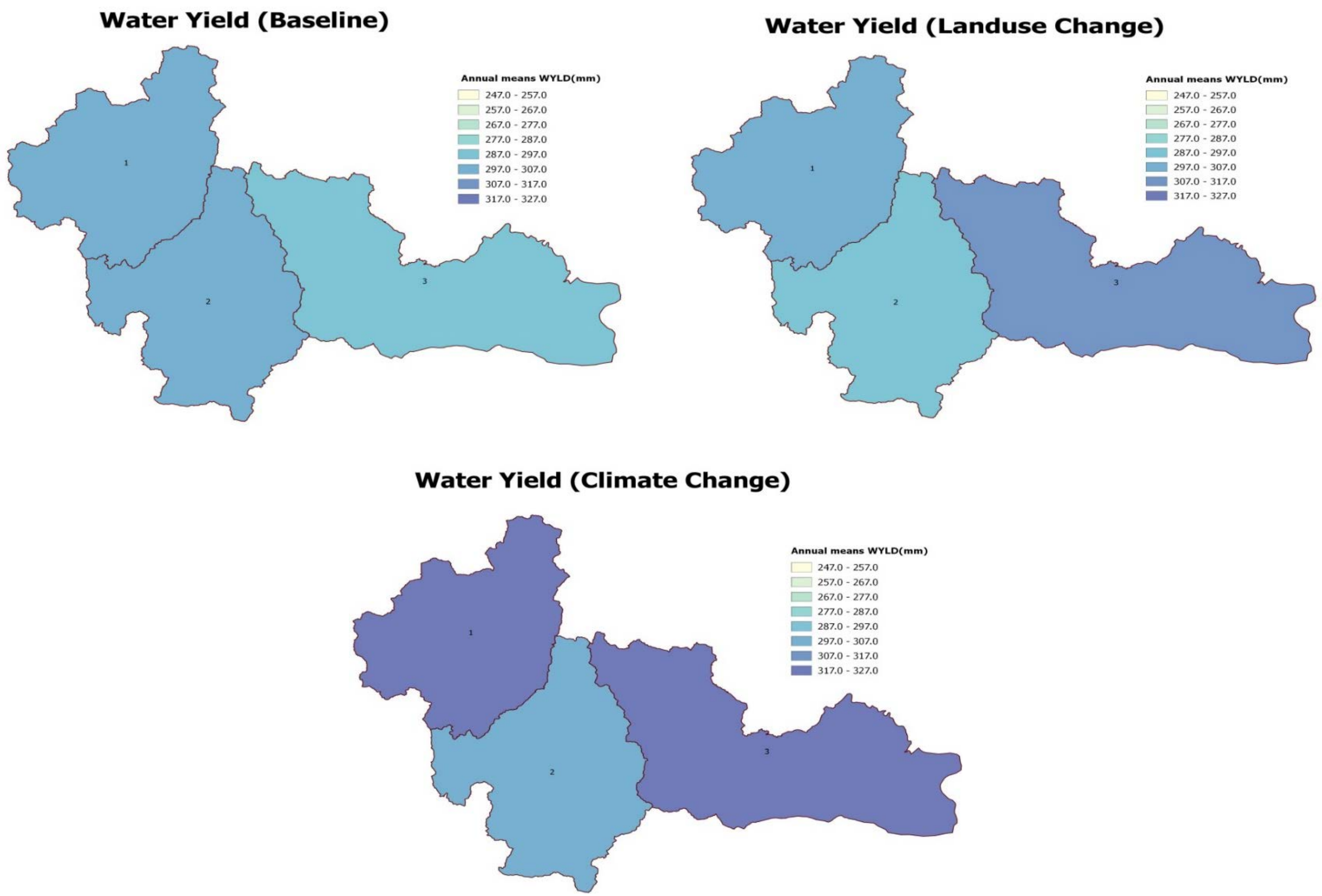


Figure 4-7: Water Yield under three scenarios development (a) Baseline, (b) Land use change and (c) Climate Change

