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Research Paper

Integrated impacts of climate change and land use change on surface hydrology in the future in Nakdong river basin in Korea

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ABSTRACT

The main objective of this paper is to forecast the integrated impacts of both climate change and land use changes on surface hydrology which is focused particularly on streamflow assessment under scenarios (A2, B1, and A1B) of climate change and land use change (2030, 2050, and 2080) in Nakdong basin by combination of both models as hydrology model (ArcSWAT) and land use change model (CA_Markov). The results indicated that the mean annual integrated impacts of climate change and land use change on streamflow in the future showed an increase tendency for all periods under scenarios A2, B1, and A1B. However, B1 scenario showed the highest of +3.97%, while A2 showed the lowest increase of +1.1%. However, the mean months of streamflow showed different changes that were forecasted large changes as an increase from +12 to +18% in months of Jan, Feb, Jul and Aug, while it showed a significant reduction from -9.0% to -19% in May and Oct for all periods under A2, B1, and A1B scenarios. Moreover, results were also to reveal that land use change and climate change both increased on the mean annual streamflow, but the impact of climate change was higher than that of land use change.

1. Introduction

In fact, there are many factors impacting hydrology process, which directly influenced surface hydrology specifically on the streamflow in river, the climate change and land use change are two main factors, and they strongly affected streamflow in river basin, which did not only happen last decades but also continues in the future. It is clearly realized that the change in climate is possible from the fossil fuel consumption that has caused an increase in anthropogenic emissions of carbon dioxide (CO2) and other greenhouse gases (IPCC, 2007). Due to higher concentrations of these gases in the atmosphere, the proportion of solar radiation hitting the Earth that is reflected back into space is reduced, leading to a net warming of the planet (Kalnay and Cai, 2003). The magnitude of this increase will depend on future human activities, but all IPCC (2007) scenarios have predicted that increases in atmospheric greenhouse gas concentrations will raise surface temperatures, and other changes as in precipitation, evapotranspiration rates. These changes will in turn affect runoff and thus may affect alterative regional hydrologic conditions and result in a variety of impacts on water resource systems. There are many coupled atmospheric ocean general circulation

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Note: Discussion on this paper is open until June 2019 model (AOGCM) experiments have been performed in the past two decades to investigate the effects of increasing greenhouse gas concentrations. For example, the effect of increasing greenhouse gas concentrations global climate according to the studies indicated that a rise in global mean temperature of between 1.4ºC and 5.8ºC would be expected following a doubling of carbon dioxide (CO2) concentrations in future (Houghton et al., 2007). The changes in precipitation and temperature in the past three decades are more variable projections especially for smaller basins as change from 6.6% to 9.3% in precipitation, and increase from 0.8 ºC to 3.2 ºC in temperature in the future in Korea (Bae. D.H et al., 2011). The temperature and precipitation change have significant effects on water yield, and stream flow. Increasing CO2 concentration to 970 ppm and temperature by 6.4 °C caused, resulting in increases of water yield by 36.5%, and stream flow by 23.5% compared to the present-day climate that are simulated on average over 50 years (Darren L. Ficklin, et al., 2009). Over the past 50 years average temperature in Vietnam has increased about 0.5-0.70C, and the consequences of climate change are considered to be serious and present significant threats to the achievement of Millennium Development Goals and nation’s sustainable development. Moreover, the climate change is undergoing globally at some different regions, as an example, in Europe the mean annual temperatures is likely to increase more than the global mean, with the largest warming in the summer for the Mediterranean area, but annual precipitation is very likely to decrease (Christensen et al., 2007). In addition, climate model projections also show an increase in the global mean surface air temperature, all climatic processes are not only the average climatic conditions change, but also their variability and frequency (IPCC, 2001). This is likely to lead to a more vigorous hydrological cycle that will in turn affect water availability and runoff and thus may affect the discharge regime of rivers. Therefore, the impact of climate change on the hydrological regime is an important aspect of water resources management, reservoir storage design, as well as safe surface water withdrawals. On the other hand, some studies have been carried out to estimate the effect of land use changes on the hydrologic response of catchments. The principle of the paired watershed design has served as the reference for all research of the impact of land use changes on hydrology (Ranjith et al., 2002; Bishop et al., 2005). Other researches were used SWAT model to simulate the surface hydrology and water resources of catchments. For example, Vache et al., (2002); Bosch et al., (2005), where impacts of various management scenarios were investigated; Stonefelt et al., (2000); Fontaine et al., (2001); Van Liew and Garbrecht, (2001); Stone et al., (2001); Varanou et al., (2002), who studied the impacts of climate change on water yields. Most of these studies concluded that SWAT is suitable for long-term simulations for monthly and yearly and that daily flows are simulated with lower efficiencies. Other SWAT applications include Srinivasan et al., (1998a,b); Spruill et al., (2000); Zhang et al., (2003); Singh et al., (2005); Pohlert et al., (2005, 2006), among many others. In Korea, SWAT model has been applied such as Choi et al., (2011) in Yongdam reservoir covers. SWAT has been applied in various studies to assess watershed response to land use changes. Fohrer et al., (2001) used hypothetical land use changes to support the development of sustainable land use concepts although the impact of land use change on the annual water balance was relatively small, Heuvelmans et al., (2004) also used hypothetical scenarios to assess implications of land use impact on catchment hydrology. Pikounis et al., (2003) studied hydrological effects of specific land use in a catchment in Greece, which resulted in an increase in discharge during wet months and a decrease during dry periods, while the deforestation scenario resulted in the greatest modification of total monthly runoff. Eckhardt and Ulbrich (2003) used climate change scenarios that resulted in small effects on mean annual stream-flow, as increased atmospheric CO2 levels reduce stomata conductance thus counteracting increasing potential evapotranspiration induced by the temperature rise and decreasing precipitation. Manoj et al., (2006) used both CO2 sensitivity and GCM climate change scenarios in upper Mississippi River Basin. They concluded that the climate change scenarios showed a large degree of uncertainty in the climate change forecasts for the region and that the simulated hydrology was very sensitive to those forecasts.

Easily to realize that, there are several different between climate change and land use/land cover change that impact on streamflow. Example: while climate change effects on the flow routing time, peak flows and volume (Prowse et al., 2006), surface runoff change (Lee et al., 2010), while land use and land cover change that is also change in different spatial in river basin and it can be the results of change of flood frequency, base flow (Wang et al., 2006), the land use impact on hydrology and water quality (Jong et al., 2009)

Recent, there were many researches considering for assessment to hydrological impacts of only climate change (Zhi et al., 2009), or only land use (Yu et al., 2007), (Park et al,. 2008) analyzed impact of land use change on hydrology and water quality. In addition, such as (Faith et al., 2009;) used SWAT model to simulate the climate on the stream-flow, (Antje et al., 2009) used

SWAT model to predict the impacts of alternative management practice on water quality and quantity. (Alexandra D et al., 2005) used a cellular automata model to forecast the effects of urban growth on habitat pattern in southern California. That mean, the potential integrated impacts on both climate change and land use under spatial distribution on hydrology regime in the future are big problem that is very essential for an innovative research to clearly access these impacts.

