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Evaluation of Future Climate Change Impact on Streamflow of Gyeongancheon Watershed Using SLURP Hydrological Model

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Abstract : The impact on streamflow and groundwater recharge considering future potential climate and land use change was assessed using SLURP (Semi-distributed Land-Use Runoff Process) continuous hydrologic model. The model was calibrated and verified using 4 years (1999-2002) daily observed streamflow data for a 260.4 km^2 which has been continuously urbanized during the past couple of decades. The model was calibrated and validated with the coefficient of determination and Nash-Sutcliffe efficiency ranging from 0.8 to 0.7 and 0.7 to 0.5, respectively. The CCCma CGCM2 data by two SRES (Special Report on Emissions Scenarios) climate change scenarios (A2 and B2) of the IPCC (Intergovernmental Panel on Climate Change) were adopted and the future weather data was downscaled by Delta Change Method using 30 years (1977 - 2006, baseline period) weather data. The future land uses were predicted by CA (Cellular Automata)-Markov technique using the time series land use data of Landsat images. The future land uses showed that the forest and paddy area decreased 10.8 % and 6.2 % respectively while the urban area increased 14.2 %. For the future vegetation cover information, a linear regression between monthly NDVI (Normalized Difference Vegetation Index) from NOAA/AVHRR images and monthly mean temperature using five years (1998 - 2002) data was derived for each land use class. The future highest NDVI value was 0.61 while the current highest NDVI value was 0.52. The model results showed that the future predicted runoff ratio ranged from 46 % to 48 % while the present runoff ratio was 59 %. On the other hand, the impact on runoff ratio by land use change showed about 3 % increase comparing with the present land use condition. The streamflow and groundwater recharge was big decrease in the future.

Key Words : SLURP, Land Use Change, CA-Markov, Climate Change, NDVI.

1. Introduction

The Intergovernmental Panel on Climate Change (IPCC) report reaffirms that the climate is changing in ways that cannot be accounted for by natural variability and that "global warming" is occurring (IPCC, 2001). This global warming is likely to have significant impacts on the hydrologic cycle (Arnell,

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1999; IPCC, 2001). An assessment of the hydrological impacts of climate change is essential to plan for future water resources management (Aleix *et al.* 2007). Modeling hydrologic impacts of climate change involves simulation results from General Circulation Models (GCMs), which are the most credible tools designed to simulate time series of climate variables globally (Ghosh and Mujumdar, 2008). Recently, a number of climate impacts on runoff have been accomplished by coupling GCM outputs and hydrological model. Kite at al. (1994) estimated the runoffs by connection of CCC GCM and SLURP model for Mackenzie and Columbia basins of Canada. Gellens and Rouline (1998) used the seven GCMs and IRMB (Integrated Runoff Model) to analyze the impact of climate change for the runoffs of eight basins of Belgium. Ahn *et al.* (2001) used the water balance model to investigate the runoff change of Daecheong-dam watershed of South Korea by using the results of GCM. Andersson *et al.* (2006) used the four GCMs and Pitman hydrological model to assess the impact of various development and climate change scenarios on downstream river flow in the Okavango river basin. Merritt at al. (2006) evaluated the hydrologic response to scenarios of climate change in Okanagan basin of british with the connection of three GCMs and UBC watershed model. Zhang *et al.* (2007) estimated the effect of potential climate change on available streamflow volume in the Luohe river basin using the two GCMs and SWAT model.

Land use changes directly affect evapotranspiration, infiltration and soil water storage changing the dynamics of surface runoff, subsurface runoff and groundwater recharge. The accompanying spatial and temporal distributions of vegetation cover influence the parameters of calculating evaporation from soils and transpiration from vegetation. Therefore, must consider with future land use and seasonal variation of vegetation cover for effective water resources management by climate change.

The main objective of this study was to assess the potential impact of climate change on streamflow and groundwater recharge of an urbanizing watershed by considering future land use changes and their vegetation cover conditions. The future land use information was prepared by applying the modified CA (Cellular Automata)-Markov technique with the past temporal series of land cover maps classified by Landsat TM and ETM+ satellite images. The corresponding seasonal vegetation cover conditions were derived by the NOAA NDVI (Normalized Difference Vegetation Index) values estimated from the relationship of NDVI-Temperature linear regression. The SLURP model was applied to evaluate the future climate impact on streamflow using the climate change results of CCCma CGCM2 by two SRES (Special Report on Emissions Scenarios) climate change scenarios (A2 and B2).

2. SLURP model description

The SLURP (Kite, 1975) basin-level hydrological model was adopted for assessing future climate and land use impact on streamflow. SLURP is a continuous simulation semi-distributed hydrological model to simulate the behavior of a watershed at many points. SLURP model particularly useful for studies in which land cover is expected to change and climate change studies (Kite, 1993). SLURP was designed to use land cover information from Landsat remotely sensed data and snow cover information from NOAA AVHRR visible and infrared data.