➢ **Soil Erosion**

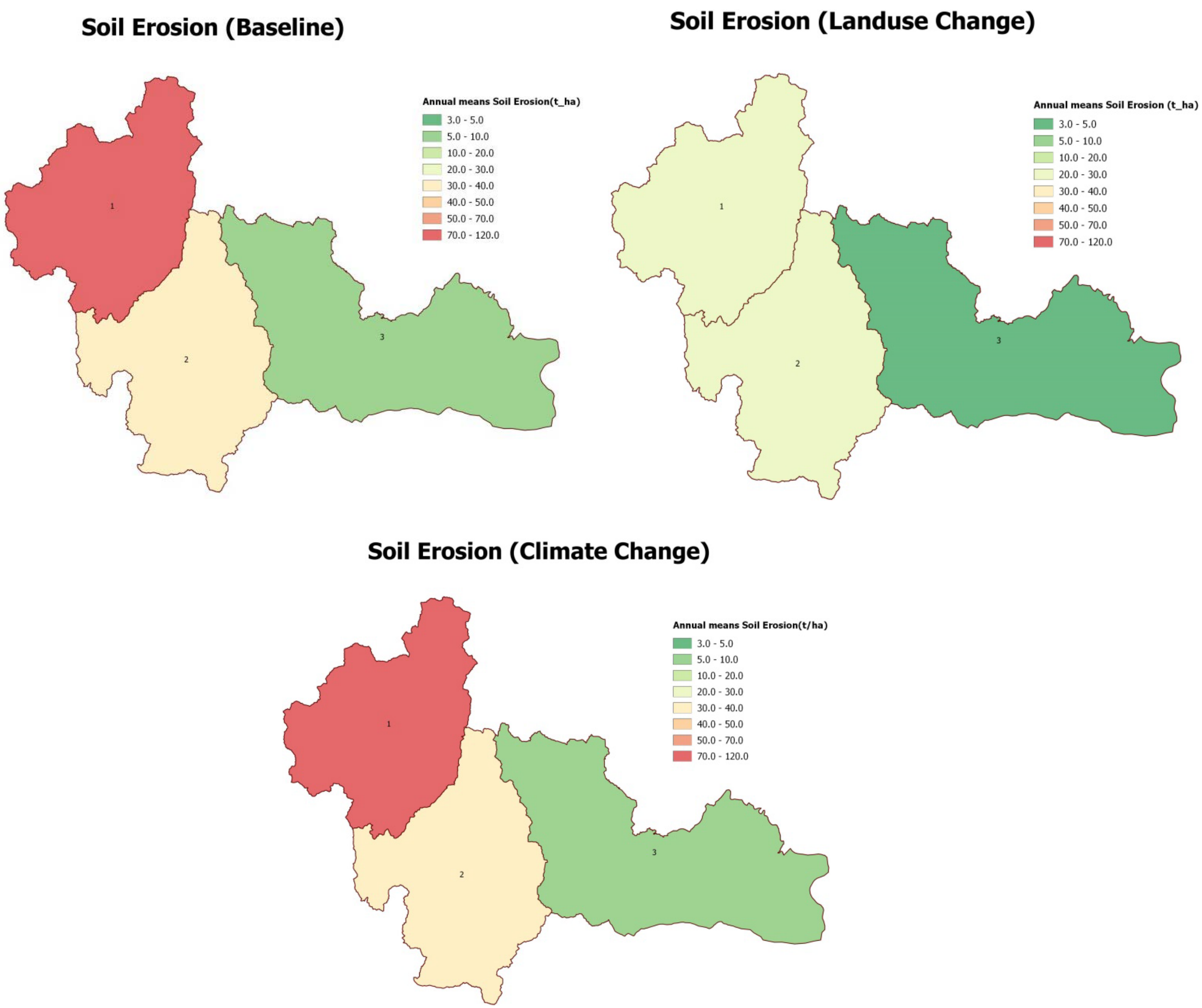


Figure 4-8: Soil Erosion under three scenarios development (a) Baseline, (b) Land use change and (c) Climate Change

