Evaluation of Climate Change Impacts on the Water Resource System of the Han-River Basin in South Korea for the AR4 SRES A2 Scenario

Soo Jun Kim[1]
PhD Student, Dept. of Civil Engineering, Inha University, Korea

Hwan Don Jun[2]
Associate Professor, Dept. of Civil Engineering, Seoul National University of Technology, Korea

Byung Sik Kim[3]
Senior Researcher, Division of Water Resources, Korea Institute of Construction Technology, Korea

Hung Soo Kim[4]
Associate Professor, Dept. of Civil Engineering, Inha University, Korea

Abstract. Global climate change has brought significant changes in hydrological environment. Those changes also have occurred in the Korea peninsular for the last several decades, increasing the magnitude of damage by droughts and floods. As an attempt to explore the impact of droughts which may be made worse by the climate change, we analyze the change in the water balance of the Han-river basin. To accomplish it, we suggest a procedure consisting of three successive sub-procedures: daily rainfall generation for 90 years by the RegCM3 with the A2 scenario, daily discharge simulations by SLURP using the generated daily rainfall data, and monthly water balance analysis by K-WEAP (Korean Water Evaluation and Planning System) based on the SLURP simulation. Since significant uncertainty is involved in forecasting the future water consumption and water yields, we assumed three water consumption scenarios and three water yields scenarios. Three water consumption scenarios are, namely, "LOW", "MEDIUM", and "HIGH" according to the expected amount of water consumption. The fifty daily discharges are obtained from the SLURP simulations during the drought period. To improve the representability of possible daily rainfall events, fifty sets of daily rainfall data for 90 years are generated and then each set is used as an input for the SLURP simulation. Finally, water balance analysis is performed by K-WEAP based on 150 combinations from three water consumption scenarios and the fifty daily discharges. By these procedures, it is possible to explore various water consumption and water yield scenarios and the results of this study can be used to establish appropriate plans for minimizing the impact of drought resulted from the climate change in Korean peninsula.
Keywords : Climatic Change, SLURP Model, K-WEAP, Water Balance Analysis

1. Introduction

Global warming is clearly evidenced by the rise of the earth's average temperature and sea water temperature, widespread melting of snow and glaciers, and the rise of the earth's sea level, which have been observed and measured. It is expected that the availability of usable fresh water in Central Asia, South Asia, East Asia, Southeast Asia will decrease by 2050. In particular, areas neighboring large rivers will be seriously affected (The Synthesis Report of the IPCC Fourth Assessment Report, 2007). In fact, evidences of climate change have been found in diverse parts of the world in the last decades and many researchers have demonstrated the increase in frequency and size of floods and droughts.

In many countries of the world, various studies have been actively implemented to evaluate the impact of the climate change on the water resource system. Christensen et

[1] Center for Hydrology and Ecology, Civil Engineering Department, Inha University,, Incheon, Korea ; Tel: 82-32-876-9783; e-mail: soojuny@empal.com

al. (2004) evaluated the impact of climate change on water resources in the Colorado River basin. They used RCM to analyze the impact of the change on hydrological phenomena and water resources. Using RCM and SWAT model, Jha et al. (2003) analyzed the impact of the climate change on the river outflow in the upper reaches of the Mississippi River. Similar researches have been carried out in Korea. SNURCM, a climate model, was developed by Seoul National University and the Ministry of Environment (2006) to predict and evaluate the impact of climate change on water circulation. Also, 21st Century Frontier Research & Development Project (Sejong University and the Ministry of Science and Technology, 2007) has established a system for evaluating the impact of climate change on water resources. In Korea, however, most researches in the field of water resources tend to concentrate on climate change itself and the usage of techniques for predicting changes in climate elements in accordance with global climate models. Therefore, quantitative evaluation of the impact of climate change on the water resource system has been rarely performed.

In this paper, the impact of climate change on droughts in the Han River basin was evaluated. To carry out the research, climate elements simulated by the climate change model were used to perform analyses by SLURP model, a quasi-distribution long-term outflow model. Because future water demand involves much uncertainty, three scenarios—low demand, medium demand, and high demand scenarios—were devised. In accordance with each of the scenarios, 50 different values of outflow (results of SLURP model) were used as entry data for K-WEAP model to predict the amount of water shortage in the future for each of the scenarios.

