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Climate Change Impact Assessment on Han River Long Term Runoff in South Korea Based on RCP Climate Change Scenario

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ABSTRACT

The 2007 World Economic Forum (WEF) referred to climate change as the overriding problem we face. Concerns have been raised about how global warming would accelerate future climate change and its consequences. Many climate change studies expect the possible occurrence of extreme high temperature, increase in heavy rains and strong typhoons in the near future. Currently, climate change scenarios are used to prepare an appropriate plan for these phenomena under climate change. The main purpose of this paper is to suggest and evaluate an operational method of assessing the potential impact of climate change on hydrologic components and water resources at the regional scale. Future runoff was simulated using high resolution Regional Circulation Model (RCM) (12.5 × 12.5 km) Representative Concentration Pathway (RCP) scenario operated by the Korea Meteorological Administration (KMA) and a semi-distribution model or SLURP (Semi-distributed Land Use-based Runoff Process). The study was carried out on the Han River including its nine dams. The study found that runoff characteristics, especially annual distribution, could change. The discharge in July tends to decrease while runoff can increase in August and September. The flow duration curve was estimated and compared with observed data and simulated daily runoff data for Paldang-dam to evaluate the effect of climate change. The analysis of the flow duration curve shows that the mean average low flow increased while the average wet and normal flow decreased under the climate change scenario.

Key words: Climate change, RCP scenario, Han River, Flow duration

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1. INTRODUCTION

Much research and projects on climate change and related studies are currently being carried out worldwide. In addition, the water resource field is preparing for various counter measures and responses to future climate change. From the early 2000s, Korea suffered from various climate patterns different from the past such as locally concentrated heavy rains and droughts. Recently, in the summer of 2012, tropical rainfall showed up generating damages from both droughts and floods. These phenomena from climate change should no longer be accepted as mere predictions but as a part of life.

IPCC (2001) stated that "climate change" is causing a rise in temperature, changes in the rainfall intensity and frequency leading to changes in evapotranspiration, and time and spatial fluctuations in runoff, which are forecasted to exacerbate difficulties in stably supplying and efficiently managing water resources. The intensity of extreme events and the frequency of their occurrence are forecasted to increase. The reduced number of days under rainfall is forecasted to possibly lead to both floods and droughts. Therefore, an evaluation of changes in water resources is necessary to prepare for climate change expected to accelerate in the future and properly respond to it. As such, countries worldwide are using the General Circulation Model (GCM) and Regional Circulation Model (RCM) based on the Special Report on Emission Scenario (SRES) recommended by IPCC to simulate and derive precise information about future climate. In particular, they are recently producing more accurate data and research using the RCM model that would enable effective

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collection of the topographical characteristics of some regions mainly outside of Korea (Kwon and Moon 2007).

This study entered the Semi-distributed Land Use-based Runoff Process (SLURP) model, a semi-distribution type, long-term runoff model based on the Representative Concentration Pathway (RCP) 8.5 scenario provided by the Korea Meteorological Administration (KMA), to simulate runoff from the Han River Basin from 2011 - 2100. This also compares the monthly runoff amount of the past and future for a flow regime analysis to evaluate the changes in water resources of the Han River Basin in the future. The study flow is as in Fig. 1.

2. RCP CLIMATE CHANGE SCENARIOS

The 5th report of IPCC set the greenhouse gas concentration using the impact of radiation human activities generate in the air. The RCP scenario reflected the recently changing trends of greenhouse gas concentration and updated the resolution to fit the recent forecast model. While the existing greenhouse gas scenario (SRES) only included the coercion from only the impact of greenhouse gases and aerosol among artificial factors causing climate change, the RCP scenario includes the impact from the change in land use. The concentrations of the four representative greenhouse gases presented in the RCP scenario are 2.6, 4.5, 6.0, and 8.5. Their calculation changes from the socio-economic assumption on whether policies are implemented to respond to climate change in a future society structure. RCP 2.6 is the case of possible self-recovery of the earth from the impact of human activities and 4.5 is the case wherein policies to reduce greenhouse gases are implemented largely. The 6.0 is when policies to reduce greenhouse gases are implemented to a little extent and 8.5 when greenhouse gases are emitted like now. The numbers in the RCP scenarios mean the degree of influence changing the balance of energy such as the force of radiation, that is, greenhouse gases. Each unit has about 238 W m^{-2} sun radiation reaching the W m^{-2} earth surface and the 8.5/6.0/4.5/2.6 RCP radiation forces refer to about 3.6, 2.5, 1.9, 1.1%, respectively, of ray sun radiation amount. The following Table 1 shows the CO_2 concentration of the SRES and RCP scenarios. In this study, the RCP 8.5 scenario reflecting the CO_2 reduction measures, as what we currently have, was adopted. The data for the RCP 8.5 scenario is provided by the KMA.

3. SLURP HYDROLOGICAL MODEL

To simulate the runoff considering climate change, this study adopted the SLURP model. The SLURP model is an alternative model of the complex Streamflow Synthesis and Reservoir Regulation Model (SSARR) model developed for the first time in 1975 to use on mid to large basins and has been improved 12 times since then (Kite 2000; Kim et al. 2003). At first, it was developed as a simple Lumped Reservoir Parametric (SLURP), but it transformed later into a semi-distribution type model of SLURP. This model is a semi-distribution type model, but it is a physical model that can be used as a distribution type model enabling separately considering the event of rain into rainfall and snow (Kim et al. 2007). In respect of the applicability for river areas in Korea, Precipitation-Runoff Modeling System (PRMS), which has been applied to the River Basin Investment Project, was found to be superior. Considering the way to calculate evapotranspiration, PRMS and SSARR were outstanding since they use solely temperature data. SLURP with Global Optimization is highly applicable to parameter calibration. SLURP is known for its high applicability for basin areas from small watersheds to large watersheds, with areas covering 250, 7500 - 35000, and 1.8 × 106 km^2 (Kite et al. 1994). Therefore, SLURP is considered the most

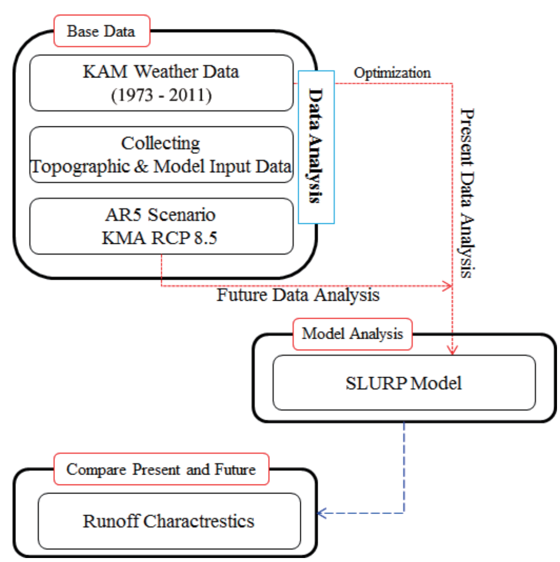

Fig. 1. Flowchart of this study.