➢ Groundwater Recharge

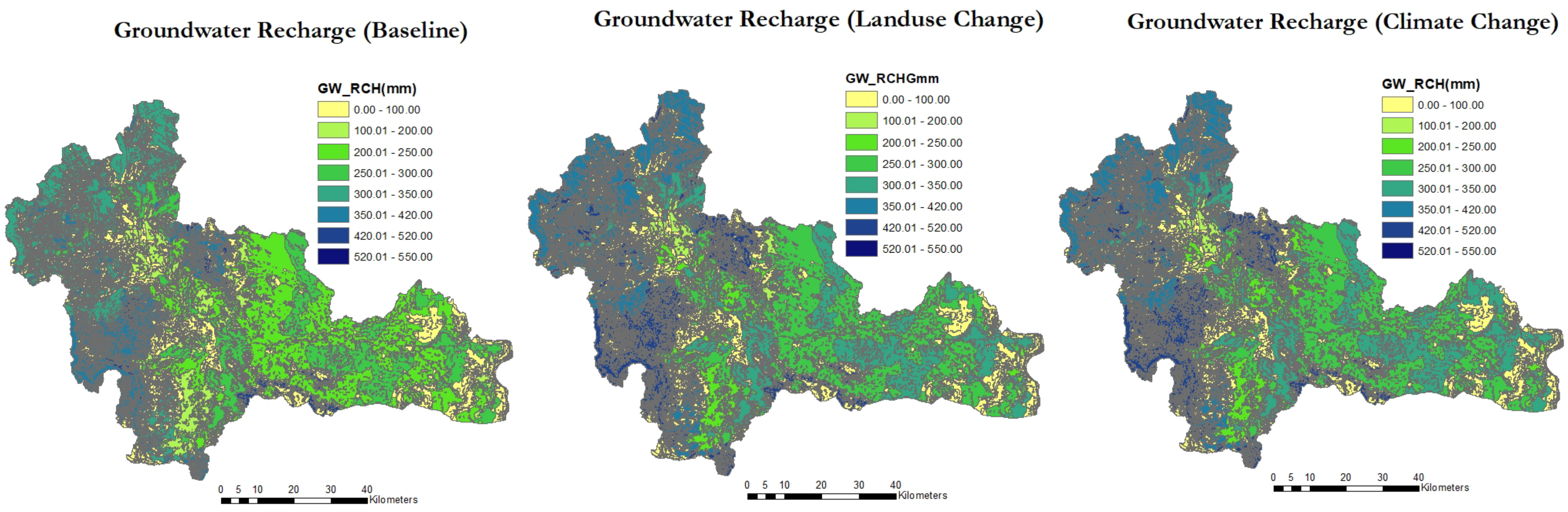


Figure 4-9: Groundwater Recharge under three scenarios development (a) Baseline, (b) Land use change and (c) Climate Change

5 Conclusion

SWAT is successfully employed to assess the potential impact of land use change (proposed land allocation) and climate change on streamflow, soil erosion and groundwater recharge within the Prek Thnot watershed.

A total of 14 model parameters are calibrated with observed daily runoff data for 1996-2008 and validated for 2009-2014 for baseline conditions. The baseline test results of Nash-Sutcliffe model efficiency (NSE) values ranged between 0.63 and 0.67 across the calibration and validation periods, indicating that SWAT accurately considered to be adequate for its intended use for further assessment. Consequently, we are able to identify the spatial and temporal aspects of the magnitude and direction of various development condition in the Prek Thnot watershed SWAT model together with spatial assessment tools.

In overall, the development scenarios of Landuse change result in a decrease in surface runoff and soil erosion but significant increase in groundwater recharge. These results further showed that increasing in Sustainable Forest Management (SFM), Rice Production preservation, reducing in Industrial Tree Plantations (ITP) and Industrial Crop (detail information can be seen in land allocation in section 3.1) has a higher capacity to conserve the water as compared to pasture land and other landuse types. The results of the land allocation simulation revealed that SFM under land allocation is the largest contributor to decrease in water yield and soil erosion but increase in groundwater recharge. Existing landuse under baseline condition covering urbanization, deforestation for paddy field and so on can be considered as a potential major environmental stressor controlling hydrological components.

For development scenarios of climate change illustrates an increasing of surface runoff with high soil erosion as well as groundwater recharge.

Large scale soil erosion would result in a loss of land around the Prek Thnot watershed which causes a serious problem on environment and productivities. More importantly, groundwater recharge reductions can also have deleterious effects for people living within the watershed as well as wildlife at Prek Thnot watershed. With proposed land allocation, the model resulted in decreasing soil erosion and increase groundwater recharge. Consequently, farmer will achieve higher yields , then poverty status at household level would be minimized.

