Shrestha, M., Shrestha, S., **Shrestha, P.K.** (2020):
Evaluation of land use change and its impact on water yield in Songkhram River Basin, Thailand
International Journal of River Basin Management **18** (1), 23 – 31

http://dx.doi.org/10.1080/15715124.2019.1566239

Publisher: Taylor & Francis & International Association for Hydro-Environment Engineering and Research

Journal: *Intl. J. River Basin Management*

DOI: 10.1080/15715124.2019.1566239

Evaluation of landuse change and its impact on water yield in Songkhram River Basin, Thailand

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Abstract

Songkhram River Basin (SRB), a wetland region and the largest Mekong tributary in the upper northeast region, is undergoing several changes. Understanding the impact of landuse change on the hydrological cycle is very important for a sustainable development and management of water resources in any watershed. This research aims to analyze the past landuse change, forecast the future the future landuse maps under various scenarios and finally analyze its impact on the water availability of SRB. The analysis of past landuse maps reveals a rapid conversion of crops, paddy and natural forest into rubber farms. The landuse change model DynaCLUE coupled with water yield module of InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs Tool) model was used to evaluate the impact of landuse change on the water availability based on different policy scenarios. Landuse maps up to 2100 were generated based on three future scenarios focused on economy, conservation and agriculture. The result of this study shows an increase in water yield under economic scenario as a result of increase in urban areas and rubber plantation whereas, a small decrease in water yield is seen under conservation scenario. However, no significant changes are seen under agriculture focus scenario. This study presents utility of landuse model analysis in foreseeing future landuse change impact on water availability. Thus, the results serve as model-backed reference to decision makers to formulate new policies or adjust the existing ones regarding landuse in SRB.

Keywords: *Dyna-CLUE, InVEST, water yield, landuse change, hydrology*

1. Introduction

Land use and land cover directly affects biogeochemical cycles, biodiversity, and people‟s livelihood through land surface processes (Trisurat, Alkemade, and Verburg 2010). Studying changes in land use dynamics, therefore, can help predict the effects of land use changes on land degradation, the feedback on livelihood strategies from land use degradation, and vulnerability of the places. Among the impacts of landuse change, the consequences on biodiversity and availability of natural resources are the most sensitive ones (Koomen, Rietveld, and de Nijs 2008).

In global extent, the landuse conversion over the last three centuries shows that the forest clearing for cropland has increase significantly since 1950. A report published by (ITTO, 2002) estimates 850 Mha (Million hector) of forest land has been degraded. Deforestation results into various negative consequences like increase in sediment yield, decrease in rainfall, increase in variability of surface runoff, and induce flood in rainy season and drought in dry season (Delang 2002). Moreover, changing landuse from forest area to agricultural and urban areas will have a profound impact on the hydrology, affecting the region‟s water quality and quantity. Changes in landuse alters the hydrological processes of a basin by affecting its soil infiltration, surface runoff and evapotranspiration (Dwarakish and Ganasri 2015; McColl and Aggett 2007).

Landscape and water resources management are the major challenges that the Southeast Asian countries are currently facing (Thanapakpawin et al. 2007). The impacts of changing landuse patterns, especially from natural to manmade, has created critical tensions from local to national levels. Consequently, most of the Asian countries have been experiencing frequent floods and droughts over the past decades. In the tropical areas like Thailand, conversion of natural landscape to agricultural one is particularly evident. With an annual rate of loss of 400,000 ha of forest, Thailand has lost 14.4 million ha of forest within 37 years (Charuphat, 2000). With that Thailand ranks first in terms of forest loss in the Mekong region (Trisurat, Alkemade, and Verburg 2010). This loss of forest can be attributed to mainly three reasons: 1) Conversion of forest land to farmland and urban-commercial land; 2) Legalization of forest logging in 1989 which was illegal before; and 3) Farming in the forest by highland minorities (ICRAF, 2001; Kaosa-ard & Rutherford, 2002). About 1.2 million agriculture household and 17,000 km of roads were added to the Northern Thailand during the period of 1976 and 1989 (Maureen Cropper Charles Griffiths 1999; Trisurat, Alkemade, and Verburg 2010). The Songkhram River Basin is no exception to these rapid changes in land use.

Even though the Government of Thailand has recognized the Lower Songkhram River Basin wetland as of international significance, there has not been any formal or legal action to protect it (Blake, D. J., Sunthornratana, U., Promphakping, B., Buaphuan, S., Sarkkula, J., Kummu, Osbeck 2010). As a result, the forest areas were slowly converted to agricultural land. However, the agriculture areas in recent years, are getting converted to cash crops with the promotion of rubber tree plantation by national agricultural policy. The area planted to rubber trees in the northeast region increased by 102.5 % in five years from 1998 to 2003. This increase can be prominently found in the Nakhon Phanom and Sakhon Nakhon Provinces (Blake and Pitakhepsombut 2006).