The Nakdong basin is one of largest area in Korea and there are abundant natural resources with richness of terrestrial and aquatic bio-diversity, wildlife and fisheries. That is not only plays a significant role in agriculture development but also great significance in livelihood for people in this region. Especially, this water resource was supplied for all sectors to develop the economy in region. However, the watershed hydrology cycle and its natural resources is under great pressure due to rapid urbanization, industrial growth expected to grow even more rapidly in the future, human activities, poor agricultural practices, deforestation, industrial waste water, and extreme climate change in region. Hence, hydrology cycle and water resources management will become even more important with a change in climate and land use. Management of water resources of basin is one of the greatest challenges. If the water resources of this river basin are managed properly, it will offer the great potential as a lever for development in Nakdong basin in specific and in the whole Korea generally. Therefore, the main objective of the study is to assess the integrated impacts of both climate change and land use changes on streamflow under scenarios of climate change and land use change in river basin in the future, which was solved by combination of a hydrological model and land use change model that were a really appropriate way to achieve this study goals. This would help to estimate the watershed's surface hydrology that specific such as streamflow. These estimates could support decision makers, both water resources management and land use management, water quality management to optimize water supply, and the sustainable water resources management strategies and policy in this study area.

2. Study area and data descriptions

The Nakdong river basin is one of the biggest basins in South Korea, located in the monsoon region (35–37° N, 127–129° E) (**Fig. 1**). This region is characterized by heavy rainfall in the monsoon season in early summer from Middle June to August.

The river drains an area of 23,817 km2 and the length of the main stream is over 525 km. The annual mean precipitation across the river basin is about 1200 mm, but more than 60% of the annual rainfall is concentrated during the summer season (June–August). The mean air temperature is 2.2°C during the coldest month (January), and 25.9°C in the warmest month (August). The Nakdong River basin is an important water resource for the southeastern area with about 7 million people residing within the basin and more than 13 million people taking drinking-water from the river. In particular, the large amount of water demand for agricultural productivity is greatly dependent on the amount of water supplied and the cause of the water shortage in the region.

In this study, the data that were collected for both hydrological and land-use models were used in clued spatial data and time series. Spatial data include a Digital Elevation Model (DEM), a digital layer of land use/land cover, a soil map and a river system layer. Time series data included daily data of precipitation, maximum and minimum temperature, solar radiation, humidity, and wind speed and direction for fourteen weather stations. Hydrology data included monthly flow for the period of 1995-2011 around Nakdong basin stations. All of the data sources were collected by Korea Meteorological Administration (KMA) and the Water Management Information System (WAMIS), which was built for providing services including scientifically collecting, creating, and processing water-resource information

This study of climate change is based on available climate-change data from the Intergovernmental Panel on Climate Change (IPPC) of General Circulation Model (GCM) simulations data. In specific, the data obtained from the GCM of ECHO-G under A2, B1, A1B scenarios by downscaling data, which was used for analysis and assessment in this study. In order to assist in comparison and assessment, as well as identification of average change in the future periods relative to the past 29-year observed baseline period of 1983-2011, the future long period under climate data was divided into three periods of 2012-2040, 2041-2069, and 2070-2098 which are used to simulate streamflow for three different periods

The result analysis of climate change data, in which the mean annual of both the temperature and of precipitation under all of scenarios showed more increase for all periods than baseline data. In specific of the precipitation, the analysis result under A2 scenario showed that the mean annual precipitation increase of +3.0%, +5.7% and +8.4% for periods as 2012-2040, 2041-2069, and 2070-2098, respectively. B1 scenario showed an increase of +6.1%, +5.9%, +9.8%; and A1B scenario as increasing of +5.5%, +3.5%, +11.7% in the same periods respectively. In specific of the temperature, under A2 the mean annual temperature showed an increase of +1.1°C (2012-2040), +2.1°C (2041-2069), +3.7°C (2070-2098); Under B1 scenarios as increasing of +0.8°C (2012-2040), +1.6°C (2012-2040), +2.8°C (2012-2040) and under A1B scenarios as increasing of +1.0°C (2012-2040), +2.0°C (2041-2069), +3.0°C (2070-2098) respectively.