Table 1. CO_2 concentration of SRES and RCP scenarios.

ppm \ Scenario	RCP				SRES		
	2.6	4.5	6.0	8.5	B1	A1B	A2
CO_2	421	538	670	936	550	720	830

Note: Current CO_2 concentration in Korea: about 400 ppm (as of 2010).

appropriate since we can see the Han River area (26355 km^2 of basin area excluding Imjin River basin) which occupies 23% of the nation's total land area, has multiple dams, displays climate change factors, land cover and vegetation changes. For this reason, in this study SLURP was adopted to simulate discharge considering climate change.

When using the SLURP model, the concept of a sub-basin called the Aggregated Simulation Area (ASA) was used to classify and divide an entire basin into sub-basins. Here, each sub-basin has been subcategorized into sub-basins according to the land cover. A daily time step runoff simulation demands physical parameters such as topographical parameters like the average height, stream channel length, and land cover characteristics of ASA other than meteorological time step data including temperature and precipitation as well as the infiltration rate as entry data. The SLURP model analyzes the vertical water balance of each ASA and again traces the stream channel of each ASA to simulate the amount of runoff at the exit point of the entire basin. The vertical water balance is as in Fig. 2. It is composed of four layers and the main parameter variables are the undercurrent amount at the start of snow, the undercurrent amount at the start of subsurface storage, the maximum infiltration rate, and the Manning coefficient, among others (Kite 2007).

4. COLLECTING DATA AND FOUNDATION OF MODEL

4.1 Target Area

The basin subject to this study is the Han River Basin, which is the largest in Korea. Around the basin are aggregated major socio-economically important facilities and large cities. This is also where multi-purpose dams are located. These dams provide water to Seoul, Gyeonggi-do and Gangwon-do. Therefore, the basin is deemed the ideal basin to evaluate the impact of future climate change on water resource systems and was selected for this study. The basin is geographically located at 36°30' - 38°55' latitude and 126°24' - 129°02' longitude. It covers 23 percent of Korea's total land area at 26018 km^2. The artery extension of the basin is 481.7 km long. Figure 3 shows the location of the Han River Basin and the 21 meteorological observatories used in this study. This study collected five (rainfall amount, relative humidity, average temperature, average wind speed and sunshine hours) meteorological data of each observatory from 1973 - 2011 for a total of 38 years to analyze.

4.2 Future Drought Project

To extract topographical parameter, the digital evaluation model, land cover map and a soil map provided by the Water Management Information System (WAMIS) were used. First, an estimating of the distribution of land cover of the Han River Basin using the land cover map provided by the system (2000, classified into eight categories) shows that the basin is 74.2% covered with forests, 12.5% with paddies and 2.2% with fields. In addition, regions turning into cities and grassland amount to about 11%. The following Fig. 4 shows the Digital Elevation Model (DEM), land cover and soil map used to extract the topographical parameter of the basin.

To reflect the soil characteristics, instead of the Curve Number (CN), a runoff curve coefficient used by most

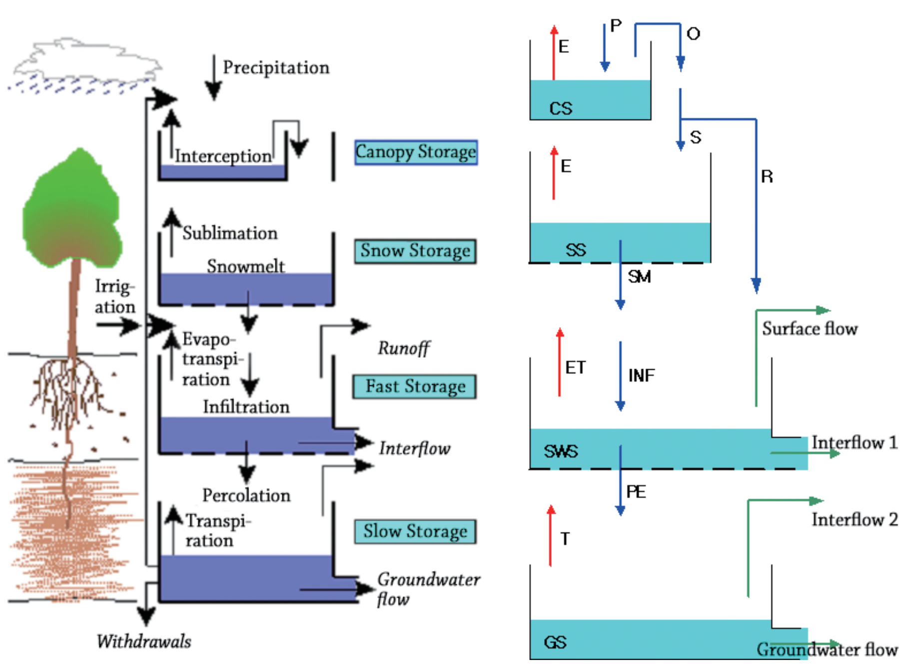

Fig. 2. SLURP Vertical Water Balance (Kim 2007; Kite 2007).

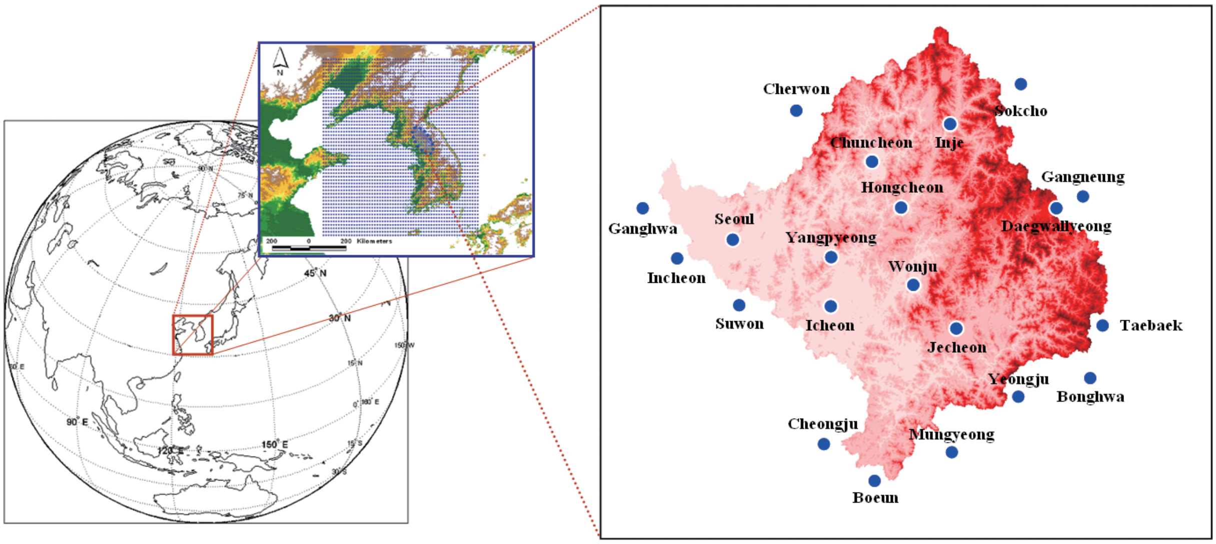

Fig. 3. Location of the Han River Basin and Meteorological Observation Stations.