The watershed is divided into aggregated simulation areas (ASAs). The model routes precipitation through the appropriate processes and generates outputs (evaporation, transpiration and runoff) and changes in storage (canopy interception, snowpack and soil moisture). Runoffs are accumulated from each land cover within an ASA using a time/contributing area relationship for each land cover and the combined runoff is converted to streamflow and routed between each ASA.

3. Data collection and Preparation

1) Watershed, GIS/RS data

The study watershed is a 260.4 km^2 watershed which has Gyeongan water level gauge station at the watershed outlet. The watershed has been continuously urbanized during the past couple of decades. The stream is one of the main tributaries of Han river basin directly linked to the Paldang lake. The watershed average precipitation is 1200.5 mm and mean temperature is 10.9 °C. (Fig. 1).

Elevation data was rasterized from a vector map of 1:5,000 scale that was supplied by the Korea National Geography Institute (Fig. 2a). Soil data were rasterized from a vector map of 1:50,000 scale that was supplied by the Korea Rural Development Administration. Soil series and type are shown in Fig. 2c and Fig. 2d.

The 5 past land use (1987, 1991, 1996, 2001 and 2004) were prepared using Landsat TM and ETM+

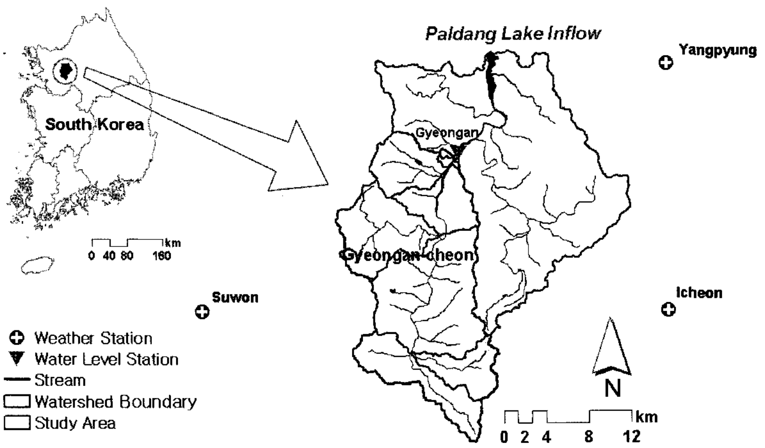


Fig. 1. The Study Watershed.

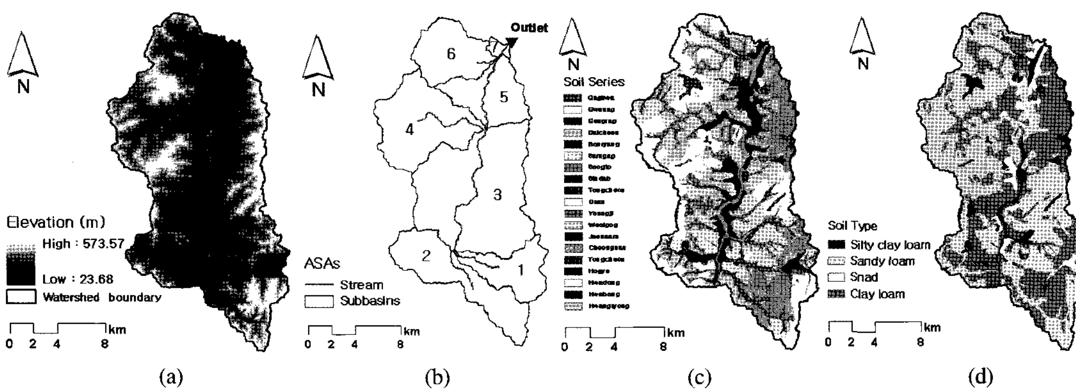


Fig. 2. GIS Data (a) Elevation, (b) Sub-basins, (c) Soil series, (d) Soil type.

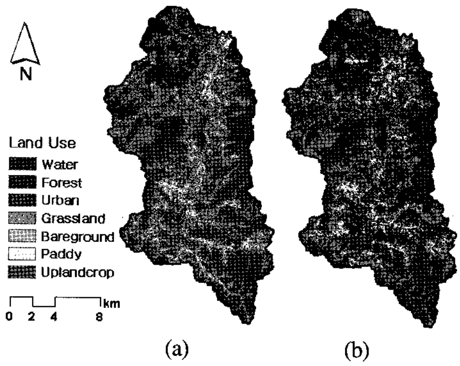


Fig. 3. Comparison of (a) Landsat classified and (b) CA-Markov predicted land use of 2004.