2. Basic Theory

2.1 Climate Change Model

In this study, A2 climate change scenario created by RegCM3 model was reviewed. RegCM3 is a middle-range climate model developed by the International Center for Theoretical Physics (ICTP). In June 2004, "Second Workshop on the Theory and Use of Regional Climate Models" held by the ICTP released codes of RegCM3 that includes one-way nesting technique. Essentially, the mechanical system of RegCM3 is based on hydrostatic version of MM5. Vertically, RegCM3 uses a sigma coordinate system; horizontally, it uses Arakawa B-grid coordinate system. As major methods of physical parametrization, Grell cumulus parametrization (Grell, 1993) and CCM3 radiation process (Kiehl et al., 1996) were used whereas Non-local vertical diffusion (Holtslag et al. 1990) was used for planetary boundary layer process.

2.2 Water Demand Scenario

Long-term Comprehensive Water Resources Plan (2006-2020) introduced scenarios to overcome the uncertainty involving future social and economic outlooks and the limits of data used for estimating demand. Demand for water for domestic use, industrial water, and agricultural water was divided into high-demand, standard-demand, and low-demand situations to produce scenarios. The following are the criteria for each of the scenarios.

2.3 K-WEAP Model

K-WEAP is a model developed by "Comprehensive Basin Water Balance Analysis and Water Resources Planning & Technology Development Project," a project undertaken by "Project Corps for the Development of Technologies for Sustainable Supply of Water Resources," which was one of the 21st Century Frontier R & D Projects. The model was developed as a joint research carried out by Water Resources

Research Division of Korea Institute of Construction Technology and Stockholm Environment Institute-Boston Center.

Table 1. Establishment of scenarios for estimating future water demand (Long-term Comprehensive Water Resources Plan (2006-2020))

Use	Demand categories	Scenarios
Water for domestic use	High demand	Current diminishing water demand and up to 50% water-saving are taken into consideration
	Standard demand	Current diminishing water demand and up to 70% water-saving are taken into consideration (including demand management plan of the Ministry of Environment)
	Low demand	Current diminishing water demand and maximum degree of water-saving are taken into consideration
Industrial water	High demand	Demand necessitated by 4.0% economic growth
	Standard demand	Demand necessitated by 3.5% economic growth
	Low demand	Demand necessitated by 3.0% economic growth
Agricultural water	High demand	Maintenance of maximum area of rice field for food security; cultivated acreage of 1,773 thousand ha (rice field: 1,100 thousand ha; fields: 673 thousand ha) in 2013
	Standard demand	Plan that considers current agricultural environment: Comprehensive Plan for Agriculture and Rural Communities (Ministry of Agriculture and Forestry, 2004); cultivated acreage of 1,731 thousand ha in 2013 (rice field: 1,058 thousand ha; fields: 673 thousand ha)
	Low demand	Diminishment of rice field acreage due to the opening of rice market is taken into consideration. - Application of estimates by “Agriculture Outlook 2005” (Korea Rural Economic Institute, 2005) (treatment as an advanced industrialized country, 15% decrease in tariff during five years, up to 8% increase of tariff rate quotas (TRQ); cultivated acreage of 1,638 thousand ha in 2013 (rice field: 1,004 thousand ha; fields: 634 thousand ha)

K-WEAP, which is operated by the basic principles of water balance analysis, can be applied to the water demand-supply system of farming areas, a single small basin, or complex river basins. In addition, K-WEAP can deal with wide-ranging issues: analysis of water demand by usage, water-saving, water right and priorities in distribution, river water and groundwater simulation, reservoir management, hydroelectric power generation, tracking of pollutants, and analysis of water necessary for the eco-system.

As shown in the following figure, K-WEAP is implemented in a number of steps. First, elements of basic water resources system such as the following are established: target years for plans, spatial boundaries of target areas, current status of water supply and demand in the region, and networks. Second, the status of the water supply system in the target year is established by considering the following factors: actual water demand, pollution loading amount, local water supply source and distribution facilities, hydrological characteristics of rivers and sewage treatment facilities. Third, future scenarios and alternatives are established by considering the following factors: policy, cost, technology development or demand, pollution, distribution, and other factors that affect hydrological conditions. Finally, K-WEAP can evaluate the extent of sensitivity caused by uncertainty of major factors such as the amount of water shortage, pollution loading amount, the level of stream maintenance water, etc. in each of the scenarios.