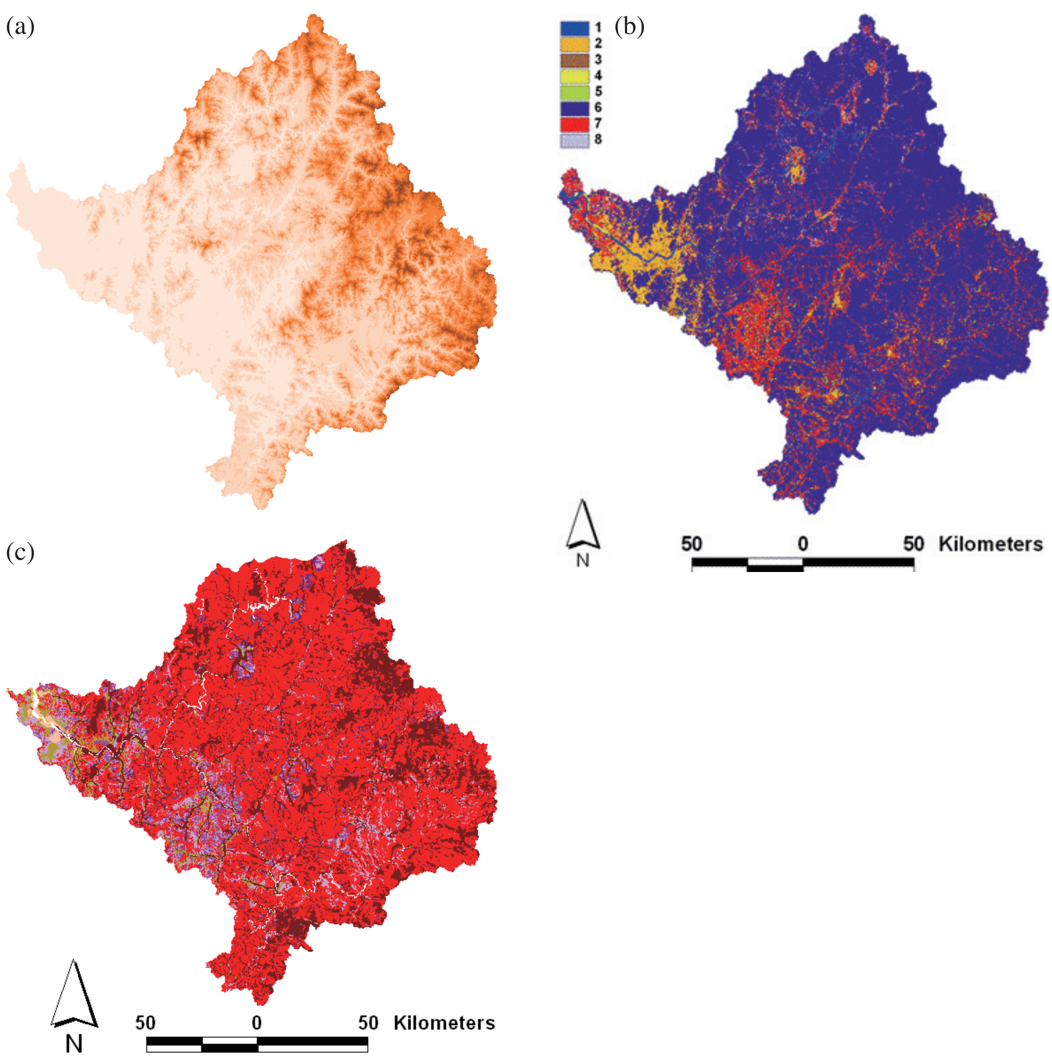

Fig. 4. Topographical factors of the Han River Basin (a) DEM, (b) Land Cover, (c) Soil Map.

floodgates models, the SLURP model uses the pedo-transfer function (PTF) model (Kim et al. 2004a). This study categorized the basin's soil characteristics by land cover type. The results were entered into the PTF to calculate the value of each characteristic. Table 2 shows the soil characteristic values of each land cover of the basin calculated using the PTF.

This study divided the basin into ASA and used Topographic Parameterization (TOPAZ) (Garbrecht and Campbell 1997), a digital terrain analysis model, to extract the physical parameter variables, the stream's current length, and average altitude of ASA, as topographical parameter variables of the SLURP model (Kim et al. 2004b). This study considered the area of the studied basin to reconstruct and apply the DEM length from 30 - 100 m.

A TOPAZ analysis showed a classification of the basin into 139 ASAs as in Fig. 5 and their topographical parameters were extracted.

4.3 Normalized Difference Vegetation Index (NDVI)

The SLURP model considered the blocking of rainfall by vegetation and used the Leaf Area Index (LAI) to

Table 2. Soil characteristic values of the Han River Basin.

Classify	Land cover	Sand (%)	Clay (%)	FC	WP	Porosity	AW
1	Water	78.90	21.10	0.215	0.006	0.453	0.209
2	Urban	84.74	15.26	0.190	0.003	0.449	0.187
3	Barren	81.16	18.84	0.207	0.005	0.202	0.452
4	Wetland	72.80	27.20	0.240	0.011	0.457	0.457
5	Grass	76.32	23.68	0.228	0.008	0.455	0.220
6	Forest	68.17	31.83	0.369	0.073	0.426	0.296
7	Paddy	77.45	22.55	0.219	0.070	0.454	0.213
8	Crop	76.32	23.68	0.229	0.008	0.455	0.220

Note: FC: Field Capacity, WP: Wilting Point, AW: Water Activity.

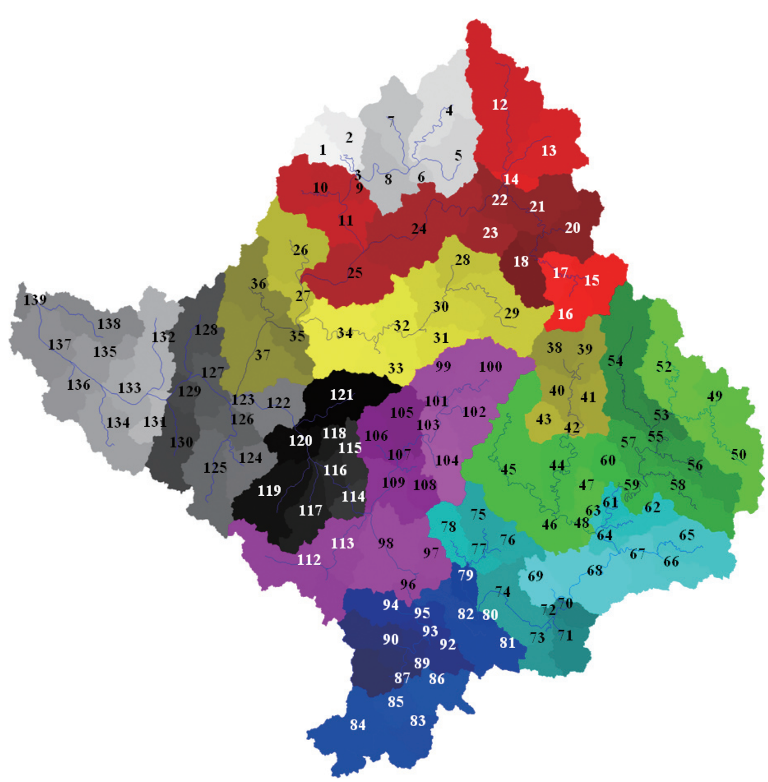

Fig. 5. 139 sub-basins (ASA) of the Han River Basin.

divide the transpiration from vegetation and the evaporated amount from soil and vegetation. Further, they were calculated within the model from the monthly NDVI separated from the Simple Biosphere Model (SiB) vegetation coefficient (Rouse et al. 1973; Kite 1995). The larger the NDVI value, the higher the usage and amount of vegetation are at each point.