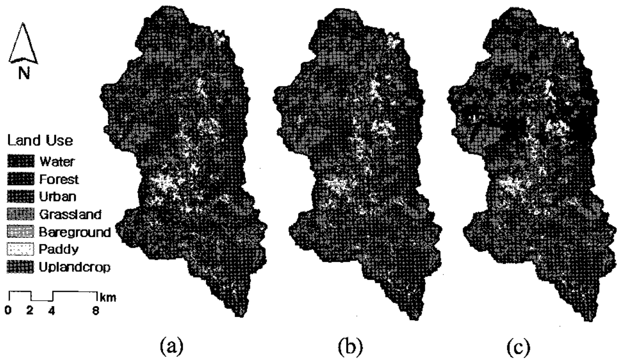


Fig. 4. The predicted land uses by the modified CA-Markov techniques (a) 2030, (b) 2060 and (c) 2090.

Table 1. The Landsat classified land use from 1987 to 2004 and the CA-Markov predicted land use of 2030, 2060 and 2090

Year		Land use class							
		Water	Forest	Urban	Grassland	Bare ground	Paddy rice	Upland crop	Total
Landsat (km^2 [%])	1987	0.7 [0.3]	152.3 [58.5]	11.5 [4.4]	5.3 [2.0]	11.8 [4.5]	45.2 [17.3]	33.6 [12.9]	260.4 [100.0]
	1991	0.7 [0.3]	156.9 [60.2]	10.6 [4.1]	9.7 [3.7]	27.6 [10.6]	40.4 [15.5]	14.5 [5.6]	260.4 [100.0]
	1996	1.1 [0.4]	149.2 [57.3]	11.3 [4.3]	7.3 [2.8]	17.2 [6.6]	42.4 [16.3]	31.9 [12.2]	260.4 [100.0]
	2001	0.5 [0.2]	156.6 [60.1]	13.1 [5.0]	13.2 [5.1]	16.6 [6.4]	27.1 [10.4]	33.3 [12.8]	260.4 [100.0]
	2004	0.8 [0.3]	141.8 [54.4]	14.7 [5.7]	21.7 [8.4]	22.3 [8.6]	25.4 [9.7]	33.7 [12.9]	260.4 [100.0]
CA-Markov (km^2 [%])	2004	1.4 [0.5]	146.0 [56.1]	36.9 [14.2]	23.2 [8.9]	12.4 [4.8]	19.3 [7.4]	21.2 [8.1]	260.4 [100.0]
	2030	1.5 [0.6]	135.9 [52.2]	47.5 [18.2]	24.9 [9.6]	20.8 [8.0]	13.7 [5.3]	16.1 [6.2]	260.4 [100.0]
	2060	1.6 [0.6]	132.5 [50.8]	50.8 [19.5]	28.1 [10.9]	19.6 [7.5]	12.8 [4.9]	15.0 [5.8]	260.4 [100.0]
	2090	1.6 [0.6]	128.4 [49.3]	50.1 [19.2]	31.8 [12.2]	21.0 [8.1]	11.1 [4.3]	16.4 [6.3]	260.4 [100.0]

satellite images. Using the 1987 and 1996 land use, 2004 land use was predicted using modified CA-Markov technique (Lee and Kim, 2007) and the result was compared with the Landsat 2004 land use (Fig. 3) and the future predicted land uses (2030, 2060 and 2090) are shown in Fig. 4. Table 1 summarizes the prediction results. The future land uses showed that the forest and paddy area decreased 10.8 % and 6.2 % respectively while the urban area increased 14.2 %.

2) Hydrological and meteorological data

For the model run, thirty years (1977-2006) daily weather data were collected from three weather stations (Suwon, Icheon, Yangpyeong). The data are mean, maximum, minimum temperature (°C), precipitation (mm), relative humidity (%), wind speed (m/sec), and sunshine hour (hr).

The CCCma CGCM2 data by two SRES (Special Report on Emissions Scenarios) climate change scenarios (A2 and B2) of the IPCC (Intergovernmental Panel on Climate Change) were adopted, and the future weather data was downscaled by Delta Change Method (DCM) suggested by the IPCC Data Distribution Centre (IPCC, 2006). The method was used to estimate the potential change in climate (Arnell, 1996; Hay *et al.*, 2000; Zhang *et al.* 2005). In this study, the percent differences in the 30-year mean annual precipitation between the baseline (1977 to 2006) and future GCM simulations (2030s, 2060s, and 2090s) were computed for the GCM output cell. The same percent was used for the weather stations. The potential change in precipitation for each station