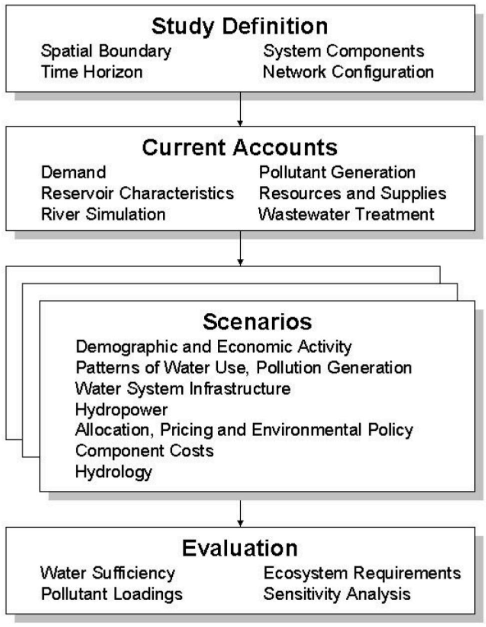


Figure 1. Water resources planning and evaluation processes in K-WEAP model

3. Application and Results

To evaluate vulnerabilities in drought and water utilization in the Han River basin, the following steps shown in the figure below were taken by this research. First, climate change-water demand scenario was produced by considering existing climate change scenarios and the water demand scenario of Revised Long-term Comprehensive Water Resources Plan (Ministry of Construction and Transportation, 2006). Second, 50-set runoff data simulated by SLURP model in accordance with the climate change scenario were applied to K-WEAP model, a model for water resources evaluation and planning, to overcome uncertainties involving the climate change. Finally, the amount of water shortage in the small basins of the Han River (mid-size areas on the water resources map) was estimated by scenarios and target years.

3.2 The scope of drainage basin and the unit of simulation

To predict future water supply and demand in the Han River basin, K-WEAP model, which is a water balance-based model, was used. To establish K-WEAP model, it was necessary to delineate the scope for future water supply and demand in the Han River basin. In this study, Water Resources Unit Map, a national standard map, was used. The Han River basin (large river zone) can be divided into four drainage areas: the Han River, Anseong-cheon (stream), the Han River-Yellow Sea, and the Han River-East Sea. In this study, the main stream of the Han River was selected as the target basin and medium-size zones of Water Resources Unit Map were selected as simulation units to produce data on the Han River basin.

3.3 The establishment of water supply network

The water supply network of the Han River basin in accordance with K-WEAP model consists of the following: 17 rivers, 38 diversions, 4 reservoirs, 67 demand sites, 100 transmission links, and 63 return flows. The network is shown in the following figure.

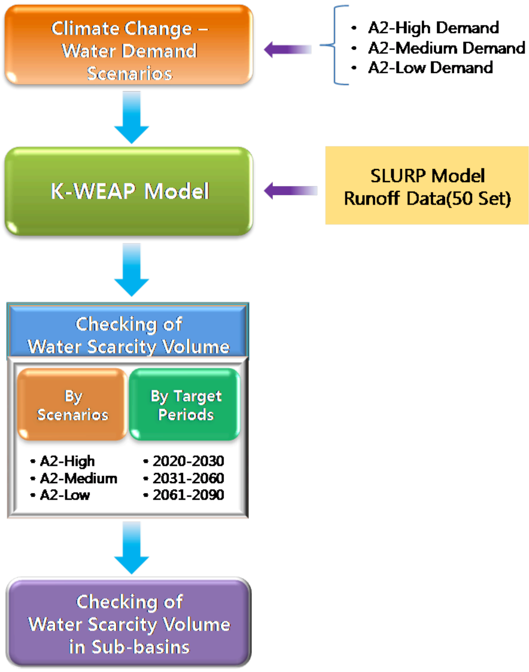


Figure 2. The process of evaluating vulnerabilities in drought and water utilization