Figure 6 shows the monthly NDVI per land cover of the Han River Basin in 2000. All land classifications showed increasing trends from May to August and of mostly decreasing trends from September.

4.4 Dams on the Han River Basin

This study investigated and used as materials for analysis the water level-area, the water level-volume curve equation, the maximum and minimum allowed water level, and the monthly actual discharged amount of each representative dam on the basin. On the basin are located a total of 10 dams: three multi-purpose dams (Soyang, Chungju, and Hoengseong Dam), six power plant dams (Hwacheon, Goesan, Paldang, Uiam, Cheongpyeong, and Chuncheon Dam) and one dam for production and manufacturing use (Gwangdong Dam). Among them, the actual discharge amount is missing for Gwangdong Dam (WAMIS) that we did not consider it in our analysis and reflected nine dams in our model (Fig. 7).

4.5 Simulation of SLURP Model

When entering data of each dam in this study, the monthly actually discharged amount data were used. Simulation results of the Soyan, Chungju, and Paldang Dam located on the upper part of the basin and the observed discharged amount were used to revise the model.

The model was revised from 2009 - 2011, but because of errors in the curve equation of the water level-area and water level-amount located on the Paldang Dam basin region in 2009 and 2011, we selected 2010 as the period for revision for uniformity in optimizing the model. For details on the SLURP model's parameter variables, refer to Kite (1995, 2007), Lacroix and Martz (1998), Kim et al. (2003). Figure 8 and Table 3 show before and after the revision of models of Soyang, Chungju, and Paldang Dam. The average calculated amount of discharge was almost the same as the actually observed discharge amount after the revision of the model for each dam and the ratio of the mean error to the daily average observed discharge amount decreased, it has been confirmed.

Based on the results revised in this study, the discharge of Paldang dam in the Han River basin is compared with the observed discharge (Fig. 9). From the comparison, we could obtain 0.51 of N-S efficiency factor, which indicates there is no significant difference between the discharge of each dam calculated through the model calibration and the discharge of Paldang dam. Therefore, we analyzed the change in discharge according to climate change by using the revised results of the Han River basin.

5. FUTURE RUNOFF SIMULATION BASED ON THE CLIMATE CHANGE SCENARIOS

To analyze the impact of climate change on the Runoff changes of the Han River Basin, we entered three factors related to climate change as data to reflect them in the SLURP model. For this, we used RCP 8.5 data provided by the KMA as climate change data for a total of 90 years from 2011 - 2100.

We used rainfall and temperature of the RCP 8.5 scenario provided by the administration to the built and revised SLURP model to simulate the discharge amount from 2011 - 2100 according to the climate change scenario. We

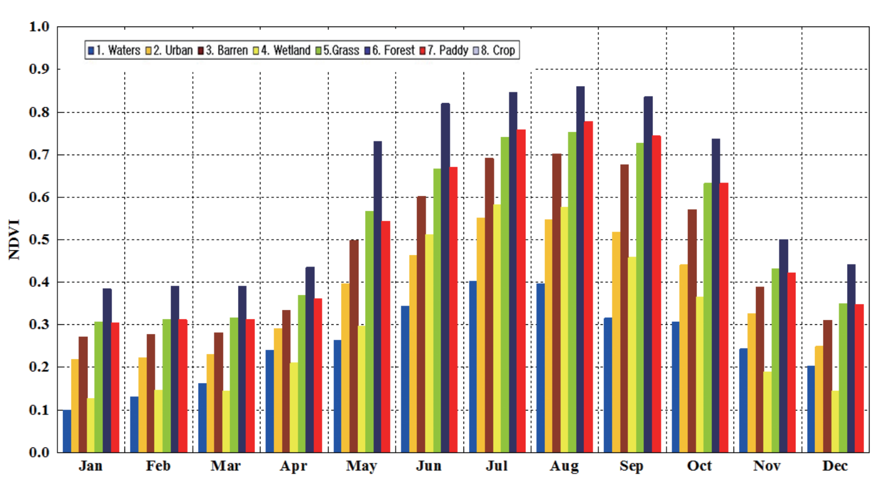

Fig. 6. NDVI of Han River Basin (in 2000).

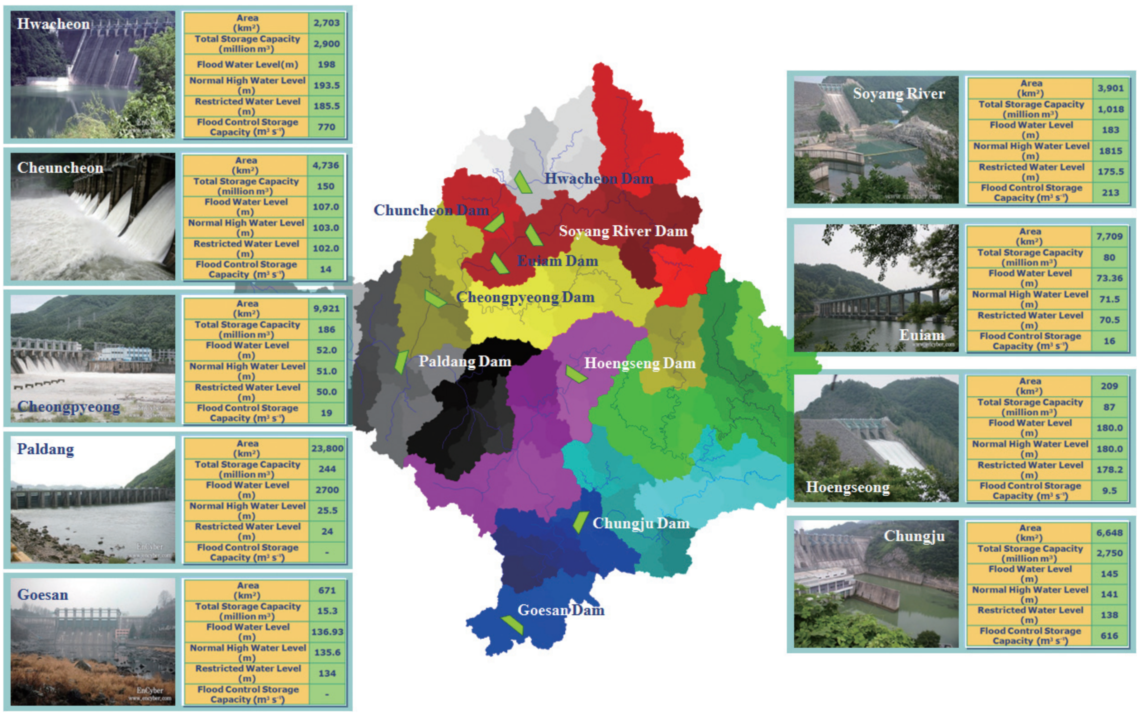

Fig. 7. Location and Pictures of Dams on the Han River Basin.