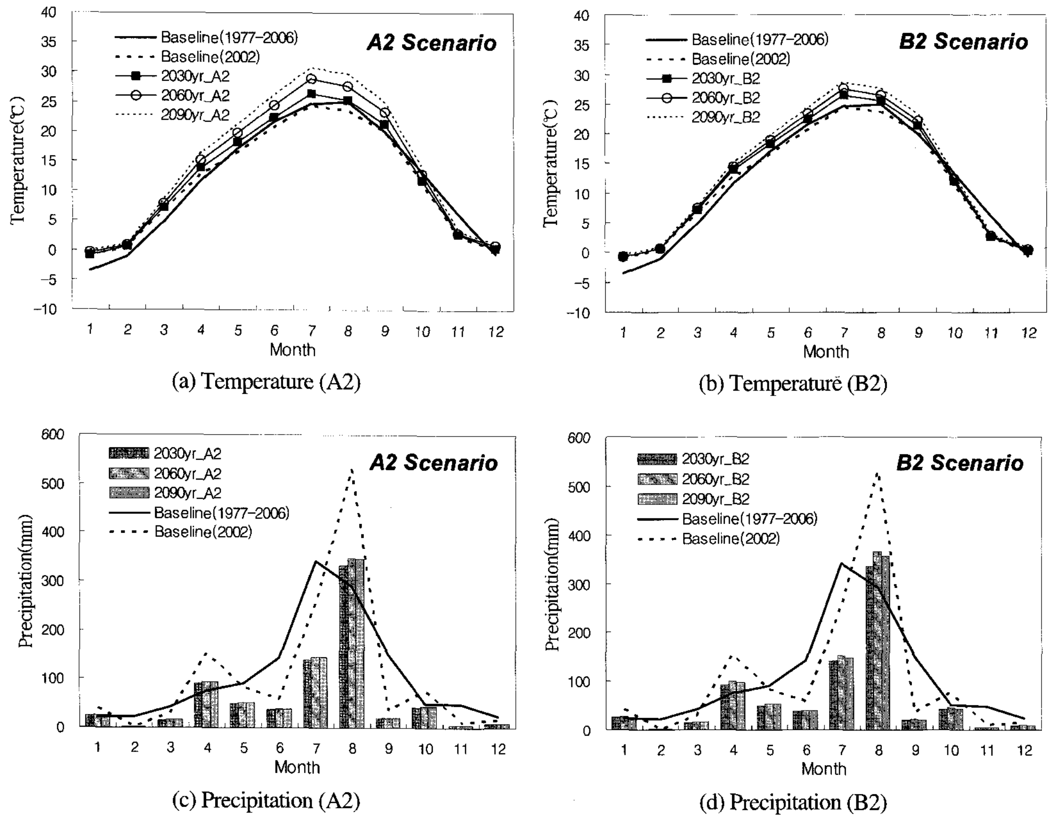


Fig. 5. Future temperature and precipitation scenarios by DCM downscaling.

was the product of the calculated change (in percent) multiplied by the 30-year observed mean annual precipitation. The same procedure was applied for other weather data. The results showed that there are 6.6 °C temperature increase and 98.1 mm precipitation decrease in case of A2 scenario, and 4.3 °C temperature increase and 91.9 mm precipitation decrease in case of B2 scenario for 2090. Fig 5 shows the future temperature and precipitation scenarios in this study by DCM downscaling

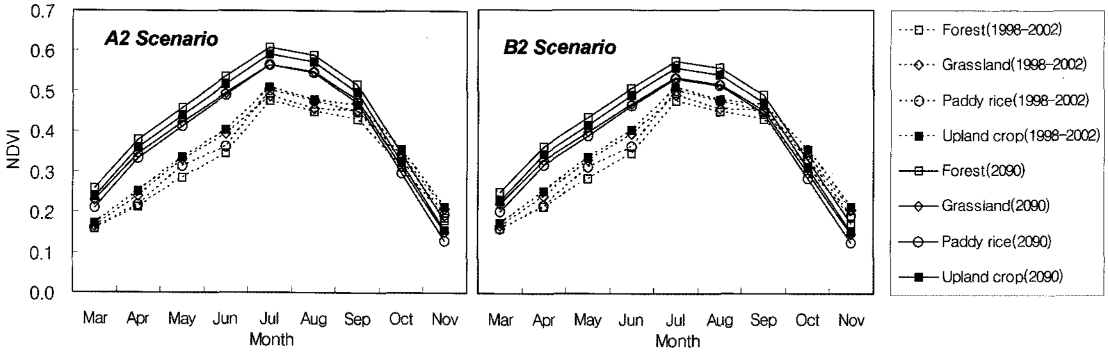
3) Future vegetation index using NOAA/AVHRR

To predict the future vegetation cover information, a linear regression between monthly NDVI (Normalized Difference Vegetation Index) of each land cover from NOAA/AVHRR satellite image and monthly mean temperature was accomplished. Table 2 shows the regression result using five years (1998-2002) monthly NDVI and monthly mean temperature from March to November. The monthly NDVIs of each land use from December to February could not be derived because of snow cover, thus they were extrapolated using the linear regression.