Land use changes can also have profound impacts on climate variability and affects the provisioning capacity of watershed (Meyer et. al, 1999). Numerous studies have been conducted on the impact of landuse change and hydrological processes. Lin et al. (2015) studied historical evidence of land use change impact using SWAT model in a coastal catchment in Southeast China. Wu et al. (2015) evaluated hydrological impacts of potential land use changes in Heihe River Basin of China using Soil and Water Assessment Tool (SWAT) and Dynamic Land Use System (DLS) models. The study concluded land use change to change water yield by almost 10% till 2030. In Yan et al. (2013), an integrated approach involving hydrological modelling and partial least squares regression (PLSR) was used to quantify the contributions of changes in individual land use types to changes in streamflow. Simpler approach for future land use change projections were observed to have been implemented in Neupane and Kumar (2015), Serpa et al. (2015), Lopez-Moreno et al. (2014) and Kalantari et al. (2014). Some other relevant studies worth mentioning include Bormann et al. 2009; McColl and Aggett 2007; Nandakumar and Mein 1997; Tang et al. 2011; Thanapakpawin et al. 2007. Therefore, for a comprehensive understanding of climate change impacts on a watershed and water system, it is important to investigate the land use changes. This study assesses the suitability of Dyna-CLUE model and InVEST model in the Songkhram River Basin with objectives to (1) analyze past landuse changes (2) to develop future landuse maps by based on various scenarios, and (3) assess the impact of future landuse change on the water availability of the river basin. The result of this study provides an insight on the factors affecting the landuse change in the basin, spatial and temporal landuse changes based on various future scenarios and finally the impact of landuse change and water availability.

2. Study Area

The Songkhram River Basin (SRB) lies in the northeast part of Thailand and has a total drainage area of 12,880 km^2. The basin covers a part of Udon Thani, Nong Khai, Sakon Nakhon and Nakhon Phanom provinces. The Songkhram River originates form Phu Phan Mountain and is the largest Mekong tributary of the upper northeast region. The annual average rainfall of the basin varies from 1200 mm at the southern part to more than 2000 mm at the northern part making the upper part of the basin more suitable for rice cultivation. The temperature of the basin ranges from 10^{0}C during winter to 40^{0}C during the summer. The SRB frequently faces problems of floods and droughts.

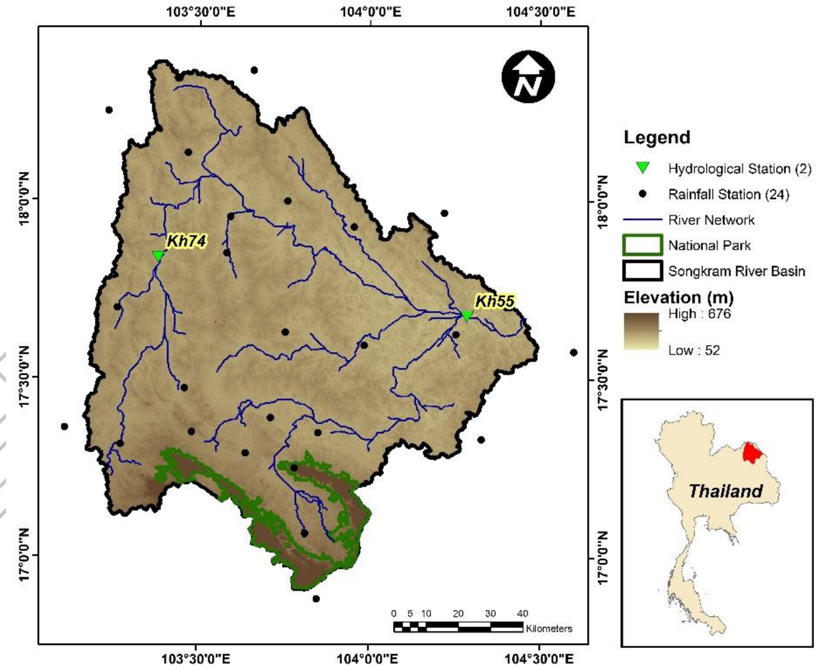


Figure 1: Location of study area

The landuse map of the basin for the periods of 2009 and 2014 was collected from Land Development Department (LDD) of Thailand. The land use type of the collected data were classified under seven classes (see Table 2). In recent years, the basin has been highly altered by human activities. Food crops currently covers 45% of the surface area and more recently rubber farms (termed as Planted trees) are getting more popular with farmers covering 18% of the total land. The forest area only covers 15% and the built-up area occupies around 4% of the basin. SRB also incorporates Phu Pha Lek national park.

3. Methodology

3.1. Landuse change modeling

The scenario base approach was adopted in order to investigate the scale and spatial landuse change of SRB and its implications on the water yield of the basin. Three plausible future scenarios were developed focusing on economy, conservation and agricultural policies. Landuse change was modelled using the spatial explicit allocation model, Dyna-CLUE (P. H. Verburg and Overmars 2009) up to the year 2100. The model has been proven to be suitable by various authors in different regions of the world (Koomen, Rietveld, and de Nijs 2008; Shoyama and Yamagata 2014; Trisurat, Alkemade, and Verburg 2010; P. H. Verburg and Overmars 2009).

3.1.1. Data used and model calibration

Dyna-CLUE model has several input requirements including initial landuse map of the area, explicit location suitability per land use type, restriction area, landuse specific conversion elasticity, and total demand of landuse. The initial landuse map of the area was defined as the year 2009. The landuse demand of each landuse type across the area based on each scenario was then prepared. Both physical and social drivers (See Table 5) of landuse were considered in the model to determine the suitability for a given landuse change. These driving factors were analyzed with logistic regression approach and were tested with the Receiver Operating Characteristics (ROC) method (P. Verburg 2010) . The value of ROC ranges from 0.5 to 1 where higher value represents good relation between drivers and landuse type.