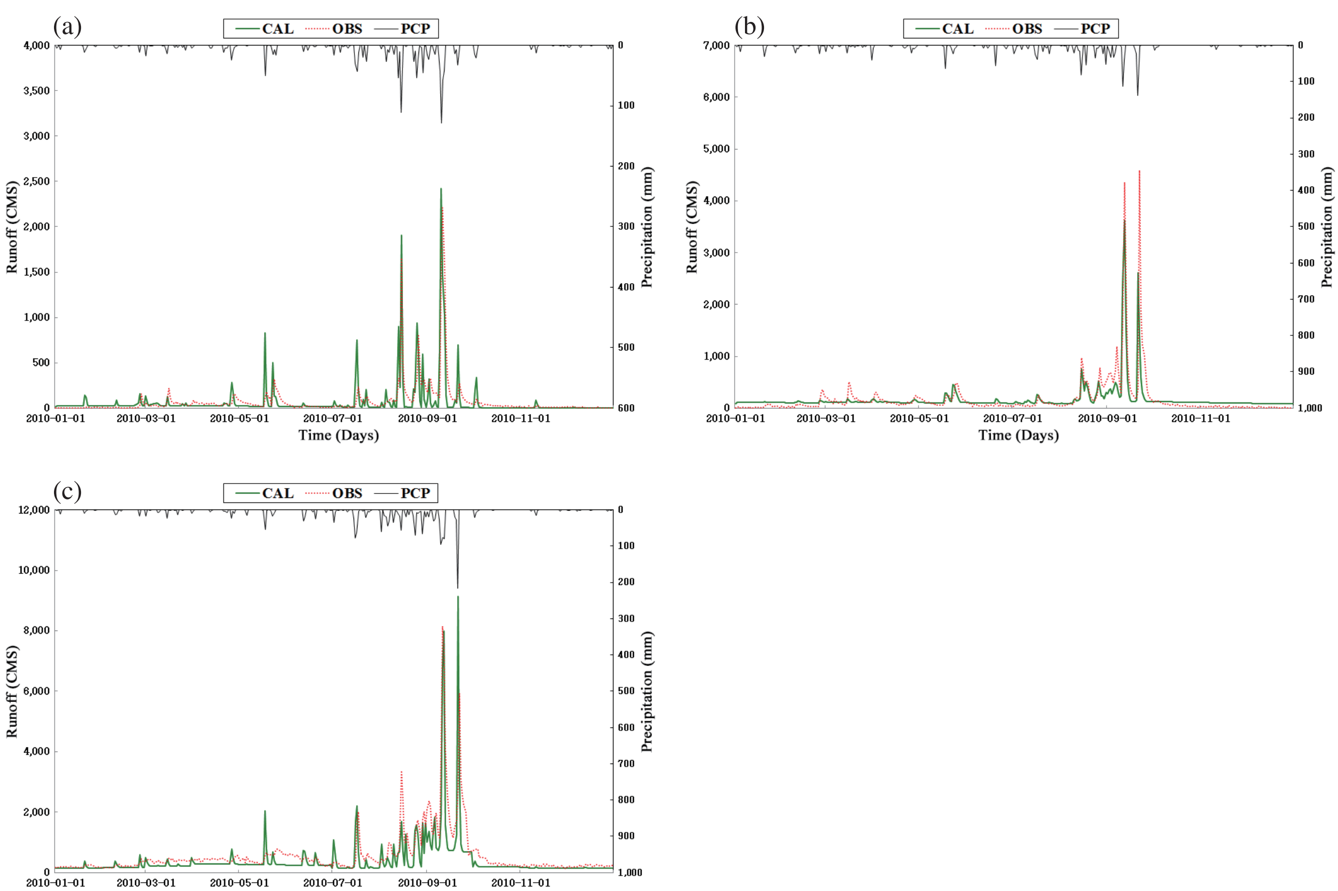

Fig. 8. Comparison of simulated and observed discharge amounts (a) Soyang Dam, (b) Chungju Dam, (c) Paldang Dam.

Table 3. Before and after revision of models for each dam.

Category	Soyang Dam		Chungju Dam		Paldang Dam	
	Before	After	Before	After	Before	After
Period of model revision	2010					
Average daily calculated discharge amount (m^3 s^{-1})	36.60	67.05	141.31	164.22	269.47	396.79
Average daily observed discharge amount (m^3 s^{-1})	74.78	74.78	168.96	168.96	573.36	573.36
Mean Error	-38.18	-7.73	-54.64	-4.74	-303.89	-176.56
Average mean error / average daily observed discharge amount (m^3 s^{-1})	-0.51	-0.10	-0.32	-0.03	-0.53	-0.31
Nash-Sutcliffe Efficiency coefficient	0.49	0.55	-0.48	0.58	0.30	0.54

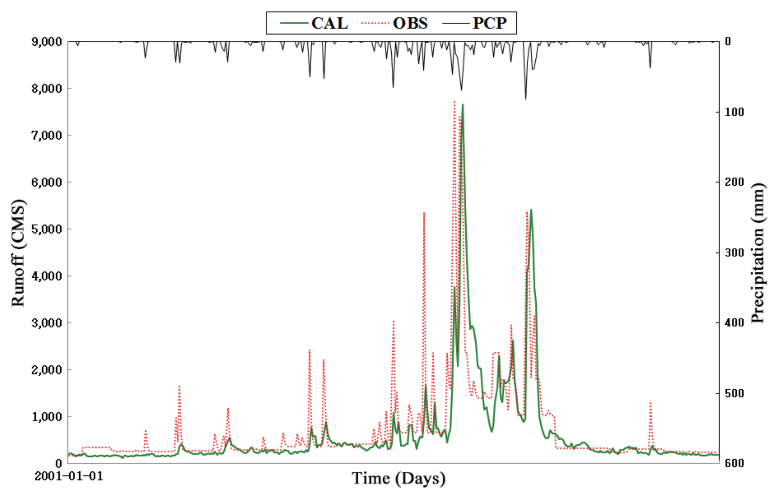

Fig. 9. Comparison of the simulated discharge with the observed discharge after parameter calibration.

also showed the monthly-simulated discharge amounts of Soyang, Chungju, and Paldang Dam among the nine dams on the basin and compared the monthly simulated future discharge amounts with the observed values and showed the flow regime analysis results to analyze the changes in future discharge amounts and flow regime fluctuations.

5.1 Future Climate Change Characteristics of the Han River Basin

To find out changes from future climate change compared to the present, we used the RCP 8.5 forecast data classifying the future into three periods (Future 1: 2011 - 2040, Future 2: 2041 - 2070, Future 3: 2071 - 2100). This study uses the 8.5 scenario wherein policies to reduce greenhouse gases are assumed as not being implemented at all and is commensurate to the A2-A1FI of SRES emission scenarios. From Figs. 10 - 12, the figures show the monthly fluctuations of the average rainfall, temperature, and evapotranspiration amount on the Han River Basin in the future compared to the present. The figures show that the farther into the future, the more rainfall, temperature and evapotranspiration amount increase. In particular, at the end of the 21st century, the average temperature in February and December are expected to be above 0°C that one can confirm the occurrence and increase of evapotranspiration during these two months.