Fig. 6 shows the future (2030, 2060, 2090)

Table 2. The derived linear regression between monthly mean temperature and NOAA NDVI for each land use class

Land use class	Regression equation	R^2
Forest	NDVI = 0.0155 · temp + 0.1282	0.73
Urban	NDVI = 0.0148 · temp + 0.0811	0.74
Grassland	NDVI = 0.0150 · temp + 0.1022	0.75
Bare ground	NDVI = 0.0148 · temp + 0.1050	0.76
Paddy rice	NDVI = 0.0157 · temp + 0.0788	0.74
Upland crop	NDVI = 0.0157 · temp + 0.1053	0.75



(a) 2090 year (A2) (b) 2090 year (B2)

Fig. 6. The future predicted monthly NDVIs for A2 and B2 scenarios of 2090.

predicted NDVIs based on the DCM downscaled temperature scenarios. The 2090 highest NDVI value was 0.61 while the current highest NDVI value was 0.52.

4. SLURP model calibration and validation

The SLURP model was calibrated and verified using 4 years (1999-2002) daily observed streamflow data of the watershed outlet which were obtained from the Han River Flood Control office. Sensitivity analysis for several model parameters was conducted repeatedly by increasing and decreasing the average value of calibration periods as a base. The results of sensitivity analysis showed that the maximum infiltration rate, maximum capacity for fast store, retention constant for slow store and precipitation factor are the most sensitive parameters (Table 3, Fig. 7). Through the sensitivity analysis and by using SCE-UA optimization technique (Duan *et al.*, 1994), the model parameters were calibrated for 2 years (1999 and 2000). The model was verified for another 2 years (2001 and 2002) using the average value of calibrated parameters (Fig. 8). A summary of model calibration and verification is given in Table 4. The calibration and validation results showed that the model was able to simulate the daily streamflow well with Nash-Sutcliffe model efficiency (Nash and Sutcliffe, 1970) ranging from 0.74 to 0.52.

Table 3. SLURP hydrological parameters and sensitivity

No.	Parameter name	Sensitivity
1	Initial contents of snow store (mm)	Medium
2	Initial contents of slow store (% of max)	Medium
3	Maximum infiltration rate (mm/day)	High
4	Manning roughness, n	Low
5	Retention constant for fast store	Medium
6	Maximum capacity for fast store (mm)	High
7	Retention constant for slow store	High
8	Maximum capacity for slow store (mm)	Medium
9	Precipitation factor	High
10	Rain/snow division temperature (°C)	Low

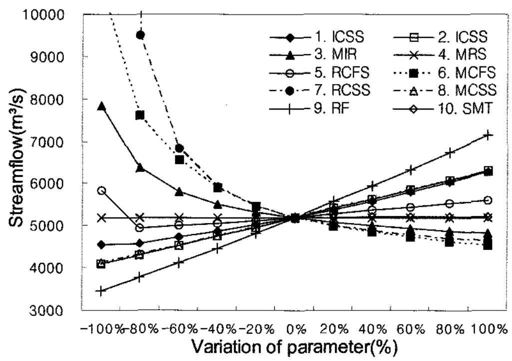


Fig. 7. Sensitivity analysis of parameters.

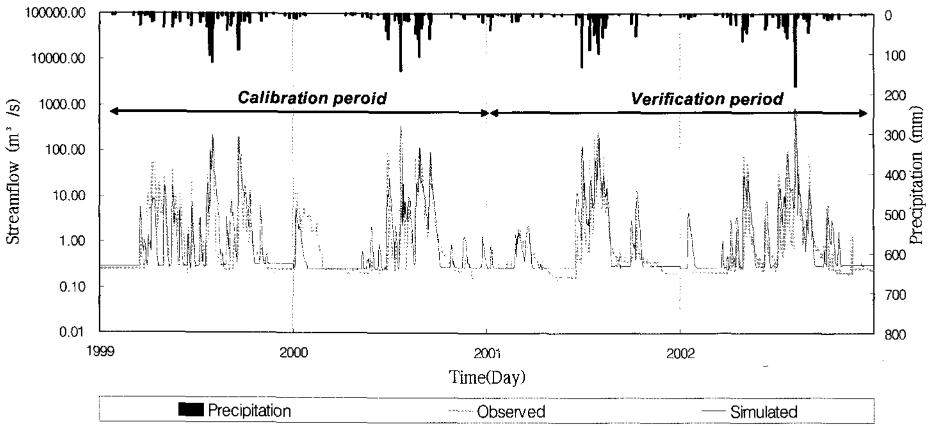


Fig. 8. Calibration and validation results (1999-2002).