Phu Pha Lek national park area was zoned as a restriction site where landuse change are not allowed in any of the future scenarios. The conversion elasticity of each landuse type were estimated with value ranging from 0 for easy conversion to 1 for irreversible change. The model was calibrated by changing the conversion elasticity for each of the landuse type. The simulated map of 2014 was then compared with reference map of 2014 using both visual inspection and kappa analysis to validate the model (Halmy et al. 2015). The value of Kappa lies between 0 and 1 with the latter bound meaning the simulation matches the actual image perfectly. The kappa value of 0.7 is considered as the threshold for model acceptance.

$$K = \frac{\Pr(a) - \Pr(e)}{1 - \Pr(e)} \qquad \text{Eq. (1)}$$

Where, Pr(a) is the observed relative agreement among all raster and Pr(e) is the hypothetical probability of change agreement.

3.1.2. Landuse change scenarios

The calibrated Dyna-CLUE model was then used to develop future landuse maps based on plausible socio-economic scenarios. Three scenarios (refer

Table **1**) were developed under three focus areas viz. 1) economic, 2) conservation, and 3) agriculture. The economic focus scenario represents business as usual where the rubber farming is increasing at 5.13% per year replacing crops, paddy and forest areas. Conservation focus scenario aims to improve the wildlife habitat of the area by increasing the forest cover to 25% by the year 2100. Finally, the agriculture focus scenario targets to increase paddy and crop production of the area by expanding the paddy and crop area. The paddy field and crops area in this scenario will cover 50% and 10% of the total SRB by the year 2100. All the future Landuse maps were generated restricting landuse changes in the National park site.

Table 1: Landuse scenario definition

Focus	Name	Restrictions	Definition
Economy	Eco	National park (NP)	Past trend with NP restrictions
Conservation	Con	National park (NP)	Increase forest to 25% of land by 2100
Agriculture	Agr	National park (NP)	Increase paddy to 50% and crops to 10% by 2100

3.2. Water yield modeling

Water yield module of InVEST was used to estimate the water availability of the SRB for each of the future landuse change scenarios. In order to perceive the change in water availability impacte by landuse change, climate and other factors in the future were kept constant. The model runs on a gridded map and is based on Budyko curve and annual average precipitation (Sharp et al. 2016). The water yield of each grid is calculated by subtracting actual evapotranspiration from precipitation and summing and averaging water yield to sub-watershed level. The data required for the model includes landuse map, average annual precipitation, potential evapotranspiration, soil depth, plant available water content, watersheds, sub-watersheds and biophysical table representing the attributes of each landuse. The precipitation data for twenty-four stations from Thai Metrological Department, potential evapotranspiration from CGIAR-CSI GeoPortal and soil properties from FAO were preprocessed in ArcGIS. The watershed and sub-watershed were delineated from ASTER DEM. A total of 99 sub-basins were created in the model for SRB.

The empirical constant Z captures the watershed characteristics of seasonality, rainfall and topography that are not described by the plant availability water content and annual precipitation (Sharp et al. 2016). The value of Z was use as a parameter to calibrate the model. The simulated annual water availability was converted to annual average discharge and was compared with annual averaged observed discharge at two hydrological stations.

4. Results and Discussion

4.1. Past landuse change

The area percentage of each landuse in 2009 and 2014 is shown in **Table 2**. The built- up area increased from 3.7% in 2009 to 4.3% in 2014. Similarly, the planted trees or the rubber plant landuse type has also increased significantly from 14.4% to 18% by 2014 with an increasing rate of 5.13% per year. However, decrease in crop, paddy and forest areas at a rate of 2.91%, 1.64% and 2.16% are observed within those five years.

Table 2: Land use area in SRB for the periods of 2009 and 2014

Code	Aggregated class	Thai landuse classification	2009	2014	% Change/ year
0	Crop	Field crop, Horticulture, Integrated farm/ Diversified farm, Orchard/Horticulture, Paddy field crop	5.9%	4.8%	-2.91
1	Built-up land	Village, Village, Transportation, Communication and Utility, Industrial land, City, Town, Commercial, Village/Orchard, Other built-up land, Pasture and farm house, Institutional land	3.7%	4.3%	3.43
2	Planted trees	Perennial, Orchard, Perennial/Orchard, Forest Plantation, Field crop/Perennial, Field crop/Orchard	14.4%	18.0%	5.13
3	Paddy	Paddy field	48.3%	45.1%	-1.64
4	Water Body	Reservoir (Built-up), Marsh and Swamp, Natural water body, Natural water body, Aquaculture land	4.9%	6.0%	4.78
5	Miscellaneous land	Other miscellaneous land, Mine, pit, Rangeland	5.8%	6.8%	5.54
6	Forest	Evergreen forest, Deciduous forest	17.0%	14.9%	-2.16

Three types of landuse change are possible; gross gain, gross loss and swap (Pontius, Shusas, and McEachern 2004; Shoyama and Yamagata 2014). Here, gain refers to increase in cell number of landuse class, loss refers to decrease in cell number of landuse class, and swap refers to change in location of landuse class.