5.2 Flow Regime of the Han River Basin from Climate Change

This study applied the RCM 8.5 scenario as explained in 5.1 to simulate the future runoff changes under climate change. The simulated period is a total of 90 years from 2011 - 2100. To grasp the discharge characteristics of the basin, we present the results of analyses carried out on Soyang, Chungju, and Paldang Dam selected as major points on the upper part of the basin. We show the changes in the seasonal characteristics of discharge, flow regime analysis results, and other data of each dam for three future periods (Future 1: 2011 - 2040, Future 2: 2041 - 2070, Future 3: 2071 - 2100).

As can be confirmed in Fig. 13, the same changes in

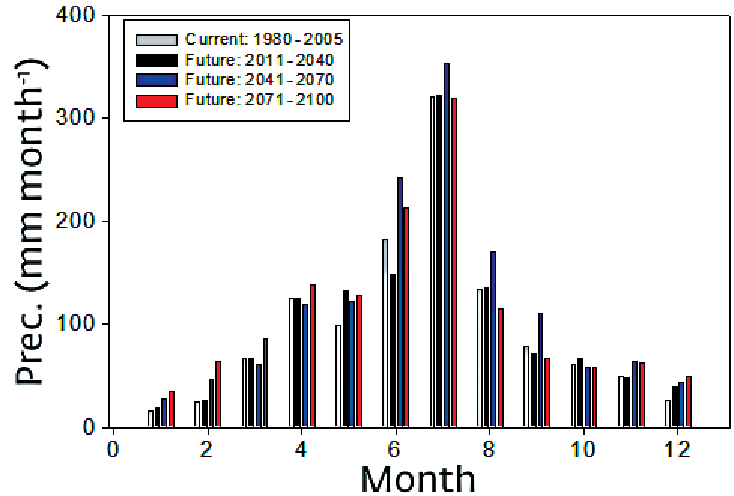

Fig. 10. Future monthly precipitation changes compared to the present.

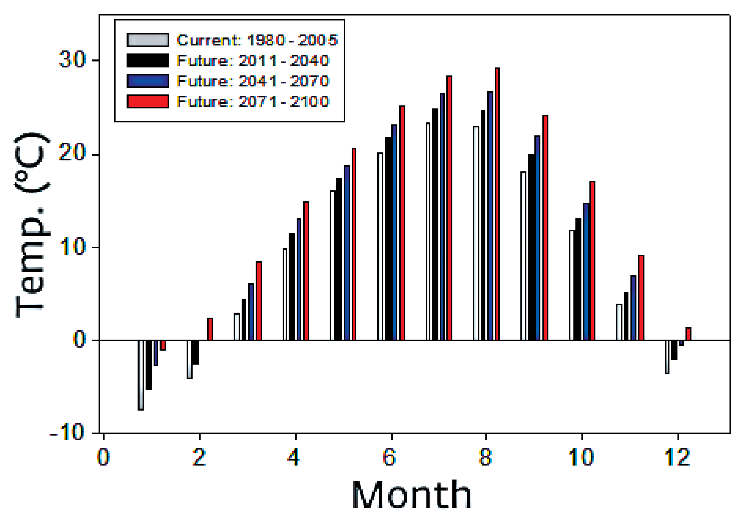

Fig. 11. Future monthly temperature changes compared to the present.

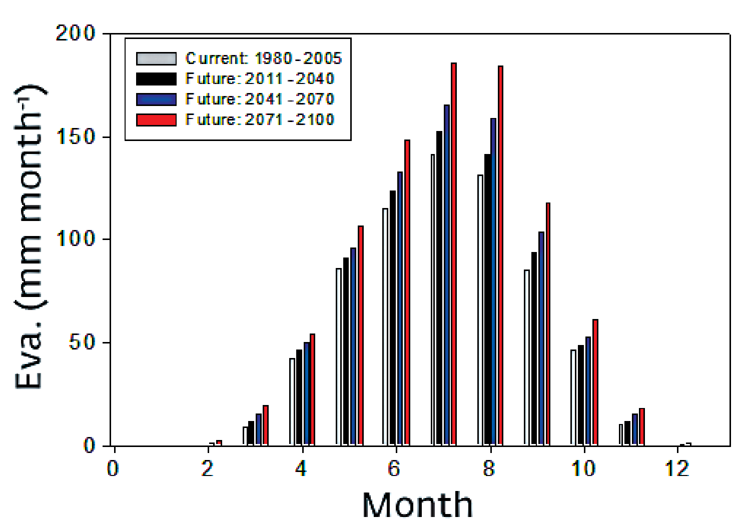

Fig. 12. Future monthly evapotranspiration changes compared to the present.