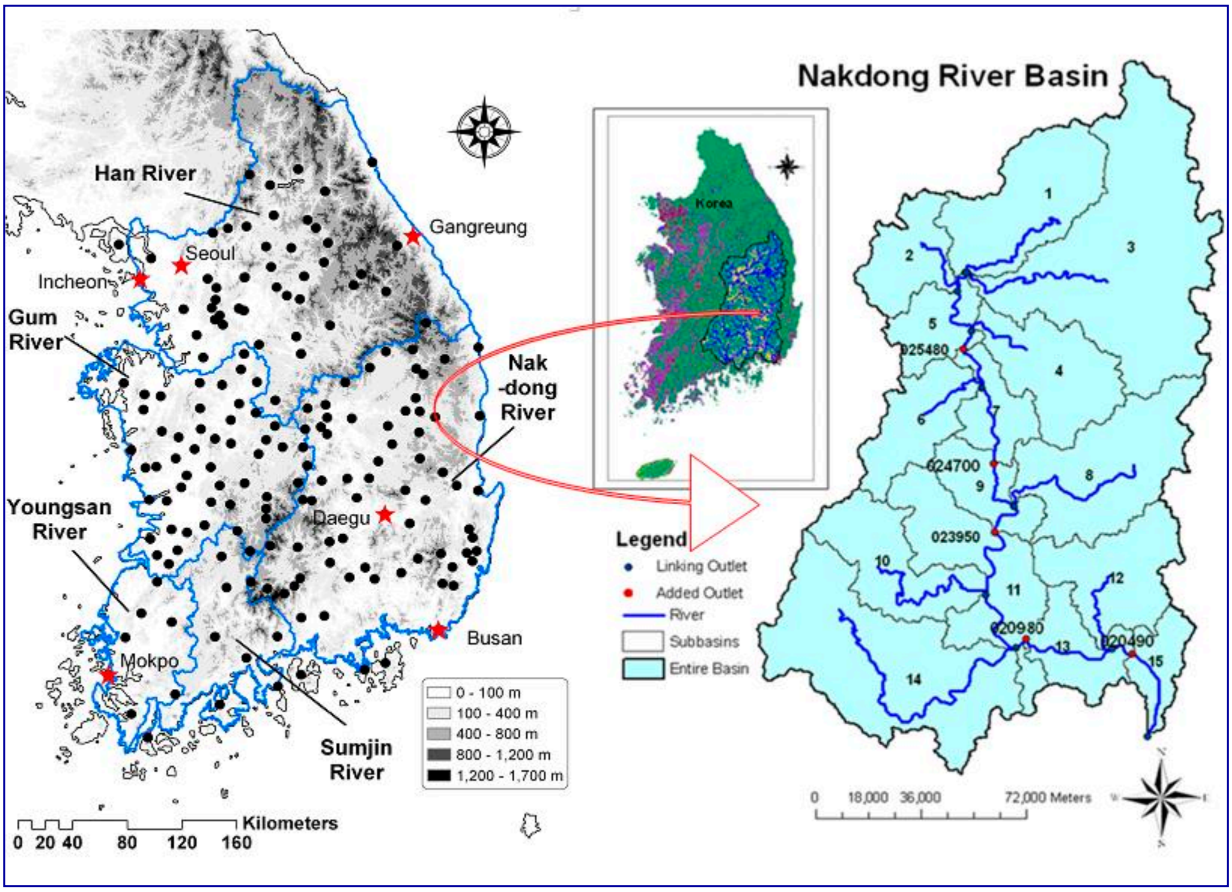


Fig.1. Local of the Nakdong River Basin and river systems

3. Methods and materials

The climate change and land use change are two main factors, which not only significantly influenced the hydrology process during the last decades but will continue to influence this process more extremely in the future in the complex watershed hydrology. In this study, the hydrology model of Soil and Water Assessment Tool (ArcSWAT) and the land use change CA_Markov and model (the Soil and Water Assessment Tools) were combined to assess integrated impacts of climate change and land use change on streamflow in the future on Nakdong basin (**Fig. 1**).

3.1 Hydrology model

The impacts of climate change on the hydrological characteristics of the basin are assessed through models. The method used in this study is focused on the use of SWAT model to assess the impact of climate variability and land use change on surface hydrology in Nakdong river basin. SWAT is a watershed-scale, physically based distributed hydrological model developed to predict the impact of land management practices on hydrologic and water quality response of complex watersheds with soils and land use conditions (Arnold et al., 1998). The hydrologic cycle is based on the water balance equation

$$SWt = SW0+(Rda-Qsurf-Ea-Wdeep-Qgw) \qquad [1]$$

where SWt is the final soil water content (mm H2O), SW0 is the initial soil water content on day i (mm H2O), t is the time (days), Rday is the amount of precipitation on day i (mm H2O), Qsurf is the amount of surface runoff on day i (mm H2O), Ea is the amount of evapotranspiration on day i (mm H2O), Wdeep is the amount of water into the deep aquifer on day i (mm H2O), and Qgw is the amount of return flow on day i (mm H2O). The hydrologic cycle is involved processes when precipitation falls to the soil surface. Water on the soil surface will infiltrate into the soil profile or flow overland as runoff. Runoff moves relatively quickly toward a stream channel and contributes to short-term stream response. Infiltrated water may be held in the soil and later evapotranspired or it may slowly make its way to the surface-water system via underground paths. SWAT simulates various processes that include hydrology, weather, erosion and sedimentation, soil temperature, plant growth, nutrients, pesticides, and land management. SWAT model provides several options when simulating hydrologic processes, which can be chosen by users based on their data availability (can be simulated with the Cure Number or Green-Ampt method in infiltration, and Potential Evapotranspiration (PET) with Priestley-Taylor, or Penman–Monteith equation), the surface runoff is estimated using a modified SCS curve number method based on moisture content. The watershed is subdivided into sub-basins that are spatially related to one another and further into hydrologic response units (HRUs). The HRUs are homogenous units that possess unique land use/cover and soil attributes. Runoff was predicted separately for each hydrologic response unit (HRU) and routed to obtain the total runoff for the watershed. More details can be found in the SWAT User's Manual (Neitsch et al., 2005). This model being able to estimate the impact of land uses on water, sediment and agricultural chemicals on a sub-catchments and land use unit scale over long periods of time (Sun and Cornish, 2005). The basic SWAT model inputs are precipitation, maximum and minimum temperature, **radiation**, wind speed, relative humidity, land use/cover, soil, and Digital Elevation Model (DEM).

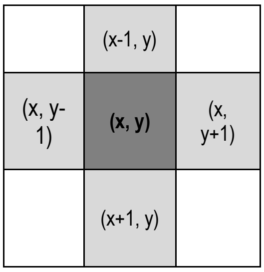
3.2 Land use change model

Land use model does not only plays a significant role to assess land use changes but also provides great help for effective environmental management, land use resources planning and management in the future. In this study, the CA_Markov model is used for land use change forecasting based on observed of land use. This model is combined between Cellular Automata (CA) and Markov Chain model that adds an element of spatial continuity as well as knowledge of the likely spatial distribution of transition to Markov change analysis. Specifically, the Markov chain analysis describes the probability of land use change from period to another by developing a transition probability matrix between t1 and t2. Therefore, CA_Markov has the ability to predict transition among any number of classes. In conclusion, the Markov chain process controls temporal dynamics among the land use classes based on transition probabilities, while the spatial dynamics are controlled by local rules determined by the Cellular Automata, and the simulation of land use change was based on integration of Markov transition probabilities and a Cellular automata spatial filter. A cellular automata is defined by a grid with start states and set of rules for state transitions. Generally, CA are composed of four elements as described flowing general equation below:

$$CA = \{X,S,N,R\} \qquad [1]$$

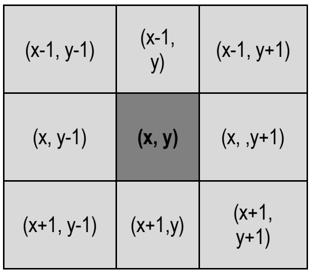
Where, CA= Cellular automaton,
X= CA cell space,
S = CA states,
N= CA cell neighborhood,
R= CA transition rule,

(i) Cell space: The cell space is composed of individual cell. Theoretically, these cells may be in any geometric shape. Most CA adopts regular grids to represent such space, which make CA very similar to a raster GIS. All cells have some forms of neighborhood. *(ii) Cell states*: The states of each cell may represent any spatial variable, the various types of land use. *(iii) Transition rules:* These rules are the heart of a CA that guides its dynamic evolution. A transition rule normally specifies the states of cell before and after updating based on its neighborhood conditions. *(iv) Neighborhood:* This is defined by the local neighborhoods of a cell. In a two-dimension cellular automata model there are two common types neighborhood, the Von Neumann neighborhood with four neighboring cells (a) and the Moore neighborhood with eight neighbors are shown in (b). The future state of a cell in a CA is dependent on its current state, neighborhood states, and transition rules which are setup and fine-tuned using transition suitability or potential scores of individual cells, all of algorithms and equations are integrated in land use change model (CA_Markov). A shaped neighborhood that can be used to define a set of cells surrounding a given cell (x,y) that may affect the evolution of a two-dimensional cellular automaton on a square grid.