In short, the results obtained from this study will be a value added for watershed manager and decision makers in watershed management responding to the predicted hydrological condition under future change of climate and landuse (land allocation).

6 References

Arnold JG, Kiniry JR, Srinivasan R, Williams JR, Haney EB and Neitsch SL, 2012. Soil and Water Assessment Tool, Input/Output File Documentation,Version 2012. Texas Water Research Institute. Technical Report 439, College Station, Texas

Calder, I.R., 1993. Hydrologic effects of land-use change. In: Maidment, D.R. (Ed.), Handbook of Hydrology. McGraw-Hill, New York, pp. 13.1–13.50.

Gitas I. Z., Douros K., Minakou C., Silleos G.N. and Karydas C.G., 2009. Multi-temporal soil erosion risk assessment in N. Chalkidiki using a modified USLE raster model. EARSel eProceedings8

Ma, L., J. C. Ascough II, L. R. Ahuja, M. J. Shaffer, J. D. Hanson, and K. W. Rojas. 2000. Root Zone Water Quality Model sensitivity analysis using Monte Carlo simulation. Trans. ASAE 43(4): 883-895.

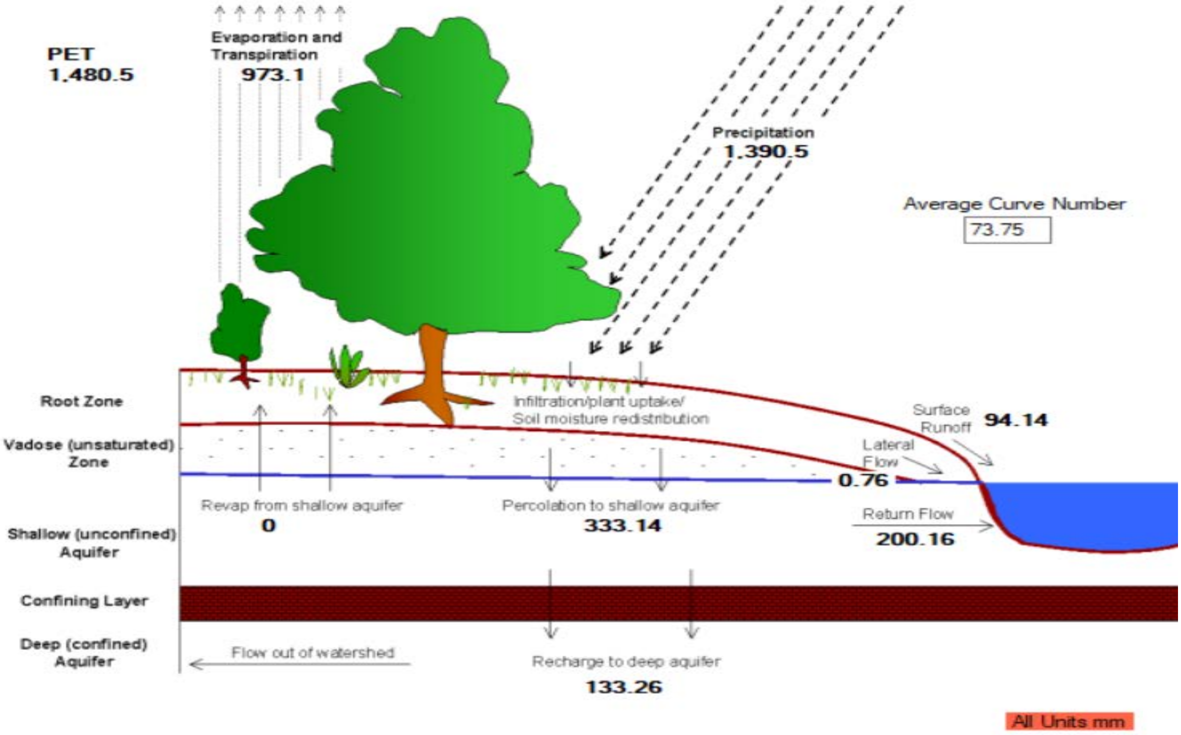
Montgomery D.R., 2007. Soil erosion and agriculture sustainability. Proceeding of the National Academy of Sciences of the United States of America. Vol 104(33), pp 13268-13272

Nash, J.E., Sutcliffe, J.V., 1970. River flow forecasting through conceptual models. Part I – A discussion of principles. J. Hydrol. 10 (3), 282–290.