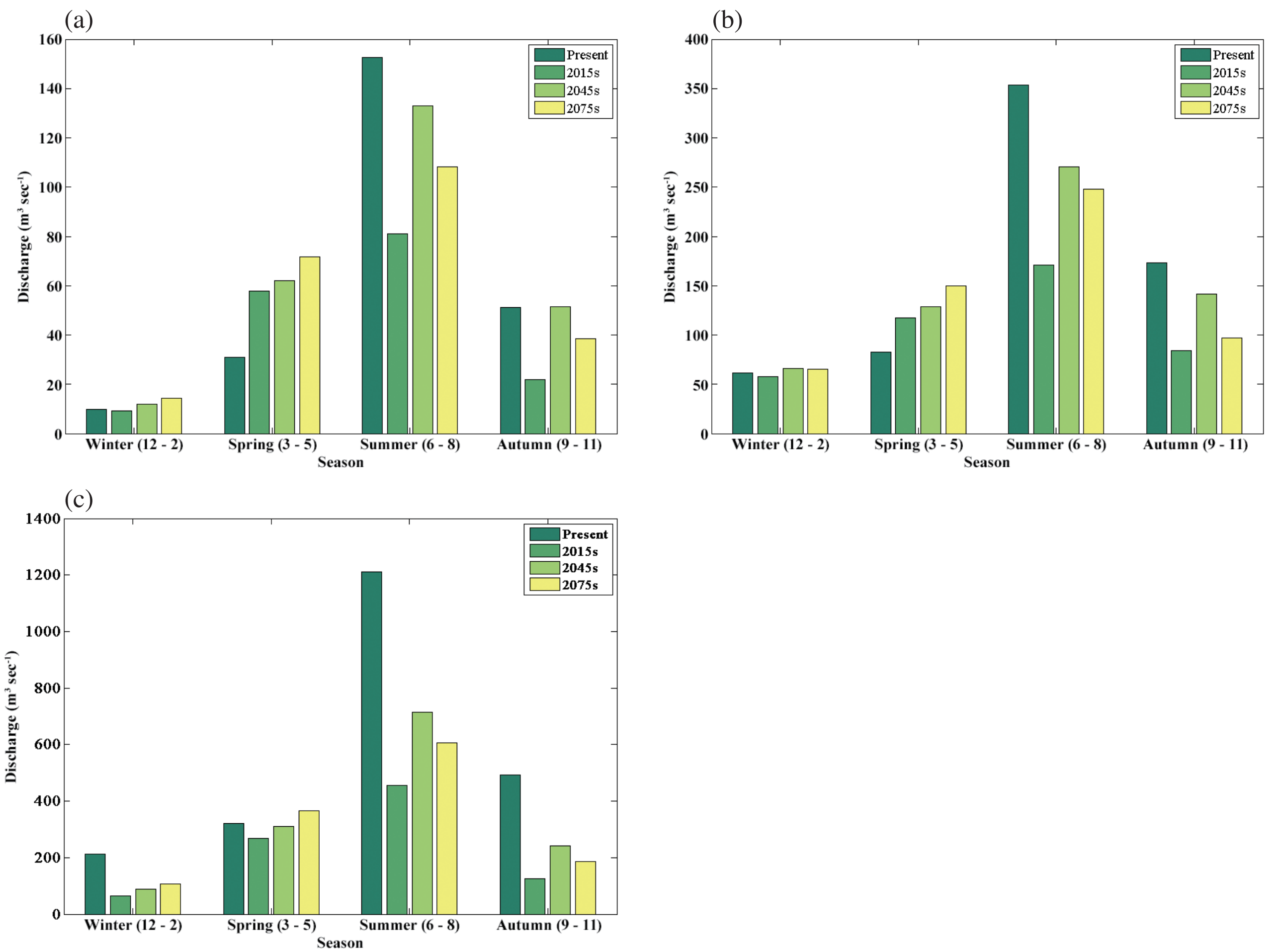

Fig. 13. Seasonal runoff changes of the Han River Basin (in the order of winter, spring, summer and fall). (a) Soyang Dam, (b) Chungju Dam, (c) Paldang Dam.

the seasonal discharge fluctuations showed up in all three parts of the Han River Basin. In the past, discharge was concentrated in the summer in a similar pattern as Korea's rainfall. However, in the future, discharge in the summer and autumn will decrease for all three points (Soyang, Chungju, and Paldang Dam) than current, according to the simulation. This means that unlike the past, when rainfall was concentrated in the summer, in the future, the rainfall pattern will change and concentrate in the spring, increasing discharge during the spring.

Under the current pattern, the discharge from Soyang Dam (Fig. 14a) increased from June to July in the summer season, but it started to decrease slowly from August, and sharply dropped in the winter season. By applying the climate change scenario, we could notice that the discharge generally increased in the spring, fall, and winter seasons while decreasing in the summer season for Future 1, 2, and 3.

The discharge from Chungju Dam (Fig. 14b) decreased in the summer season in general for Future 1, 2, and 3. According to the run-off simulation scenario, Chungju Dam showed a decreasing pattern in discharge from July to October, indicating a change in the rainfall pattern that is similar to Soyang Dam.

By comparing the future discharge to the observed value, we could see that from July to August, the overall discharge from Paldang Dam for Future 1, 2, and 3 decreased while it increased from March to June, and the increase in discharge is greater in March and April. In addition, this showed that the change in future rainfall pattern leads the change in the rainfall period as well. All three dams-Soyang, Chungju, and Paldang-had a significant decrease in discharge in the summer season for the future, which means the change in rainfall pattern leads the increase in discharge in the future by shifting the heavy rainfall period from summer in the past to spring and winter in the future.

In other words, December to February was considered as winter, from March to May, spring, from June to August, summer and fall from September to November. The monthly discharge fluctuations as shown in Fig. 13 forecast more discharge largely from March to June than the past as confirmed in the seasonal fluctuations. In addition, discharge from July to September will largely decrease. The discharge

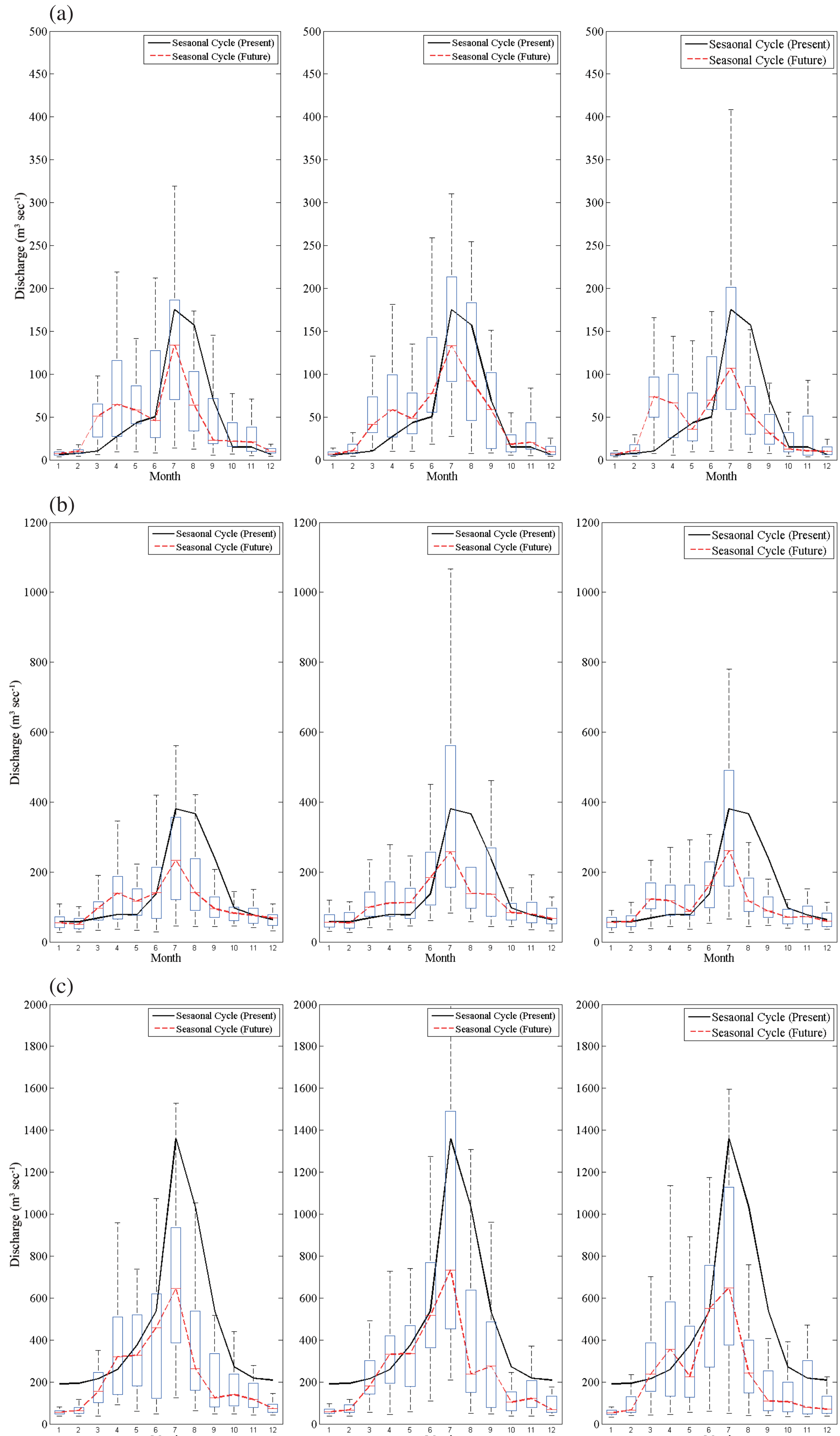

Fig. 14. Monthly mean runoff changes of the Han River Basin (left: Future 1, center: Future 2, right: Future 3), (a) Soyang Dam, (b) Chungju Dam, (c) Paldang Dam.

characteristics based on the RCP 8.5 climate change scenario show clear changes compared to the current (1973 - 2011), according to our analysis.