Figure 3. Area analyzed

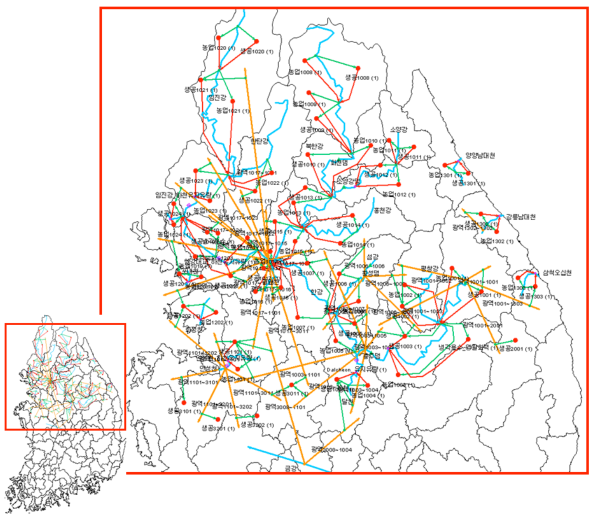


Figure 4. Water supply network in the Han River basin

3.4 Forecast of future water shortage in consideration of climate change

To estimate the amount of future water shortage, simulations were run for 70 years from 2020 to 2090. Years from 2020 to 2030 were selected as reference years and years from 2031 to 2060 and from 2061 to 2090 were selected as target years to estimate water shortage trends. To consider uncertainties involving water shortage simulation, 50-set runoff series from each of small basins (19 medium-size zones) were obtained from SLURP model and simulations were run on the amount of water shortage by each of climate change-water demand scenarios.

The following are the results of simulations. The following graph on water shortage trends shows water shortage trends, the scope of deviation, the average from 2020, the beginning year for simulations, to 2090. Here, range refers to the scope of water shortage computed by 50 sets of water shortage data and average is the average computed by taking the average of water shortage amount for each of 50-year set. To verify whether long-term changing trends are found in the amount of water shortage in comparison with reference years, moving average method was applied to the annual mean of the simulated amount of water shortage. Gradual application of the moving average method by 10 years showed a long-term increase of water shortage in the Han River basin under A2-High demand scenario.

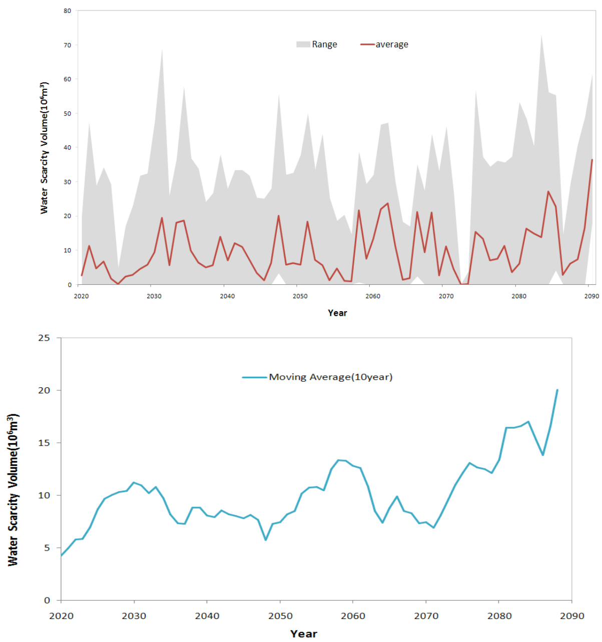


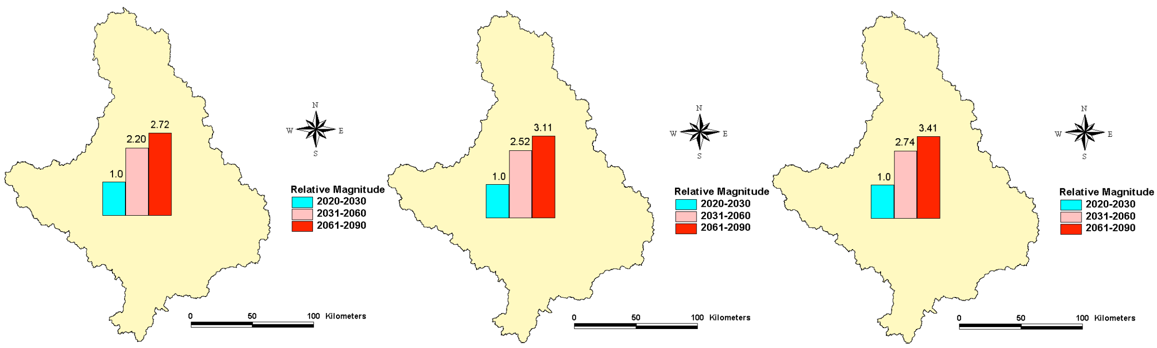
Figure 5. Water shortage and moving average trends (High demand: 50-unit set)