	(x-1, y)	
(x, y-1)	**(x, y)**	(x, y+1)
	(x+1, y)	

(a) Von Neumann neighborhood



(x-1, y-1)	(x-1, y)	(x-1, y+1)
(x, y-1)	**(x, y)**	(x, ,y+1)
(x+1, y-1)	(x+1,y)	(x+1, y+1)

(b) Moore neighborhood

In specific, this model requires a land use/cover dataset to represent the initial state, a Markov transition matrix, a suitability map, a number of iterations and a contiguity filter. The transition rules are set up using a multi-criteria evaluation techniques and fuzzy membership function to develop suitability map for each simulated land use/cover class. Suitability analysis ranks available land in a systematic procedure according to which the combined effects of various factors assumed to determine location preferences are derived through evaluation, weighting, and overlay. The main land use types in this basin are simulated simultaneously, and during the iteration process, each land use class becomes categories.

3.3 Application models

In study, the ArcSWAT is based on varying of climates and land cover/land use over long periods of time. The model data inputs include climate change time series as rainfall, maximum and minimum temperature, radiation, wind speed, relative humidity and land cover spatial and digital elevation model data. The land use change in the future have been forecasted based on CA-Markov which is integrated by power tool of Cellular Automata (CA) analysis is operating on a grid based cells to determine the state of a cell as a dynamic system while Markov chain allowing the transition probabilities of one cell to be a function of neighboring cells.

First, ArcSWAT model was set up, calibrated and validated for Nakdong River Basin. Second, the future of land use scenarios were forecasted by CA_Markov model based on constraints and factors after the model was calibrated and validated. Third, analysis and use the scenarios for climate change. Finally, four scenarios of climate change and land use change were put into the calibrated ArcSWAT model to simulate streamflow in the future. In specific: (i) Scenario 1 (SR1 as baseline): both of climate and land use were not changed in scenario. (ii) Scenario 2 (SR2): holding climate while land use was changed in scenario. (iii) Scenario 3 (SR3): climate was changed while holding land use. (iv) Scenario 4 (SR4): both of climate and land use was changed in scenario. The flowchart of study methodology is given in this study as shown in (**Fig. 2**).

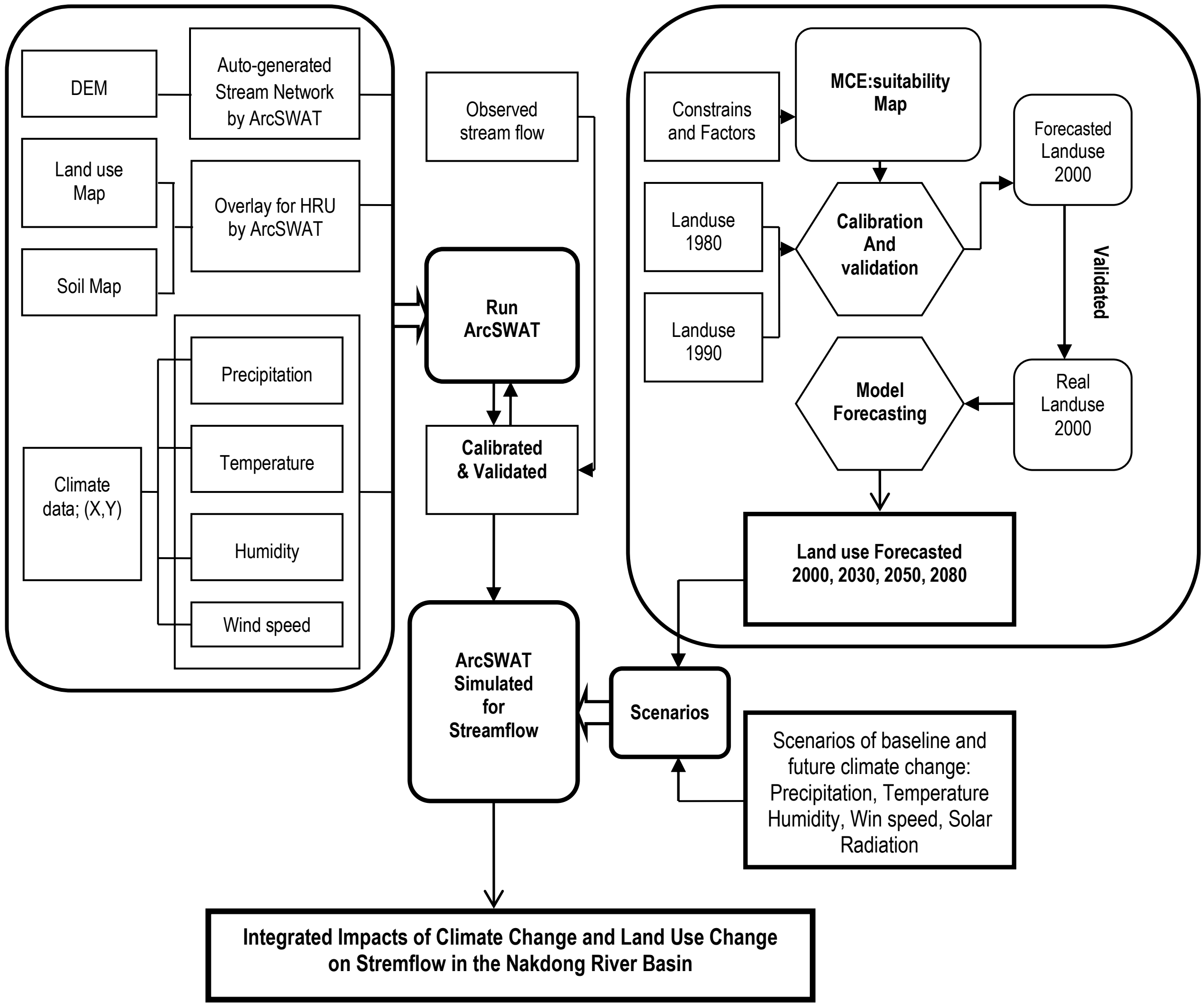


Fig.2. Schematic diagram of the study method

In simulation of ArSWAT, the watershed is subdivided into subbasins that are spatially related to one another. This configuration preserves the natural channels and flow paths of the watershed. The subbasin watershed components can be categorized into the following components hydrology, weather, erosion and sedimentation, soil temperature, plant growth, nutrients, pesticides and land management. In the land phase of the hydrologic cycle, runoff is predicted separately for each hydrologic response unit (HRU) and routed to obtain the total runoff for the watershed. Once the loadings (water, sediment, nutrients and pesticides) to the main channel are determined, they are routed through the stream systems of the watershed. The hydrologic cycle is based on the water balance equation