Last, to examine future discharge characteristics, we examined the flow regime changes in the future (Fig. 15). If considering the Paldang Dam as the lowest downstream point, Soyang and Chungju Dam show similar flow duration curves as in the past. However, the future flow duration curve of Paldang Dam showed lower values overall than the present. This means that the water shortage problem may be severe in the future. The upstream currents affecting the Paldang Dam show a possible negative impact on the consolidation of water from periodical and discharge scale changes of unexpected or localized short-term characteristics. Therefore, instead of consolidating water focusing on quantity only, changes to the dam managing system reflecting its seasonal changes and characteristics will be demanded.

6. SUMMARY AND CONCLUSION

This study linked a climate change scenario with a hydrologic model to simulate a runoff changes scenario and evaluate the impact of future climate change on flow regime. Here, we evaluated the timing of runoff changes and the quantitative changes from a long-term perspective and used the SLURP model, a semi-distributed hydrologic model to consider the land cover and vegetation changes other than meteorological data. We further used the RCP 8.5 scenario provided by the KMA to simulate a runoff change scenario.

(1) We analyzed the characteristics of future climate change data for the RCM 8.5 scenario. The RCM 8.5 scenario is based on the premise that no policy at all for the reduction of greenhouse gases is implemented and is commensurate to the emission scenarios of A2-A1FI of SRES. The farther into the future, the more the average monthly fluctuations of rainfall, temperature, and evapotranspiration increase in the Han River Basin. In particular, at the end of the 21st century, the average temperature in February and December is expected to be above 0°C that evapotranspiration will likely occur and increase during the two months, we confirmed. In addition, the ratio of rainfall to evapotranspiration will increase overall the farther into the future that the danger of droughts is likely to rise.

(2) For information of each dam located on the Han River Basin, we used the monthly actually measured discharge

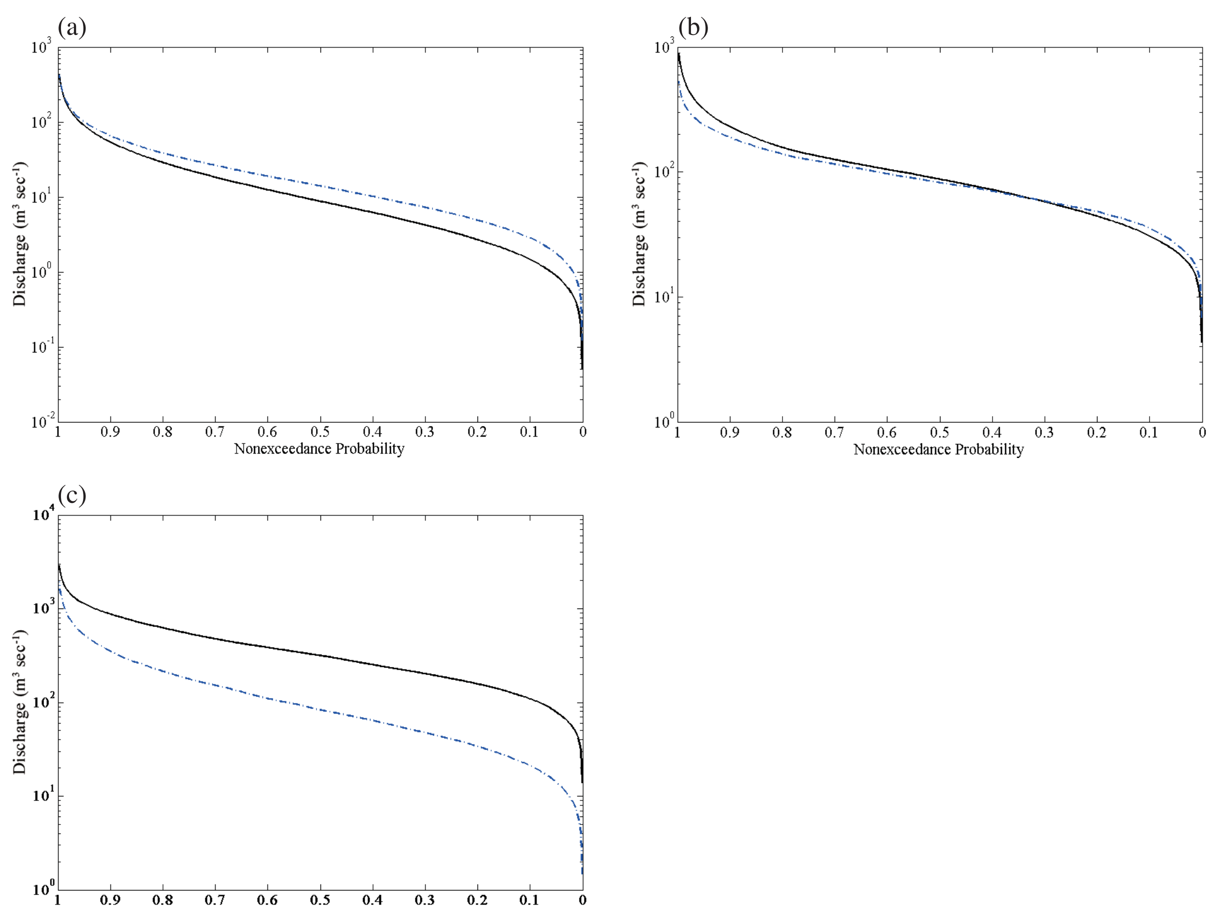

Fig. 15. Duration curve of the Han River Basin (present: line, future: dotted line). (a) Soyang Dam, (b) Chungju Dam, (c) Paldang Dam.

amounts provided by WAMIS and an investigation of water supply capacity of existing dams and Korean dams to simulate the discharge. We revised the model of 2010 for the upstream of Soyang, Chungju, and Paldang Dam, which showed overall similar discharge levels to the present, to analyze the discharge characteristics from future climate change.

(3) According to a simulation of the monthly discharge amount of a future climate change scenario for the Paldang Dam basin, the meeting point of the Bukhan River and Namhan River on the Han River Basin, the discharge amount shows a decreasing trend overall and an increasing trend in the spring and fall. These results seem to derive from changing patterns of rainfall of the RCP 8.5 scenario used in this study. On the other hand, an analysis of the present and future flow duration changes of Paldang Dam shows that the future duration flow curve will decrease from the present, we confirmed. This means that water use in the future will not be stable. In addition, upstream currents affecting the Paldang Dam can negatively impact the consolidation of water from changes in the discharge characteristics and scale generated from unexpected and localized short-term heavy rainfall. Therefore, instead of focusing only on quantitatively consolidating water, changes to the dam management system reflecting seasonal changes and characteristics will likely be demanded. Analyzing in the future the discharge characteristics of other types of RCP scenarios provided by the KMA would help to grasp more effectively the changes in water resource characteristics from future climate change by grasping the discharge characteristics from various rainfall characteristics.

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