Table 3: Summary of landuse change from 2009 to 2014 (% of area)

Landuse	Gain (1)	Loss (2)	Total Change (3) [1+2]	Swap (4) [2 X min (1, 2)]	Net change (5) [3-4]
Crops	1.5%	2.6%	4.1%	2.9%	1.2%
Built-Up land	0.8%	0.2%	0.9%	0.3%	0.6%
Planted trees	5.6%	2.2%	7.8%	4.3%	3.5%
Paddy	1.4%	4.4%	5.8%	2.8%	3.0%
Water	1.3%	0.2%	1.6%	0.5%	1.1%
Miscellaneous	2.5%	1.5%	4.0%	2.9%	1.1%
Forest	1.4%	3.4%	4.8%	2.7%	2.1%
Total	14.5%	14.5%	29.0%	16.5%	12.5%

Built-up land, planted trees and miscellaneous experienced more gain whereas, crops, paddy and forest experienced mores loss (**Table 3**). The highest gain was seen for planted trees in over 5.6% of the area followed by miscellaneous (2.5%) and built-up land (0.8%). Whereas, the highest loss was experienced by paddy (4.4%) followed by forest (3.4%) and crops (2.6%). The total change in landuse due to change in location was 57% while that due to quantity was 43%. This implies that change in landscape in SRB due to change in location is slightly higher than change due to quantity.

Table **4** shows the summary of landuse transition from 2009 to 2011. The highest transition (indicated in bold) implies that the crop, paddy and forest areas are being converted to planted trees. The reason can be the planted forest (rubber trees in SRB) provide much more income to the farmers compared to food crops. Similarly, the paddy field area is also being converted to built-up area and miscellaneous land. In addition, the built-up land and water was not converted to other landuse class suggesting high value of conversion elasticity. The diagonal values (indicated in italic) shows the percentage of area that remain unchanged during 2009 to 2011.

Table 4: Transition of landuse from 2009 to 2011 (% of area)

	2014							
2009	**Crops**	**Built-Up land**	**Planted trees**	**Paddy**	**Water**	**Miscellaneous**	**Forest**	**Total**
Crops	*3.3%*	0.1%	**2.0%**	0.1%	0.0%	0.3%	0.1%	6.0%
Built-Up land	0.0%	*3.6%*	0.0%	0.0%	0.0%	0.0%	0.0%	3.8%
Planted trees	0.7%	0.1%	*12.3%*	0.5%	0.1%	0.3%	0.6%	14.4%
Paddy	0.3%	**0.3%**	**1.7%**	*43.6%*	0.6%	**1.1%**	0.5%	48.0%
Water	0.0%	0.0%	0.0%	0.1%	*4.7%*	0.0%	0.0%	4.9%
Miscellaneous	0.1%	0.0%	0.5%	0.2%	0.3%	*4.4%*	0.2%	5.8%
Forest	0.4%	0.2%	**1.4%**	0.4%	0.3%	**0.8%**	*13.6%*	17.0%
Total	4.8%	4.4%	17.9%	45.0%	6.1%	6.9%	15.0%	100%

4.2. Landuse model setup and calibration

The landuse map of 2009 was used to setup the Dyna-CLUE model to simulate the landuse map of 2014. Five physical drivers; elevation, slope, aspect, rainfall and soil (5 types of soil area available in SRB based on FAO data) and four social drivers; distance from river, road, capital city and population density were selected to determine the suitability of location for each landuse types from the logistic regression analysis (Table 5). These factors were selected based on the previous study done by Lin et al. 2009. The ROC value between spatial distribution of landuse map and drivers were calculated. All landuse except the built-up land had ROC value of 0.7 indicating good relationship with the selected drivers. This low value of RCO can be attributed to the sparse distribution of urban-built up area. The water landuse type was considered to be constant during the analysis. In Table 5 the sign (+/-) is an indication of positive and negative correlation of landuse type and the drivers of landuse change respectively.

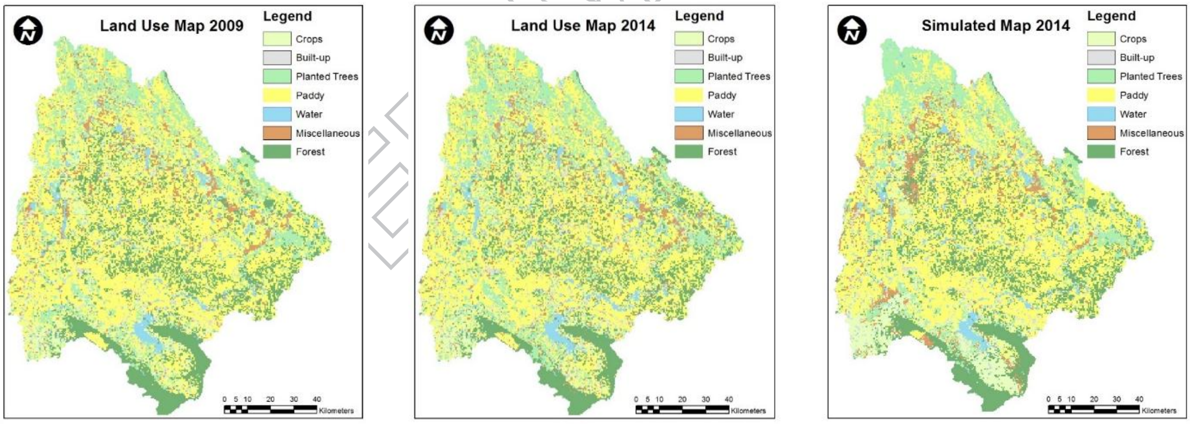
Table 5: Regression coefficient of the significant factors determining location suitability for the landuse type

	Drivers	**Crops**	**Built-Up land**	**Planted trees**	**Paddy**	**Miscellaneous**	**Forest**
cal dri	**Elevation**	.00377	-.00542	n.s.	-.00636	-.00623	n.s.