$$SW_t = SW_0 + (R_{da} - Q_{surf} - E_a - W_{deep} - Q_{gw}) \qquad [2]$$

where SW_t is the final soil water content (mm H_2O), SW_0 is the initial soil water content on day i (mm H_2O), t is the time (days), R_{day} is the amount of precipitation on day i (mm H_2O), Q_{surf} is the amount of surface runoff on day i (mm H_2O), Ea is the amount of evapotranspiration on day i (mm H_2O), W_{deep} is the amount of water into the deep aquifer on day i (mm H_2O), and Q_{gw} is the amount of return flow on day i (mm H_2O). The hydrologic cycle is involved processes when precipitation falls to the soil surface. Water on the soil surface will infiltrate into the soil profile or flow overland as runoff. Runoff moves relatively quickly toward a stream channel and contributes to short-term stream response. Infiltrated water may be held in the soil and later evapotranspired or it may slowly make its way to the surface-water system via underground paths. The runoff volume are calculated based on the SCS curve number procedure, this curve number is a function of the soil's permeability, land use and antecedent soil water conditions. These include surface storage, interception and infiltration prior to runoff and a retention parameter that varies spatially due to changes in soils, land use, management and slope and temporally due to changes in soil water content. The simulation processes of runoff, the SWAT predicts the runoff based on rule of separation for each HRU and routed to obtain the total runoff for the watershed. The first subdivision of the catchment is the subbasin. Subbasins are spatially related to one another and contain at least one HRU, a tributary channel and a main channel or reach. In other words, an HRU is the total area in the subbasin with a particular landuse, land cover, and soil. While individual HRUs may be scattered throughout a subbasin, their areas are lumped together to form one HRU. Thus, the HRUs serve to account for the complexity of the landscape within the subbasins. The benefit of HRUs is the increase in accuracy it adds to the prediction of loadings from the subbasin.

4. Results and discussions

The climate change data in the future was used from the GCM model of ECHO under A2, B1, and A1B scenarios. This data was used to simulate streamflow for three different periods 2012-2040, 2041-2069, and 2070-2098 as well as land use change in future periods as 2030, 2050 and 2080 by using model after calibrated and validated model. The integrated impacts of climate changes and land use change on streamflow under different spatial distribution were quantified by comparing between future period and baseline period of 1983-2011 with land use 2000.

4.1 *Model calibrations and validations*

The results of calibration and validation are suitable and acceptable as until the best fit curve of simulated versus observed data (by using ENS and R^2 coefficient equations). They are calculated by the following equation, respectively:

$$R^2 = \frac{\left[\sum_{i=1}^{n}(Q_{si}-\bar{Q}_s)(Q_{0i}-\bar{Q}_0)\right]}{\sum_{i=1}^{n}(Q_{si}-\bar{Q}_s)^2\sum_{i=1}^{n}(Q_{0i}-\bar{Q}_0)^2} \qquad [3]$$

$$E_{NS} = 1 - \frac{\sum_{i=1}^{n}(Q_{0i}-Q_{si})^2}{\sum_{i=1}^{n}(Q_{0i}-\bar{Q}_0)^2} \qquad [4]$$

Where: Q_{si} is the simulated values of the quantity in each model time step (in this case, monthly); Q_{oi} is the observed values of the quantity in each model time step (in this case, monthly); $\bar{Q}_s$ is the average simulated value of the quantity in each model time step (in this case, monthly); $\bar{Q}_o$ is the average observed value of the quantity in each model time step (in this case, monthly); n is the number of observations. In this study, each model time step is monthly.

The results are determined specifically as at Nakdong Station_025480: the results values are determined for calibrated of (R^2=0.86, E_{NS}=0.79), and for validated of (R^2=0.81, E_{NS}=0.75) **(Fig.3, 4)**. At Goeagwan Station_024700: the results values are determined for calibrated of (R^2=0.83, E_{NS}=0.76), and for validated of (R^2=0.78, E_{NS}=0.72) **(Fig. 5, 6)**. At Samyanjin Station_020490: the results values are determined for calibrated of (R^2=0.81, E_{NS}=0.72), and for validated of (R^2=0.77, E_{NS}=0.69) **(Fig. 7, 8).** Final, the results are summarized in **Table 1** calibrated and validated for Nakdong, Goeagwan and Samyanjin stations, respectively.

In general, SWAT simulated values accurately tracked the observed streamflows for the time period, most values showed a strong correlation between the simulated and observed flows, although some peak flow months were under simulated and the low flow months were over simulated.

Table 1. Evaluation criteria for calibrated and validated model

Types	Stations	Calibrated (1995-2004)		Validated (2005-2011)	
		R^2	E_{NS}	R^2	E_{NS}
Monthly streamflow	Nakdong	0.86	0.79	0.81	0.75
	Goeagwan	0.83	0.76	0.78	0.72
	Samyangjin	0.81	0.72	0.77	0.69

Except several years during which simulated peaks are greater than observed ones, most of the years have a good agreement between the simulated and observed streamflow. In addition, the calibration period statistics were stronger than those computed for the validation period as shown in **Table 1**. In particular, the low flow were simulated very well in shape but different in values, and in year of 2001, the peak flow values of simulated are significantly higher than observed values. However, the errors are acceptable (Santhi et.al., (2001) by an acceptable calibration for hydrology when errors among at $R^2>0.6$ and $E_{NS}>0.5$. Thus, result was good agreement between the simulated and observed streamflow.

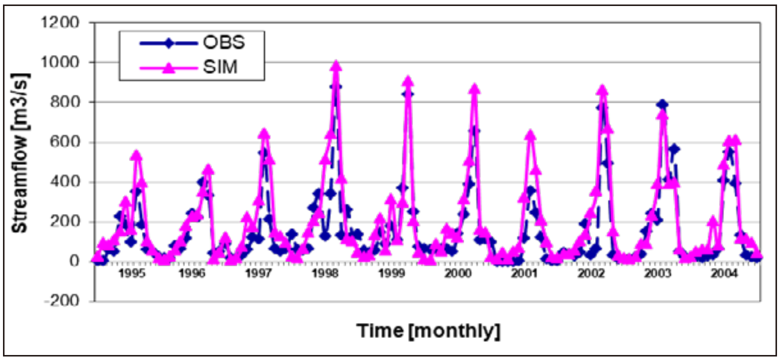


Fig.3. Monthly streamflow calibrated for 1995-2004 at Nakdong station.