Table 4. Summary of model calibration and verification

year	Observed			Simulated			Statistical summary			Note
	P (mm)	Q (mm)	QR (%)	Q (mm)	QR (%)	ET (mm)	RMSE (mm/day)	R^2	ME	
1999	1600.5	752.8	47	650.8	41	679.9	3.7	0.87	0.74	C
2000	1289.8	618.9	48	470.8	36	469.1	3.5	0.79	0.62	C
2001	994.3	583.4	59	534.7	54	476.9	5.3	0.73	0.52	V
2002	1299.2	813.5	63	760.3	59	655.8	12.3	0.75	0.55	V

P: Precipitation, Q: Streamflow, QR: Runoff ratio, ET: Evapotranspiration, R2: Coefficient of Determination, ME: Nash-Sutcliffe Model Efficiency, C: Calibration, V: Validation

5. Analysis of future climate and land use change impact on streamflow

For the evaluation of climate and land use change impact on streamflow, the SLURP model was run with the future downscaled climate data, the predicted CA-Markov land use data and the future NOAA NDVI vegetation information. Fig. 9 shows the predicted streamflow results of 2030, 2060 and 2090 for SRES A2 and B2 scenarios. Table 5 summarizes the prediction results. Based on the precipitation decrease of 35.2 % to 40.8 % in the future, the future runoff ratio without land use change was predicted from 46 % to 48 % while the 2001 runoff ratio was 59 %. The runoff ratio was 49 % to 51 % when future land use changes are considered. The 2.6 % to 3.3 % increase of runoff ration came from the increase of impervious area. The portion of predicted ET about precipitation was maintained relatively high even though the future precipitation was 60 % to 65 % level of the present precipitation. Some studies also have reported that there was increase in quantity of evapotranspiration (Kim, 2005), while the streamflow decreased for future climate change of decreasing precipitation (Merritt at al. 2006; Andersson *et al.* 2006; Aleix *et al.* 2007).

Fig. 10 shows the comparison of future predicted monthly streamflow, evapotranspiration, soil moisture and groundwater recharge. It is shown that there are big decrease in streamflow and groundwater recharge in the future. The shortage of both surface water and groundwater will give us more weighted water deficit for all water demands.