Under the assumption of long-term increase in water shortage, analysis on water shortage was carried out to find the extent of the increase. Relative sizes of the shortage amount in reference years (2020-2030) vis-à-vis target years (2031-2060, 2061-2090) were analyzed. As shown in the table below, future climate change was found to cause 2-3.5 times increase in water shortage in the Han River basin depending upon the scenario.

In addition to the forecast of water shortage in the Han River as a whole, the amount of water shortage by small basins (medium-size zones), the simulation units of K-WEAP, was estimated. To calculate the extent of water shortage by small basins, the mean of the results of 50-set simulations was taken into consideration. The following figure shows percentages of water shortage by small basins. The percentages illustrate the share of the amount of water shortage incurred by each of the small basins in the overall water shortage in the Han River basin for each of the periods. The percentages of water shortage by small basins were shown by reference years ((a) 2020-2030) and target years ((b) 2031-2060, (c) 2061-2090). The total amount of water shortage in the Han River basin in the target years is represented by the number 100. The share of small basins is represented by respective numbers, which add up to 100. Therefore, the causes of the amount of water shortage in the target years in the Han River basin can be found by analyzing the amount of shortage in each of small basins. In comparison with reference years, the number of small basins affected by water shortage is found to increase in the target years. According to simulations, water shortage increases in most of small basins in the target years of 2061-2090.

Table 2. The amount of water shortage and increase rate by scenarios and target years

Scenarios	2020-2030		2031-2060		2061-2090	
	Volume ($10^6 \times m^3$)	Relative Magnitude	Volume ($10^6 \times m^3$)	Relative Magnitude	Volume ($10^6 \times m^3$)	Relative Magnitude
A2-High	4.88	1.0	10.76	2.20	13.29	2.72
A2-Medium	3.24	1.0	8.16	2.52	10.08	3.11
A2-Low	1.99	1.0	5.45	2.74	6.78	3.41



(a) A2-High (b) A2-Medium (c) A2-Low

Figure 6. Increase rates of water shortage in target years by scenarios

In the target years of 2061-2090, water shortage will concentrate in the South Han River and the mainstream of the Han River rather than the North Han River. Therefore, it is expected that water shortage in the future will deteriorate in the mainstream of the Han River and the South Han River rather than in the North Han River.

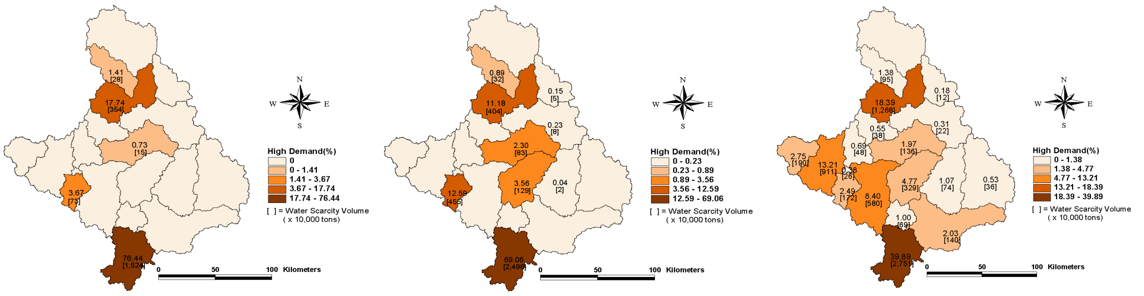
3.5 Review of the causes of water shortage

To find out the causes of water shortage in the Han River basin and changes in runoff characteristics of small basins by periods, runoff data produced by SLURP model, which was generated by simulations on the climate change scenario, were analyzed. The analysis revealed three causes that aggravate water shortage.