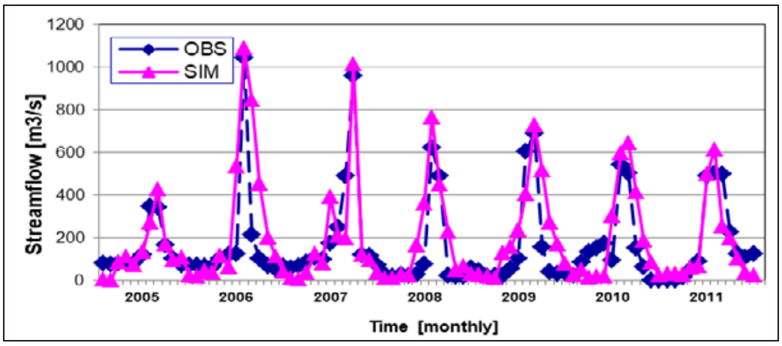


Fig.4. Monthly streamflow validated for 2005-2011 at Nakdong station.

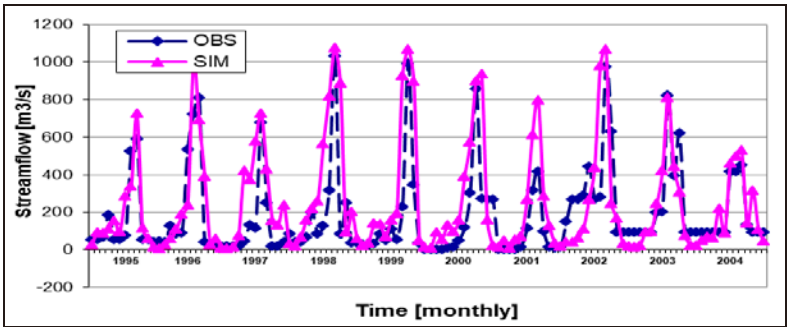


Fig.5. Monthly streamflow calibrated for 2005-2011 at Goeagwan station.

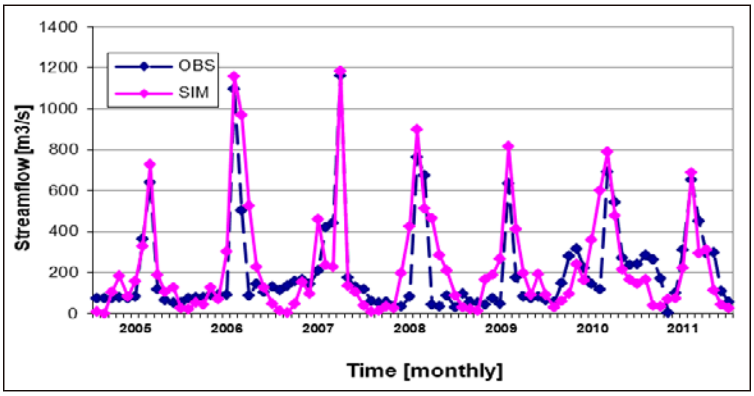


Fig.6. Monthly streamflow validated for 2005-2011 at Goeagwan station.

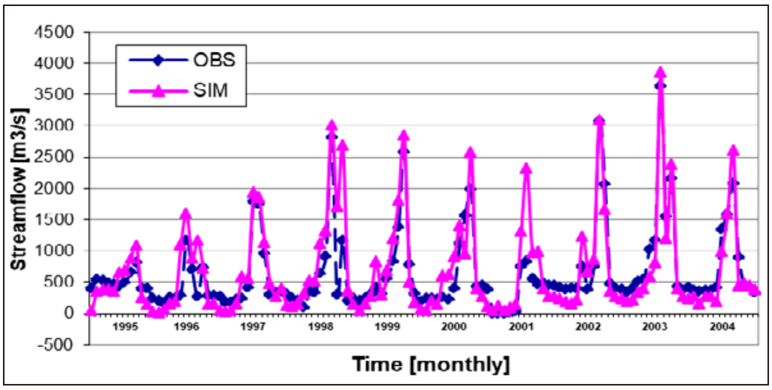


Fig.7. Monthly streamflow calibrated for 1995-2011 at Samyangjin station.

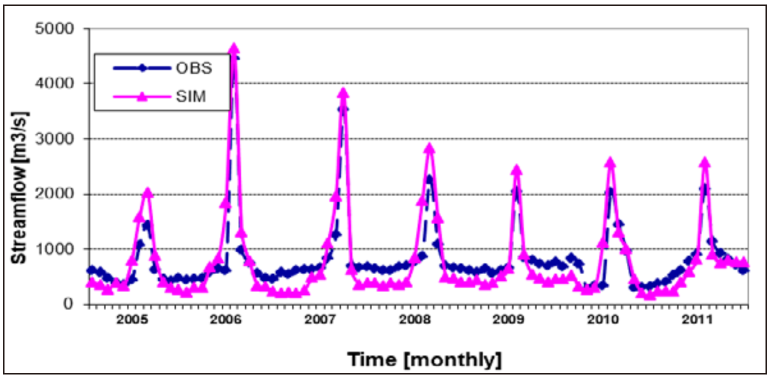


Fig.8. Monthly streamflow validated for period of 2005-2011 at Samyangjin station.

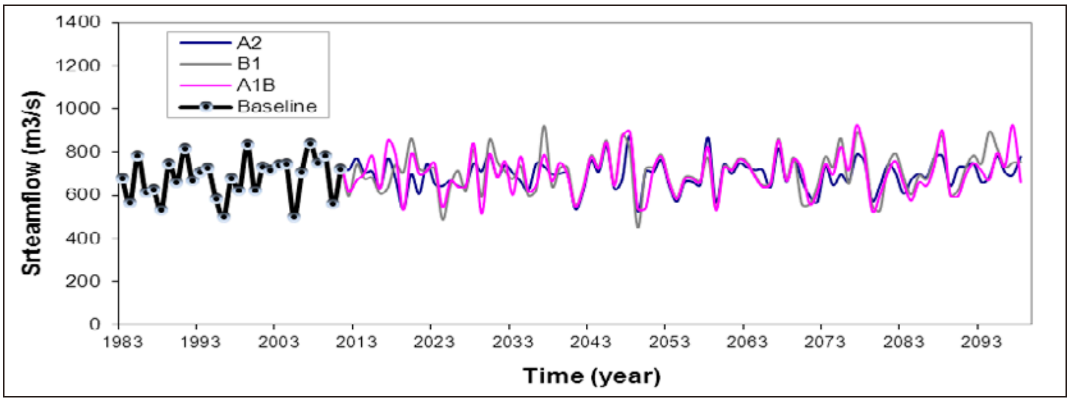


Fig. 9. Simulated integrated impacts on the mean annual streamflow of 2012-2098.

4.2 Impacts on the mean annual streamflow

As shown in **Table 2**, the result indicated large changes from +2.63% to +5.57% by integrated impacts on the mean annual streamflow in future under the B1 scenario, while separation impact of land use change and climate change were change from +0.3% to +0.58%, and from +2.25% to +4.82%, individually. In average of mean annual on streamflow for all periods showed an change of +3.97% on integrated impacts, +0.44% on land use change impact, and +3.44% on climate change impact. Others scenarios A2, and A1B showed less change than that in the same periods specifically change of +1.10%, and +2.93% on integrated impacts both of climate change and land use change, respectively.