	Slope	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	Aspect	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	Rainfall	-.00197	n.s.	n.s.	.00121	.00107	.00083
	Ao_soil	n.s.	n.s.	n.s.	-1.689	n.s.	n.s.
	Ag_soil	.39875	n.s.	n.s.	-1.529	n.s.	n.s.
	Af_soil	n.s.	n.s.	n.s.	-1.101	n.s.	n.s.
	Gd_soil	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	Ge_soil	.47685	-.69405	n.s.	-2.634	n.s.	n.s.
Social drivers	**Distance from river**	.00005	n.s.	n.s.	-.00005	n.s.	-.00004
	Distance from road	-.00006	n.s.	n.s.	n.s.	-.00005	.00012
	Distance from capital city	.00000	-.00001	.00003	.00000	.00001	-.00002
	Population density	-.00640	.00710	-.00684	.00709	n.s.	n.s.
	Constant	2.331	-3.149	-4.248	-0.560	-4.689	-2.08236
	ROC	**0.7**	**0.6**	**0.7**	**0.7**	**0.7**	**0.7**

n.s. not significant at 0.05 level; Ao, Ag,Af, Gd, and Ge are soil types

The analysis of temporal and spatial prediction of the Dyna-CLUE model was analyzed both visually and by Kappa index. The simulated map from model and reference map for the year 2014 are shown in figure 2. The kappa index was calculated to be 0.75, which indicates that model is reliable for land use change simulations.



(a) (b) (c)

Figure 2: (a) Reference landuse map for year 2009 (b) reference landuse map for year 2014 and (c) simulated landuse map for year 2014

4.3. Future landuse maps

Landuse maps in three time window as Near future (2021~2040), Mid future (2041~2060) and Far future (2061~2099) represented by landuse map of 2030, 2050 and 2080 is shown in **Figure 3**. There is a large variation on water coverage in the SRB due to the effect of backwater flow from Mekong River and rainfall during the monsoon season. This causes around 31% of the total Lower Songkhram River Basin to be under water for two to four month (Blake and Pitakhepsombut 2006). Since, Dyna-CLUE can only predict landuse change at annual scale and not seasonal or monthly scale, the water class for the study was excluded from the analysis and assumed to remain same as in the base period.

Scenario focusing on the economic growth of the region shows that more than half of the area of the basin will be covered by planted trees if the rate of increase in rubber plantation remains same as in the past (

Table 6). This will have a huge impact on the paddy, crops and forest as almost all of the area will be converted to rubber farms. The total forest area will drop from 15% to just over 5% by the end of the century. The expansion of the planted trees starts from North slowly moving towards the south and west part of the basin. Similarly, the urban area is also expected to increase nearly 3 times signifying the economic boom.

Under conservation scenario, natural forest will gradually start to expand from the area near to national park and will cover 22% by the mid-century. This scenario will restrict the rapid expansion of built-up area which will cover only 6% of the total area. The basin will also experience a decrease in the rubber farm and paddy fields so as to compensate the expanding the forest.

Scenario focusing on increasing agricultural production in the region tends to have negligible amount of changes in the basin for forest area. The percentage of forest area will remain same as in the base period of 17%. However, all the miscellaneous area will be converted to paddy field to increase the agricultural production of the basin. The urban area will increase more than two times covering around 9% of the total area. Similarly, the rubber farms are also converted to crops and paddy field which brings down the percentage area of covered by rubber farms to 4% by the end of the century.

Table 6: Future landuse projection by percentage of total area under Eco, Con and Agr scenario (Near: 2021-2040, Mid: 2041-2060, Far: 2061-2099)

		Class						
Scenario	**Period**	**Crop**	**Built-up Area**	**Planted trees**	**Paddy**	**Water**	**Miscellaneous**	**Forest**
Economy (Eco)	Near	5%	4%	27%	37%	5%	11%	12%
	Mid	3%	11%	42%	20%	5%	10%	10%
	Far	1%	11%	51%	5%	5%	20%	6%
Conservation (Con)	Near	10%	4%	14%	48%	5%	2%	17%
	Mid	9%	6%	13%	43%	5%	4%	22%
	Far	10%	6%	12%	37%	5%	1%	28%
Agriculture (Agr)	Near	11%	4%	11%	51%	5%	0%	17%
	Mid	11%	5%	9%	54%	5%	0%	17%
	Far	11%	9%	4%	54%	5%	0%	17%