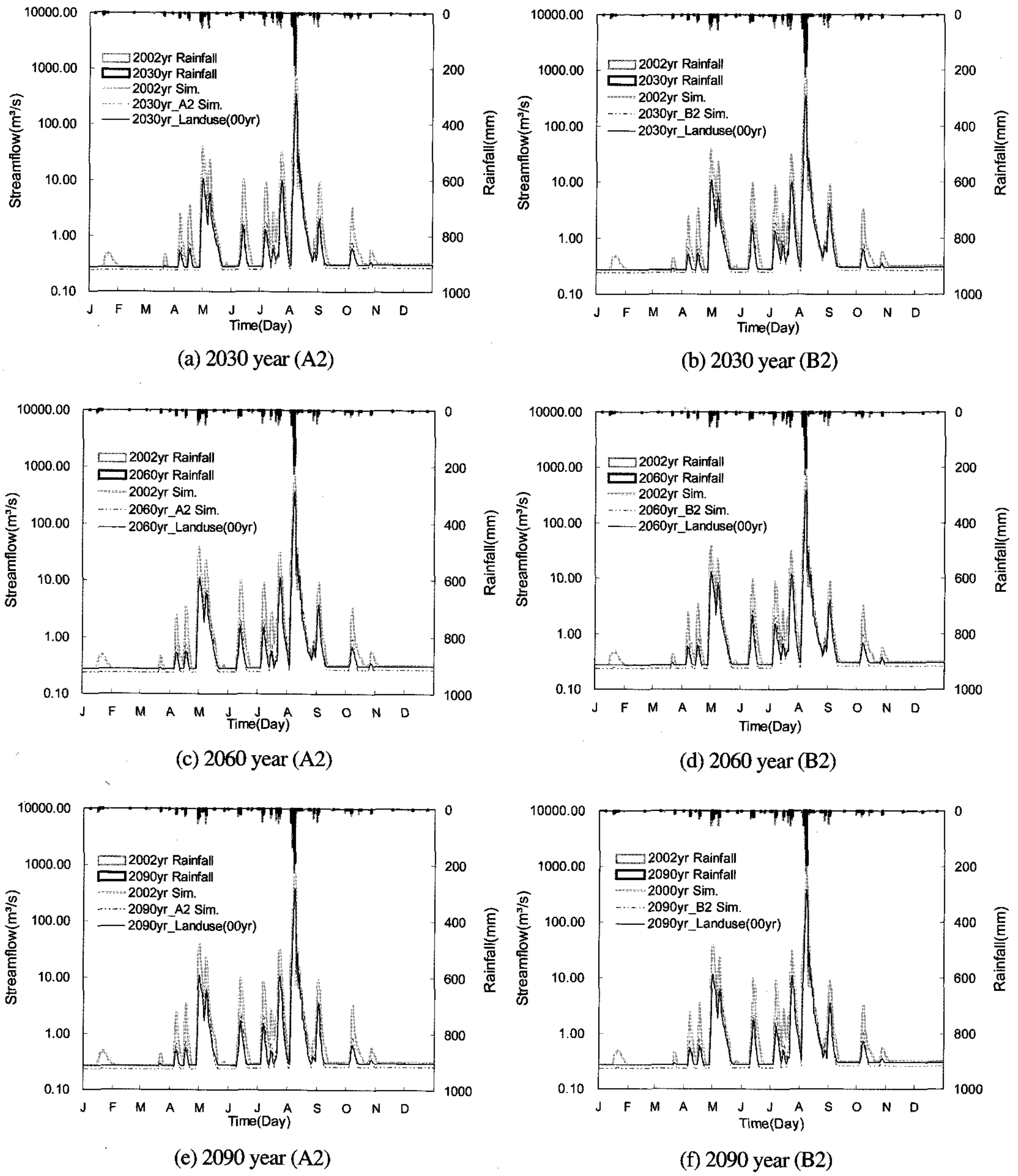


Fig. 9. Comparison of predicted and observed streamflows with CGCM2 SRES A2 and B2.

Table 5. Summary of predicted streamflow with SRES A2 and B2 scenarios

Scenario		P(mm)	P variation (%)	Without future land use change			With future CA_Markov land use		
				Q(mm) [QR(%)]	Q variation (%)	ET (mm)	Q(mm) [QR(%)]	Q variation (%)	ET (mm)
Pres.	2002	1299.2	-	760.3 [59]	-	655.8	-	-	-
A2	2030	768.8	-40.8	354.4 [46]	-53.4	541.4	374.5 [49]	-50.7	557.4
	2060	800.3	-38.4	378.9 [47]	-50.2	587.3	402.5 [50]	-47.1	590.4
	2090	798.9	-38.5	372.6 [47]	-51.0	614.9	394.9 [49]	-48.1	611.4
B2	2030	774.6	-40.4	360.2 [47]	-52.6	543.2	381.4 [49]	-49.8	549.8
	2060	841.8	-35.2	404.1 [48]	-46.8	578.8	429.5 [51]	-43.5	584.5
	2090	818.1	-37.0	387.7 [47]	-49.0	597.2	412.2 [50]	-45.8	593.1

P: Precipitation, Q: Streamflow, QR: Runoff ratio, ET: Evapotranspiration

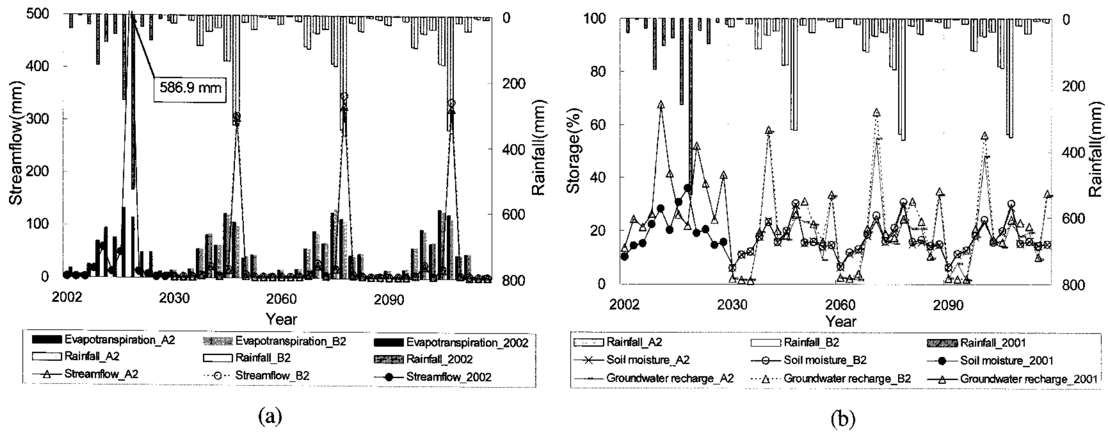


Fig. 10. The future predicted (a) Streamflow and evapotranspiration, (b) Soil moisture and groundwater recharge.

5. Conclusions

The basin-level hydrological model SLURP was applied to assess the potential impact of climate change on streamflow by considering future land use changes and their vegetation cover conditions.

The climate change results of CCCma CGCM2 based on SRES A2 and B2 were adopted and downscaled by the delta change method. The future climate showed that there are 6.6 ˚C temperature increase and 98.1 mm precipitation decrease in case of A2 scenario, and 4.3 ˚C temperature increase and 91.9 mm precipitation decrease in case of B2 scenario for 2090. A modified CA-Markov technique was applied for generating future land use information using Landsat TM and and ETM+ satellite images. The future land uses showed that the forest and paddy areas decreased 10.8 % and 6.2 % respectively while the urban area increased 14.2 %. The NOAA monthly NDVI-Temperature relationship was derived linearly for the future vegetation cover information. The future highest NDVI value was 0.57 while the current highest NDVI value was 0.43.