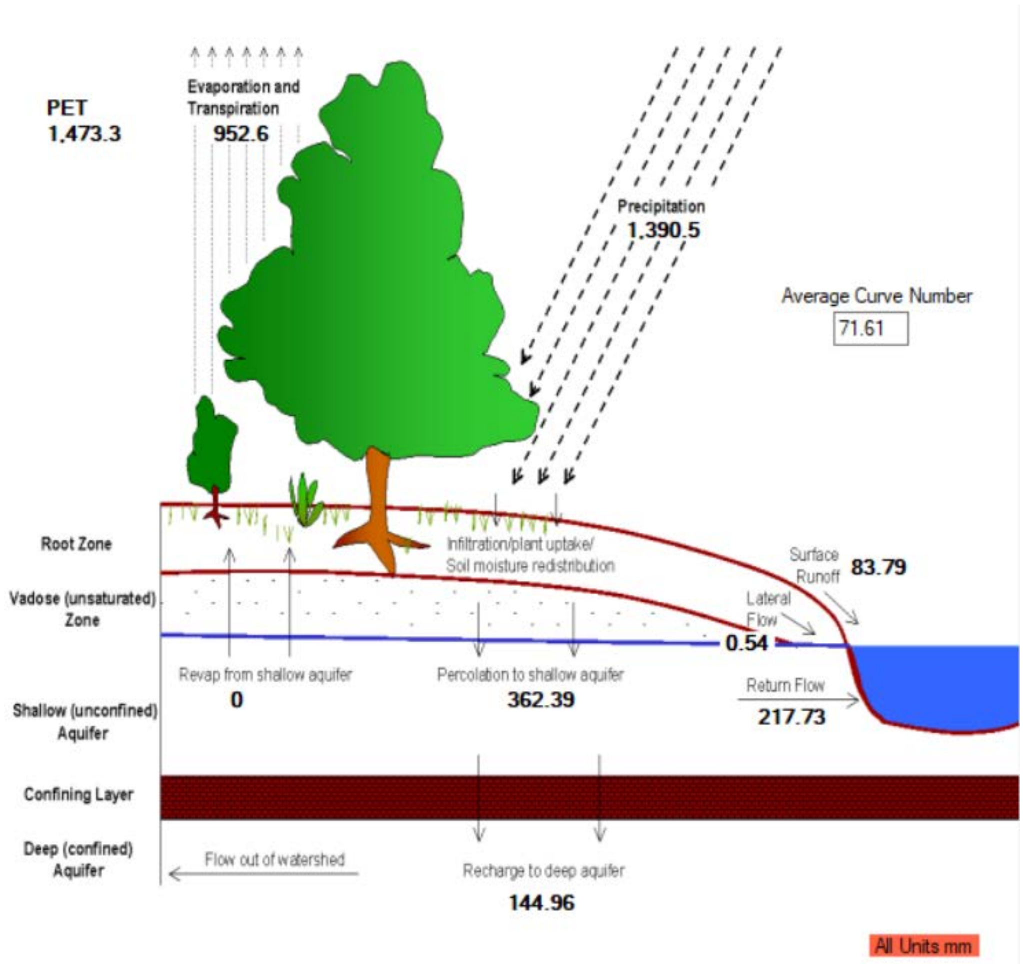
Neitsch, S.L., Arnold J.G., Kiniry J.R., Williams J.R. and King K.W., 2011. Soil and Water Assessment Tool – Theoretical Documentation – Version 2009.Grassland, Soil and Water Research Laboratory, Agricultural Research Service and Blackland Research Center, Texas Agricultural Experiment Station, Temple, Texas.

Appendix A: Overview of Hydrological phenomena derived from SWAT Check for baseline, land use change and climate change

- ✓ *Hydrology resulted from Baseline*



✓ *Hydrology resulted from Landuse Change (Land Allocation)*



✓ *Hydrology resulted Climate Change*