Table 2. Change on the mean annual streamflow in the future under B1, A2, A1B in entire basin.

GCM	Scenarios	Climate	Land use	Streamflow (m3/s)	Changed (%)
	(SR1) Baseline	**Observed climate 1983-2011**	**Observed land use 2000**	**681.36**	**0.00**
B1	**(SR2)** no CC & LUC	SR2.1: Obs climate 1983-2011	2030	683.40	+0.30
		SR2.2: Obs climate 1983-2011	2050	684.43	+0.45
		SR2.3: Obs climate 1983-2011	2080	685.31	+0.58
		Average			**+0.44**
	(SR3) **CC & no LUC**	SR3.1: 2012-2040	2000	696.69	+2.25
		SR3.2: 2041-2069	2000	703.44	+3.24
		SR3.3: 2070-2098	2000	714.20	+4.82
		Average			**+3.44**
	(SR4) **CC & LUC**	SR4.1: 2012-2040	2030	699.28	***+2.63***
		SR4.2: 2041-2069	2050	706.64	***+3.71***
		SR4.3: 2070-2098	2080	719.31	***+5.57***
		Average			**+3.97**
A2	**(SR2)** no CC & LUC	SR2.1: Obs climate 1983-2011	2030	683.40	+0.30
		SR2.2: Obs climate 1983-2011	2050	684.43	+0.45
		SR2.3: Obs climate 1983-2011	2080	685.31	+0.58
		Average			**+0.44**
	(SR3) CC & no LUC	SR3.1: 2012-2040	2000	684.15	+0.41
		SR3.2: 2041-2069	2000	689.54	+1.20
		SR3.3: 2070-2098	2000	687.97	+0.97
		Average			**+0.86**
	(SR4) CC & LUC	SR4.1: 2012-2040	2030	685.45	+0.63
		SR4.2: 2041-2069	2050	691.58	+1.50
		SR4.3: 2070-2098	2080	689.54	+1.20
		Average			**+1.10**
A1B	**(SR2)** no CC & LUC	SR2.1: Obs climate 1983-2011	2030	683.40	+0.30
		SR2.2: Obs climate 1983-2011	2050	684.43	+0.45
		SR2.3: Obs climate 1983-2011	2080	685.31	+0.58
		Average			**+0.44**
	(SR3) CC & no LUC	SR3.1: 2012-2040	2000	693.49	+1.78
		SR3.2: 2041-2069	2000	698.80	+2.56
		SR3.3: 2070-2098	2000	703.30	+3.22
		Average			**+2.52**
	(SR4) CC & LUC	SR4.1: 2012-2040	2030	695.12	+2.02
		SR4.2: 2041-2069	2050	701.05	+2.89
		SR4.3: 2070-2098	2080	707.73	+3.87
		Average			**+2.93**

4.3 Impacts on the mean months streamflow

The results also indicated that streamflow is more increased in land use 2080 than land use 2000, 2030 and 2050 as shown in (SR2) under all scenarios A2, B1, and A1B. This can be result of more urban area expanding in 2080 as increased from 1.44% to 5.59%, while it reduced from 25.99% to 21.26% in agriculture area from land use from 2000 to 2080, respectively. A much clearly of two land use types as urbanland and agricultureland change trend can be indicated when comparison the forecasted land use map 2030, 2050 and 2080 with the basic land use map of 2000. The results of the simulation indicate that there will be a significant urban land area use changes in the future in entire basin from 1.44% in 2000 to 5.59% in 2080. In contrast, the agriculture area is decreased from 25.99% in 2000 down 21.26% in 2080. Other land use types are changed insignificantly.

The above results also showed that land use change and climate change both increased on the mean annual streamflow, but the impact of climate change was higher than that of land use change, and the integrated impacts of both climate change and land use change was more increasing than of only land use change or only climate change, individually.

The results of the impacts of climate change and land use change on the mean season streamflow under A2, B1, and A21B, respectively. In specific, the decreasing tendency was showed in spring of -1.33%, while it indicated an increase in summer of +4.12% for average of all periods in the future streamflow under A2 scenario. Also of A2 scenario for period of 2070-2098, the result indicated the highest decrease of -7.08% in autumn, while it was highest increase of +9.90% in winter by integrated impacts of climate change and land use change on the streamflow in entire basin. Other values of individual impacts of land use change and climate change on season streamflow were determined also in this table for difference periods. Moreover, we can see on the mean months as the January and February in winter season, and June and July were significantly increased, due to this can be increase of precipitation in future, while it were decrease in October in autumn that can be cause precipitation reducing in this season in entire basin (**Fig. 10**).

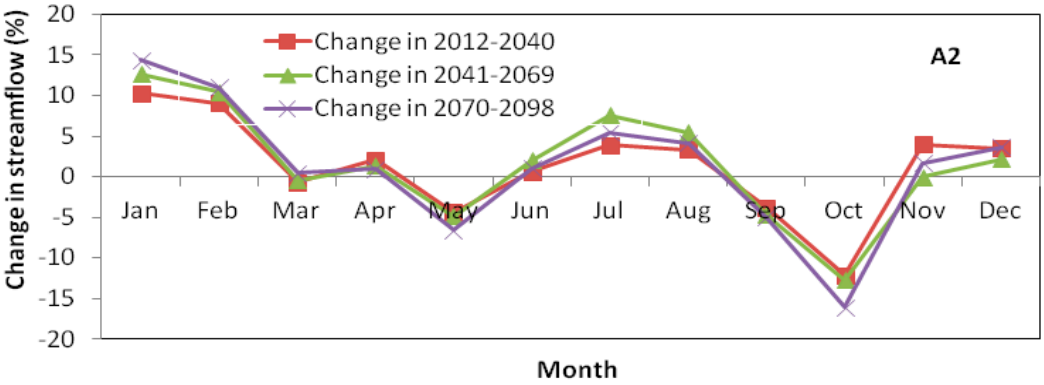


Fig.10. Change of integrated impacts on months streamflow for periods in future under A2 in entire basin