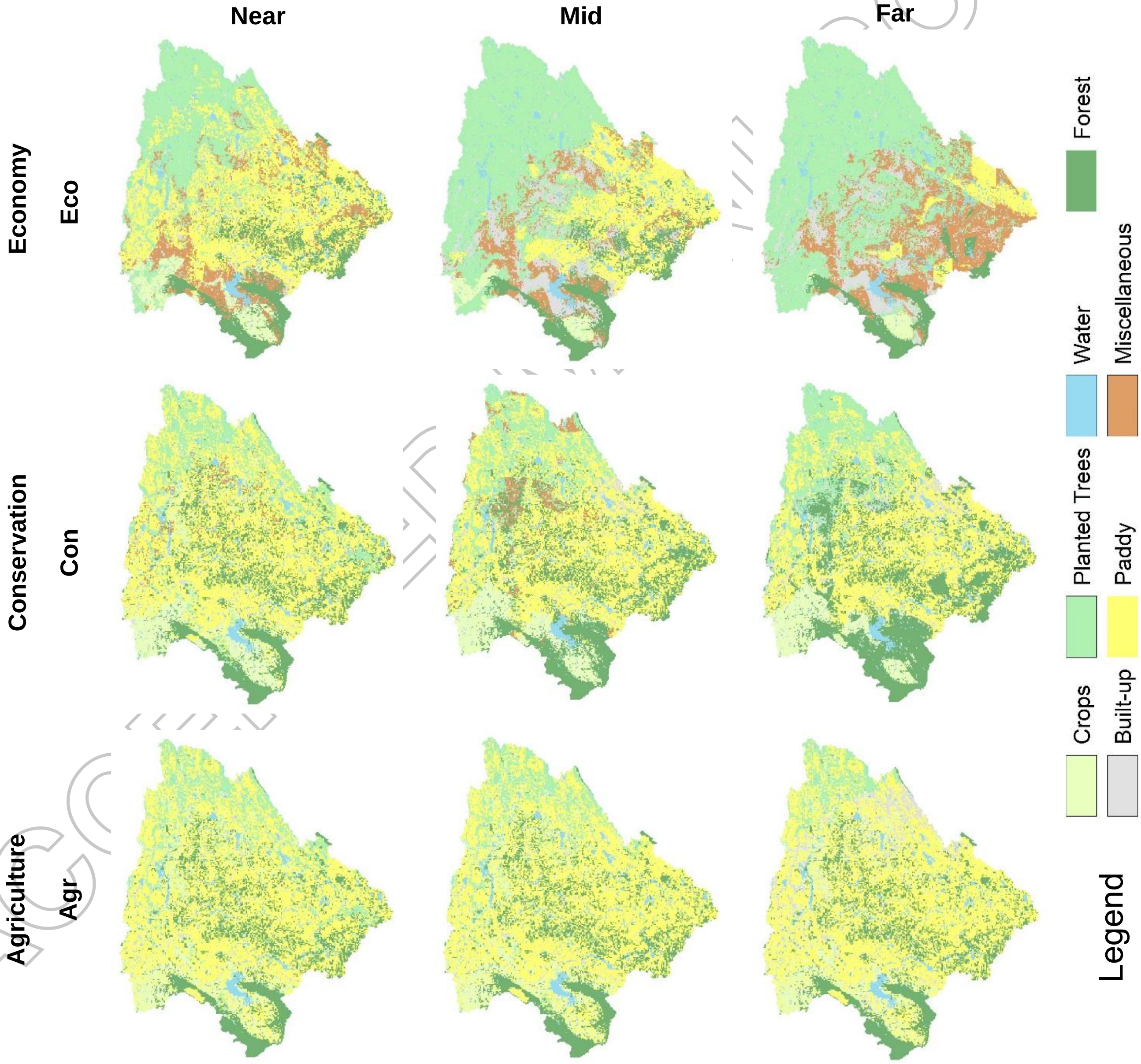


Figure 3: Projected landuse maps for different scenarios (Near: 2021-2040, Mid: 2041-2060, Far: 2061-2099)

4.4. Water yield model setup and calibration

The landuse map of 2014 was used to setup the InVEST model to simulate the water yield at each of the sub-basins. The annual average water yield at two points at station Kh55 and Kh74 were simulated and compared with the annual average observed water yield. The Z value corresponding to the seasonal distribution of precipitation and is generally lower if the region is influenced by monsoon and the wet and dry seasons are distinct (Trisurat et al., 2016). The empirical constant Z was tuned to calibrate the model and the value of 2.3 was found to be the optimum value. InVEST model calculates water yield in m^3/year, which was converted into units of m^3/s to compare with the observed data. The difference between the simulated and observed water yield in m^3/s is shown in **Error! Reference source not found.**. The model was able to capture the water yield of the SRB with very low discrepancies of -5.6% (underestimation) and 7.3% (overestimation) at Kh55 and Kh74 stations respectively suggesting that the effects of land use and land cover are adequately captured by the model. The ±10% difference in accuracy of the model is considered to be very good rating based on Moriasi et al. 2007.

Table 7: Comparison between observed and simulated discharge

Station	Obs m^3/s	Sim m^3/s	Diff %
Kh55 (outlet downstream)	275.4	260.7	-5.6
Kh74 (upstream)	39.6	42.7	7.3

4.5. Change in water yield

The calibrated InVEST model was then used to simulate the spatial and temporal water yield of the SRB using different landuse maps generated from different future scenario keeping other parameters constant. The model is based on Budyko curve and is a simple method to estimate the evapotranspiration of a natural uninhabited basin and have be used extensively in many study (Donohue et al., 2012; Xu et al., 2013; Wang and Tang, 2014). But, under economic scenario, urban area in the Songkram Basin is expected to reach 11%, and this method may not be able to capture the changes in water yield accurately. However, the goal here is to provides a useful preliminary assessment of how landuse scenarios may affect the annual delivery of water rather than provide to a high degree of accuracy and precision.