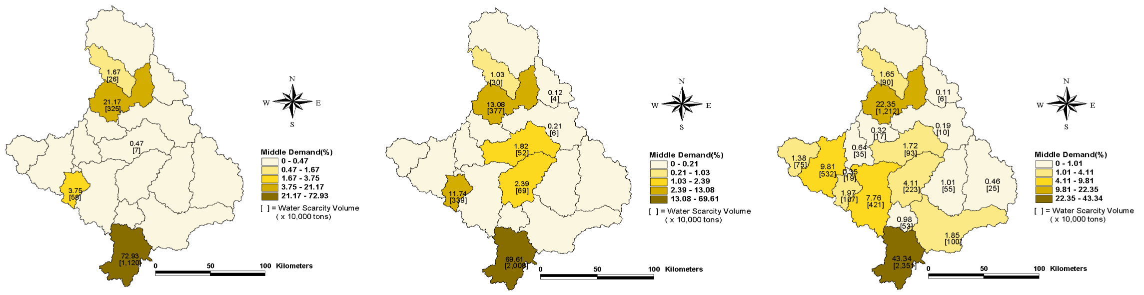
(1) Because runoff during flood periods moved from July, August, and September to August, September, and October, relative shortage of water increased in June.

(2) In some periods, general decrease in runoff caused increase in water shortage.

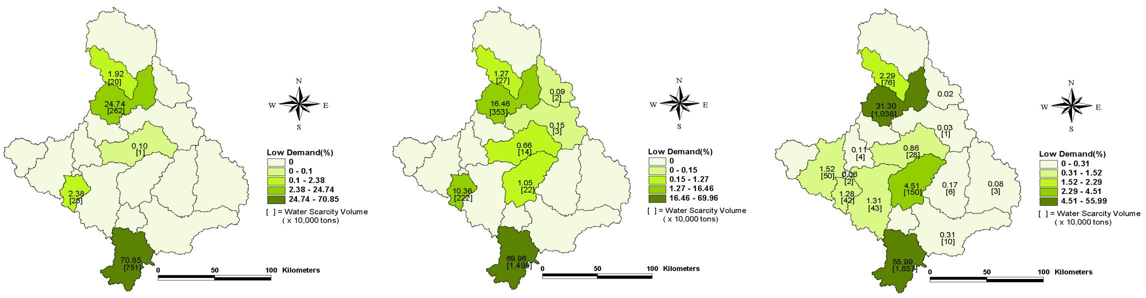
(3) Similar runoff characteristics were found between reference years of 2031-2060 and 2061-2090. However, instances of water shortage increase occurred in target years of 2061-2090 under the impact of the runoff uncertainties (degree of deviation).



(a) A2-High (2020-2030) (b) A2-High (2031-2060) (c) A2-High (2061-2090)



(a) A2-Medium (2020-2030) (b) A2-Medium (2031-2060) (c) A2-Medium (2061-2090)



(a) A2-Low (2020-2030) (b) A2-Low (2031-2060) (c) A2-Low (2061-2090)

Figure 7. The share of each of the small basins in water shortage

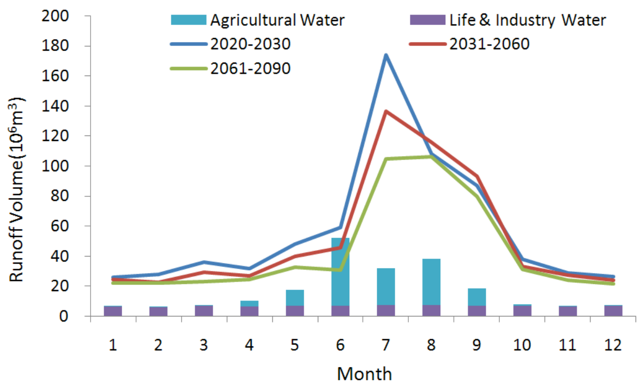


Figure 8. Runoff and demand changes by future periods (instances of water shortage)