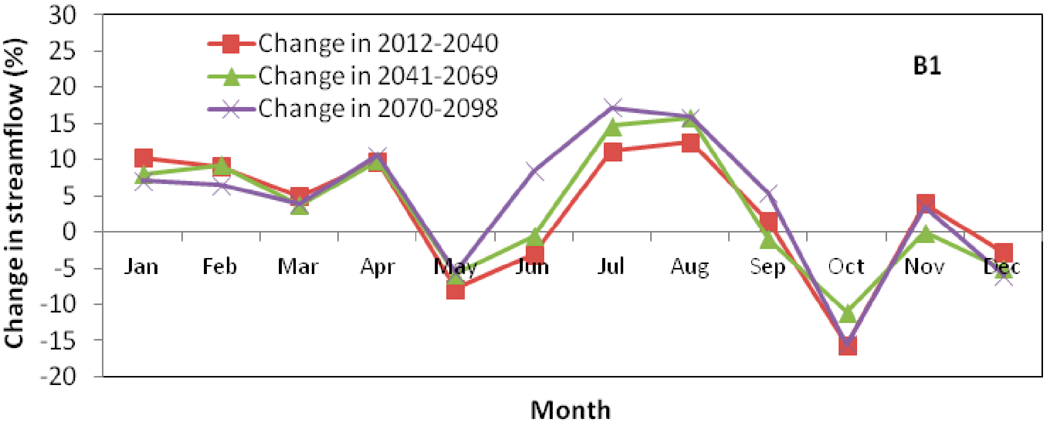


Fig.11. Change of integrated impacts on months streamflow for periods in future under B1 scenario

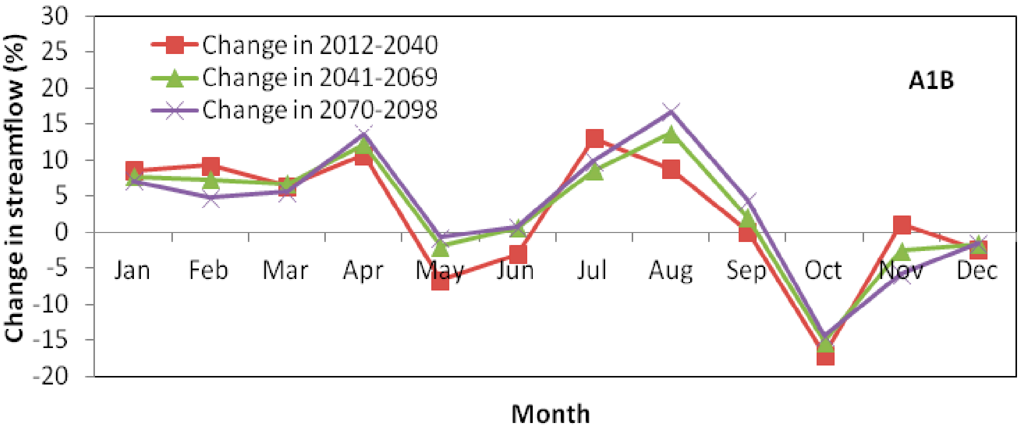


Fig.12. Change of integrated impacts on months streamflow for periods in future under A1B scenario

Under B1, and A1B scenarios for entire basin, except autumn season, the integrated impacts on the mean season streamflow for average all periods were increase all most of season of +2.65%, and +5.08% in spring season, +11.60%, and +8.93% in summer season, -2.72%, and -4.05% in autumn season, and +4.14%, and +4.37% in winter season, respectively. Moreover, the mean season of streamflow for each period showed different change that showed large change of streamflow specifically as periods 2070-2080 under B1, and A1B scenarios, result showed an increase +14.77%, and +10.39% in summer season, while streamflow in winter season reducing of -3.82%, and -3.20%, respectively. Other values of individual impacts of land use change and climate change on season streamflow were determined also in this table for difference periods. In addition, results showed integrated impacts on the mean months, the streamflow were forecasted significantly changes about +12.0% to +18.0% in months of January, February, July, August; but the monthly streamflow in May, October are decrease about -9.0% to -19.0% for most of periods under B1, and A1B because in these months the rainfall reduces it showed the reducing significantly about -10% to -40% in May, October in the most of periods and the temperature rise (average increase as +3.6°C) which lead to increase the potential evapo-transpiration and so, the stream flow of these months is decreasing that mean the season of summer and autumn are also reducing as **shown in Fig. 11 and 12**, respectively. In conclusion, in all scenarios A2, B1, A1B, the mean seasons of streamflow the period 2070-2098 and land use year 2080 are higher and more variable than in the periods of 2012-2040 and 2041-2068. In addition, the streamflow are strongly increase tendency in winter, and summer season especially in months of January, February, and July, August, while it are significantly decrease tendency in October in autumn, and May in spring. In these, the increase of streamflow during the summer season might cause flooding, while water shortage problem can be increase in autumn season and May of spring season. Therefore, there is a necessity to consider long-term adaptation and mitigation strategies for climate change and land use change for water resources management in the future.

5. Conclusions

The main objective of this study is to assess the potential integrated impacts of climate change and land use change on the streamflow under different spatial distribution by combination using the ArcSWAT model and CA_Markov model. The data of land use change in the future were forecasted for years of 2030, 2050, 2080 by using the CA_Markov model, while climate change data in the future obtained from the ECHO-G model under A2, B1, A1B scenarios that have been used in this study.

Under the A2, B1, and A1B scenarios indicated respectively changes of +1.1%%, +3.97%, and +2.93% by integrated impacts on the mean annual streamflow in future for average periods of 2012-2040, 2041-2069, 2070-2098, and land use change of 2030, 2050, 2080 for entire basin. Moreover, in periods, the results determined that integrated impacts on streamflow showed large changes in land use change year 2080 that combined with period of 2070-2098. In specific, the mean annual streamflow of +1.20% in land use change 2080 and climate change 2070-2098, while it was +0.6% for land use change 2030 and climate change of period of 2010-2040 under A2 scenario for entire basin.

In similarity, the mean annual streamflow were changes of +5.57% and +2.63% under B1, and of +3.87%, and +2.02% under A1B for pair of climate change of 2070-2098 combination with land use change 2080, and climate change 2012-2040 combination with land use change year 2030, respectively. Moreover, the above results also showed that land use change and climate change both increased on the mean annual streamflow, but the impact of climate change was higher than that of land use change. The results to reveal that largest change in January is because of precipitation increase in the future, while the most of precipitation is strongly reducing in October, due to also this is decrease of precipitation in this month. In addition, on the mean season of the streamflow are strongly increase tendency in winter, and summer season, while it are significantly decrease tendency in autumn season. In these, the increase of streamflow during the summer season might cause flooding, while water shortage problem can be increase in autumn season. Therefore, there is a necessity to consider long-term adaptation and mitigation strategies for climate change and land use change for water resources management in the future. The integrated impacts of climate change and land use change on quantitative of the streamflow will be also helpful in understanding potential water resources problems and making better planning decisions.

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Symbols and abbreviations

ArcSWAT	Soil and Water Assessment Tool
CA_Markov	Cellular Automation Markov chain
IPCC	Intergovernmental Panel on Climate Change
HRUs	Hydrologic response units
SR1	Scenarios 1
SR2	Scenarios 2
SR3	Scenarios 3
SR4	Scenarios 4
OSB	Observation
SIM	Simulation
GCM	General circulation model
CC	Climate change
LUC	Land use change