With the expansion of planted trees and decrease in agricultural land and forest area, described by economic scenario, the water yield of the basin increases. In addition, the urban area is expected to increase by three folds. As a result, there is a decrease in evapotranspiration from forest area and paddy field. The largest change can be seen at the southern and central of the basin. The water yield increases with time with the replacement of paddy field by planted trees. The water yield of the basin will increase by 11% during the far future. This could have a serious implication on the already recurring floods at the Songkhram River Basin.

Under the conservation scenario, the water yield of the basin decreased from 0.7% in the near future to 8% in the far future compared to present scenario (see Figure 4). This decrease is due to increase in evapotranspiration from the forest. The decrease in the water yield can be prominently seen in the southern part of the basin where the forest expansion starts. The change in northern and central part of the basin remain constant throughout the time period.

Under the agriculture scenarios, the impact on the water yield is very low as the agriculture area remains nearly same in the future. The forest area remains same throughout the study period, however the planted trees and the miscellaneous area decreases. Due to this, there is a small increase in evapotranspiration and slight decrease in water yield for near and mid future whereas there is a slight increase in water yield in the far future.

Even though the change in water yield at basin level is less than 12% (see figure 4), the changes in spatial variation is upto ±100% (see figure 5). The water yield model is likely to under or over estimation the water yield simulations by upto 7.3% therefore utility or acceptability of the model results should be viewed in terms of relative uncertainty.

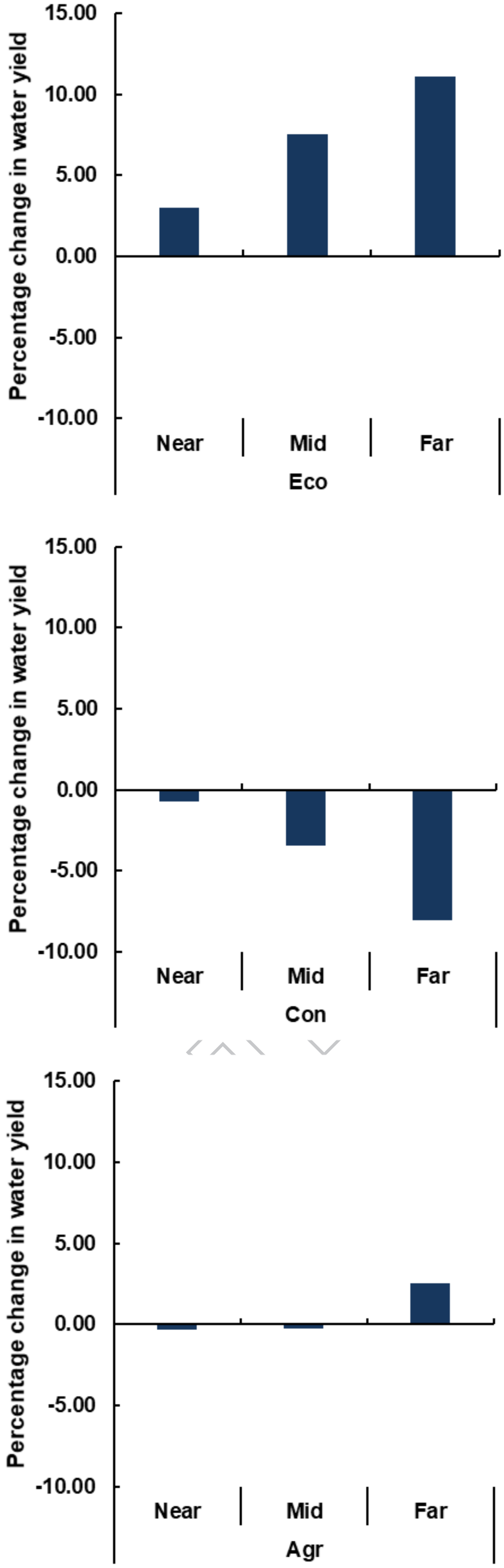

15.00
10.00
5.00
0.00
-5.00
-10.00
Percentage change in water yield
Near
Mid
Far
Eco
Con
Agr

Figure 4: Percentage change in water yield of SRB under Economy, Conservation and Agriculture scenario