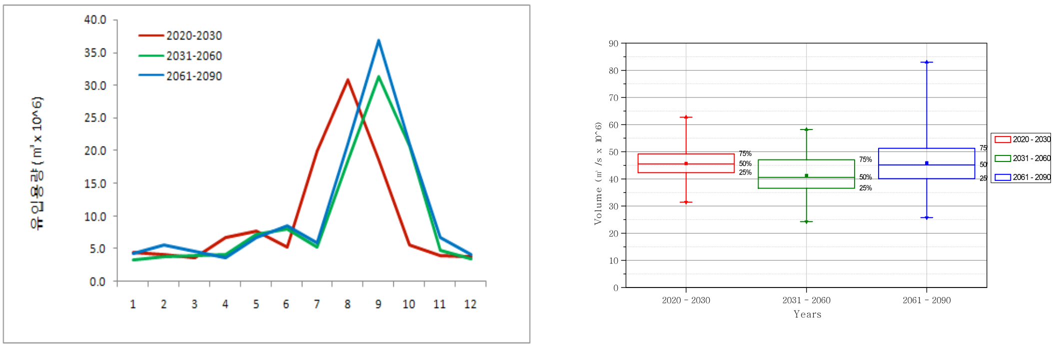


Figure 9. Comparison of monthly inflow data in Chuncheon Dam and inflow box

4. Summary and Conclusion

In this study, vulnerabilities involving drought and water utilization in the Han River basin were evaluated. Climate change-water demand scenario was established and runoff data simulated by SLURP model in accordance with climate change scenario were applied to K-WEAP model, a model for water resources evaluation and planning. The results generated by the model were used for quantitative analysis of water shortage in the Han River basin. In addition, the extent of water shortage by small basins was analyzed and the causes were presented.

The findings from each of the research steps can be summarized as the following:

1) Future trends in water shortage and the extent of uncertainty in the Han River basin were estimated by each of the scenarios. To verify long-term changing trends of water shortage, moving average by 10 years was carried out. A long-term increase in the amount of water shortage was found.
2) Under the scenarios, the shortage increased by 2.20-2.74 times from references years of 2020-2030 to target years of 2031-2060. Simulations showed 2.72-3.41 times increase in target years of 2061-2090.
3) Analysis of water shortage in small basins of the Han River basin showed concentration of water shortage in some small basins. It was also found that water shortage would increase in all small basins of the Han River basin.
4) Analysis of the causes of water shortage showed that decrease in runoff occurred in June, when demand for agricultural water peaks. This runoff characteristic was found to be caused by a shift of runoff concentration from July, August, and September to August, September, and October.

This research on vulnerabilities involving water utilization in the Han River basin in consideration of the climate change scenario demonstrated that water shortage in the Han River basin will be aggravated by future changes in runoff characteristics. Therefore, it is necessary to establish structural or non-structural countermeasures to cope with changes in runoff characteristics in the Han River basin under the impacts of the climate change. The findings also urge implementation of more quantitative researches on water shortage that can support water resources policies.

Acknowledgments

This research was supported by a grant [NEMA-09-NH-02] from the Natural Hazard Mitigation Research Group, National Emergency Management Agency of Korea.

5. References

Christensen, N.S., Wood, A.W., Voisin, N., Lettenmaier, D.P., Palmer, R.N. (2004). “The effects of climate change on the hydrology and water resources of the Colorado river basin”, Climate Change, Vol. 62, pp. 337-363.

Grell, G.A. (1993). "Prognostic evaluation of assumptions used by cumulus parameterizations", Mon. Wea. Rev., 121, 764-787.
Holtslag, A.A.M., E.I.F. de Bruijin, and H.L. Pan (1990). "A high resolution air mass transformation model for short-range weather forecasting", Mon. Wea. Rev., 118, 1561-1575.
IPCC. (2007). "Climate Change 2007", the Fourth Assessment Report (AR4) of the United Nations Intergovernmental Panel on Climate Change.
Jha, M., Arnold, J.G., Gassman, P.W., Gu, R. (2004). "Climate change ensitivity assessment on upper Mississippi river basin streamflows using SWAT", Working Paper 04-WP 353, Center for Agricultural and Rural Development Iowa State University.
Kiehl, J.T., J.J. Hack, G.B. Bonan, B.A. Boville, B.P. Briegleb, D.L. Williamson, and P.J. Rasch (1996). "Description of the NCAR Community Climate Model(CCM3)". NCAR Technical Note. Boulder, Colorado.
Sejong University and MOST. (2007). "Technology for Climate Change Impact Assessment on Water Resource", Sustainable Water Resources Research Program, The 21St Century Frontier R&D Program.
Seoul University and ME. (2006). "Prediction and Impact Assessment of water Cycle with Climate Change", Settlement of Global and International Environmental Issue.