The SLURP model was calibrated and verified by comparing daily observed with simulated streamflow results for 4 years (1999-2002). The Nash-Sutcliffe model efficiency ranged from 0.74 to 0.52. For the future climate impact on streamflow using the downscaled data, the future runoff ratio without land use change condition was predicted from 46 % to 48 % while the runoff ratio of 2001 was 59 %. The future runoff ratio with CA-Markov predicted land use was 49 % to 51 %. The 2.6 % to 3.3 % increase of runoff ration came from the increase of impervious area. The streamflow and groundwater recharge was big decrease in the future. The shortage of both surface water and groundwater will give us more weighted water deficit for all water demands.

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References

Ahn, J. H., C. S. Yoo, and Y. N. Yoon, 2001. An Analysis of Hydrologic Changes in Daechung Dam Basin using GCM Simulation Results due to Global Warming. *J. of Korea Water Resources Association*, 34(4): 335-345.

Aleix S., C., B. V. Juan, G. P. Javier, B. Kate, J. M. Luis, and M. Thomas, 2007. Modeling climate change impacts-and uncertainty-on the hydrology of a riparian system. *Journal of Hydrology*, 347: 48-66.

Andersson, L., J. Wilk, M. C. Todd, D. A. Hughes, A. Earle, D. Kniveton, R. Layberry, and H. G. Savenije, 2006. Impact of climate change and development scenarios on flow patterns in the Okavango River. *Journal of Hydrology*, 331: 43-57.

Arnell, N. W., 1996. Global Warming, River Flows, and Water Resources, New York, N.Y.: John Wiley and Sons.

Arnell, N. W., 1999. Climate Change and Global Water Resources. *Global Environmental Change*, 9: S31-S49.

Duan, Q., S. S. Sorooshian, and V. K. Gupta, 1994. Optimal use of the SCE-UA global optimization method for calibrating watershed models. *Journal of Hydrology*, 158: 265-284.

Gellens, D. and E. Rouline, 1998. Streamflow Responses of Belgian Catchments to IPCC Climate Change Scenarios. *Journal of Hydrology*, 210: 242-258.

Ghosh, S. and P. P. Mujumdar, 2008. Statistical downscaling of GCM simulations to streamflow using relevance vector machine. *Advances in water resources*, 31: 132-146.

Hay, L. E., I. L. Wilby, and G. H. Leavesley, 2000. A comparison of delta change and downscaled GCM scenarios for three mountainous basins in the United States, *Journal of American Water Resources Association*, 36(2): 387-397.

IPCC, 2001. Climate Change 2001: Scientific Basis. In: Contribution of Working Group III to the Third Assessment Report of the Intergovernmental Panel on Climate Change, B. Metz, *et al.* (Editors). Published for the Intergovernmental Panel on Climate Change [by] Cambridge University Press, Cambridge, UK, New York, USA.

IPCC., 2006. IPCC Data Distribution Centre. Available at: ipccddc.cptec.inpe.br/ipccddcbr/html/cru_data/support/faqs.html.

Kim, B. S., 2005. Impact assessment of climate change on hydrologic components and water resources in watershed. Inha University.

Kite, G. W., 1975. Performance of two deterministic hydrological models. *IASH-AISH Publication*, 115: 136-142.

Kite, G. W., 1993. Application of a land class hydrological model to climatic change. *Water Resources Research*, 29(7): 2377-2384.

Kite, G. W., A. Dalton, and K. Dion, 1994. Simulation of streamflow in a macro-scale watershed using GCM data. *Water Resources Research*, 30(5), 1546-1559.

Lee, Y. J. and S. J. Kim, 2007. A modified CA-Markov technique for prediction of future land use change, *Journal of Korean Society of Civil Engineers*, 57(6D): 809-817.

Merritt, W. S., Y. Alila, M. Barton, B. Taylor, S. Cohen, and D. Neilsen, 2006. Hydrologic response to scenario of climate change in sub watersheds of the Okanagan basin, British Columbia. *Journal of Hydrology*, 326: 79-108.

Nash, J. E. and J. V. Sutcliffe, 1970. River flow forecasting through conceptual models, Part I-A discussion of principles. *Journal of Hydrology*, 10: 283-290.

Zhang, G. H., M. A. Nearing, and B. Y. Liu, 2005. Potential effects of climate change on rainfall erosivity in the Yellow River basin of China, Trans. *ASAE*, 48(2): 511-517.

Zhang, X., R. Srinivasan, and F. Hao, 2007. Predicting hydrologic response to climate change in the Luohe River Basin Using the SWAT model, Trans. *ASAE*, 50(3): 901-910.