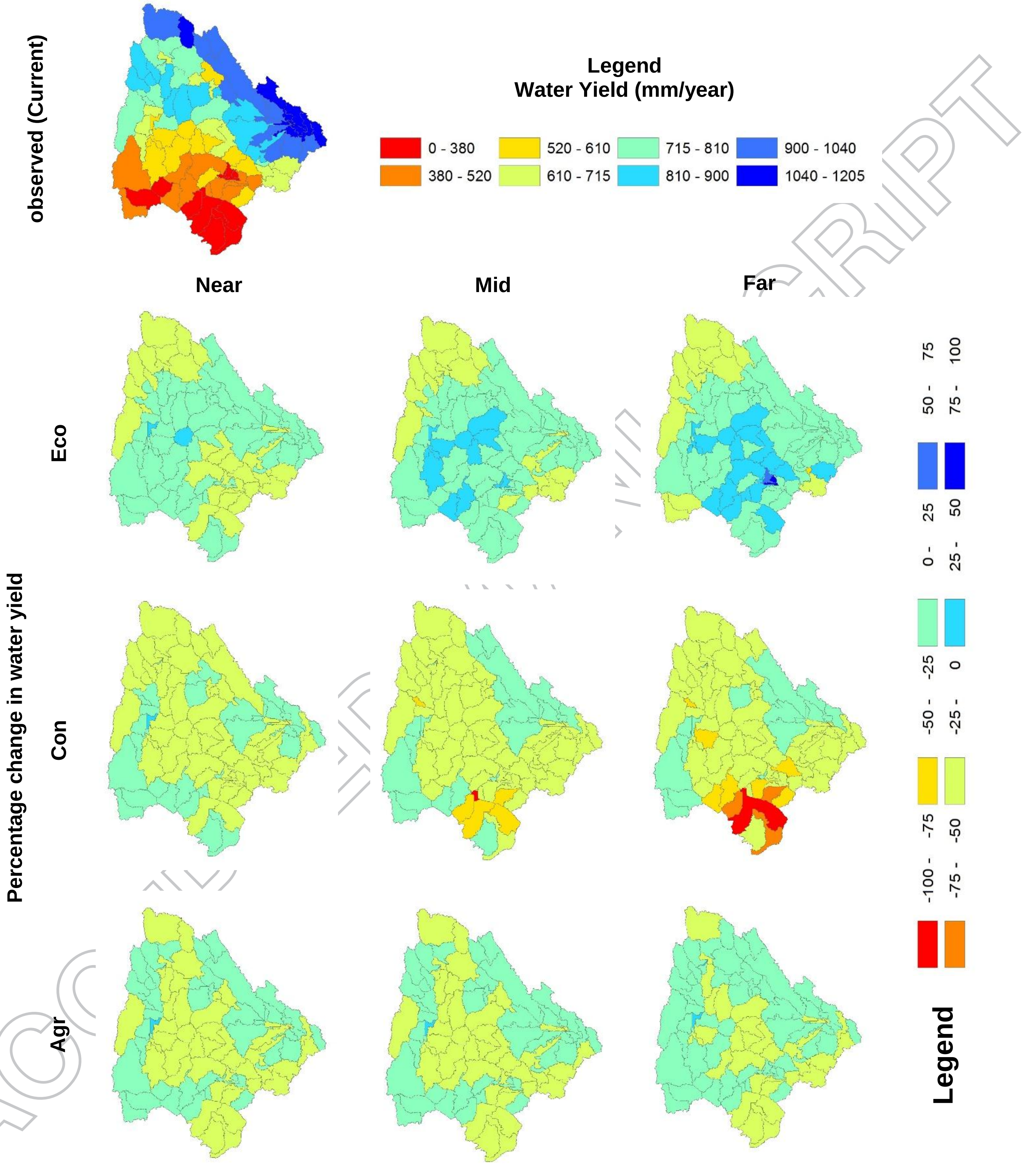


Figure 5: Percentage change in spatial and temporal water yield of Songkhram River Basin under different scenarios

5. Conclusion

This study combines a landuse change model Dyna-Clue with water yield model of InVEST to assess the future spatial and temporal water availability of Songkhram River Basin of Thailand. Physical drivers like elevation, slope, aspect, rainfall and soil types and socio-economic drivers like distance from river, distance from road, distance from city center and population density were used to analyze the probability of landuse changes in the basin. Three plausible future scenarios were developed focusing on economy, conservation and agricultural to predict the future landuse change of the basin up to the year 2100. The resulting landuse map were used as an input in the InVEST model to calculate the future water availability.

Under the economic scenario, the basin is expected to cover half of the area by planted trees due to high demand of rubber plant following the present trend. In this scenario, the urban area is expected to increase three folds resulting in the increase of water availability by 10% compared to the baseline period. This can have an adverse effect on the already recurring floods in the Songkhram River Basin. However, in the conservation scenario, where the area of natural forest is to increase more than 25%, the water availability is expected to decrease slightly by 8%. This decrease can be attributed to increase in the evapotranspiration and can be seen in the southern part of the basin. This scenario also restricts the rapid expansion of the urban area and decreases the planted trees. Finally, for the agriculture scenario, the landuse change pattern is not expected to change significantly. The miscellaneous area and planted trees will be replaced by crops, paddy and urban areas whereas the forest area is expected to remain unchanged. Negligible amount of water yield changes is seen in the future. This study presents utility of landuse model analysis in foreseeing future landuse change impact on water availability. Thus, the results provides a useful preliminary assessment of how landuse scenarios may affect the annual water yield and serves as model-backed reference to decision makers to formulate new policies or adjust the existing ones regarding landuse in SRB.

Acknowledgements

This research is supported by The Hong Kong and Shanghai Banking Corporation Limited (HSBC) and is a part of the project „*Building Capacity and Strengthening Community Participation for Water Resources Management and Wetland Ecosystem Restoration in the context of Climate Change in Lower Songkhram River Basin'* (contract no. WWF TPO 006/2015, http://wetlandwatchthailand.org). Asian Institute of Technology and World Wildlife Fund (WWF) Bangkok are the project collaborators. In regards to data support, authors would like to acknowledge the Thai Meteorological Department (TMD) for the meteorological data, Land Development Department (LDD) for the landuse maps and Royal Irrigation Department (RID) for the river discharge data.

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