 doi:10.20944/preprints202103.0290.v1

Article

Analysis of Small Hydropower Generation Potential : (2) Future Prospect of the Potential Under Climate Change

Jaewon Jung[1] , Sungeun Jung[2], Junhyeong Lee[3], Myungjin Lee[3], Hung Soo Kim[3,*]

[1] Institute of Water Resources System, Inha University, Incheon, Republic of Korea; jungjw89@gmail.com
[2] Division of Computer Science and Engineering, Sahmyook University, Seoul, Republic of Korea; sejung@syu.ac.kr
[3] Department of Civil Engineering, Inha University, Incheon, Republic of Korea; lee_junhyeong@naver.com (J.L.); lmj3544@naver.com (M.L.)
* Correspondence: sookim@inha.ac.kr

Abstract: The interest in renewable energy to replace fossil fuel is increasing as the problem caused by climate change become more severe. Small hydropower (SHP) is evaluated as a resource with high development value because of its high energy density compared to other renewable energy sources. SHP may be an attractive and sustainable power generation environmental perspective because of its potential to be found in small rivers and streams. The power generation potential could be estimated based on the discharge in the river basin. Since the river discharge depends on the climate conditions, the hydropower generation potential changes sensitively according to climate variability. Therefore, it is necessary to analyze the SHP potential in consideration of future climate change. In this study, the future prospect of SHP potential is simulated for the period of 2021 to 2100 considering the climate change in three hydropower plants of Deoksong, Hanseok, and Socheon stations, Korea. As the results, SHP potential for the near future (2021 to 2040) shows a tendency to be increased and the highest increase is 23.4% at the Deoksong SPH plant. Through the result of future prospect, we have shown that hydroelectric power generation capacity or SHP potential will be increased in the future. Therefore, we believe that it is necessary to revitalize the development of SHP in order to expand the use of renewable energy. Also, a methodology presented in this study could be used for the future prospect of the small hydropower potential.

Keywords: Climate Change Scenario, Generation Potential, Hydropower, Renewable Energy

1. Introduction

With accelerating climate change, leading countries have established long-term plans to reduce greenhouse gas (GHG) emissions and have attempted to implement such plans. To this end, they are implementing energy transition policies according to their own economic interests to ultimately reduce carbon emissions by migrating from fossil energy to renewable energy. In this situation, small hydropower (SHP), which is clean energy that uses water, is a representative renewable energy source that is sustainable even in future climate change because it reduces carbon emissions [1,2]. Thus far, the value of SHP has been relatively underestimated due to the reason that its initial investment cost is high compared to other energy sources with technical development, but the development of SHP will be gradually expanded in the future as renewable energy sources are attracting global attention [3,4]. Therefore, reliable data for selecting promising candidate sites for SHP, such as on the estimation of the available power generation potential, are important. However, SHP is sensitive to climate conditions because it generates power using the head of flowing water. In recent years, the occurrence frequency of abnormal climate, such as droughts and floods, has been

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slowly increasing due to climate change. This change also has a direct impact on the amount of power generated by the operation of SHP plants [5-7].

Many studies have been conducted on the variability of the SHP potential in consideration of climate change [8-15]. Vliet et al. (2016) evaluated changes in the hydropower generated worldwide due to climate change using GCMs [12]. Hamududu and Killingtveit (2012) simulated changes in runoff using 12 different global climate models (GCMs) and estimated the hydropower generated under climate change [9]. Kim et al. (2012) predicted the future runoff by applying the rainfall data for the future target period to the Tank model based on the IPCC A1B climate change scenario, and conducted research on the variability of the power generated by SHP under climate change [10]. Spalding-Fecher et al. (2016) evaluated the vulnerability of hydropower due to climate change in the Kambezi River basin in South Africa [11]. Chilkoti et al. (2017) evaluated the impact of climate change on hydroelectric power generation using regional climate models (RCMs) [13]. Kim et al. (2018) estimated the SHP potential under climate change using a grid-based surface runoff model [14]. In addition, Fan et al. (2020) analyzed changes in the hydropower generated in China due to climate change using representative concentration pathways (RCP) climate change scenarios [15]. Some other studies have also estimated the impact of climate change on hydropower at the national or regional scales including the United States [16], [17], Canada [18], Brazil [8], India [19], China [20], [21] and European countries [7, 22, 23].

As mentioned above, many studies have been continuously conducted to estimate the SHP potential under climate change for the existing SHP plants [9,13,24-27]. However, few studies have been conducted on the estimation of the SHP potential in ungauged basins for the estimation of the available power generation potential. Therefore, in this serial study aim to calculate the future SHP potential in ungauged basins. To this end, calculating the accurate runoff is most important. In the first part of the serial study, Jung et al. (2021) proposed a method of improving the accuracy of discharge data by applying four blending techniques after calculating the discharge using the Kajiyama formula, the modified-TPM model that calculates the runoff using hydro-meteorological data, and the Tank model that calculates the runoff based on the rainfall-runoff process [28]. For the next step, the SHP potential under climate change was predicted based on the results of Jung et al. (2021) on the calculation of the SHP potential in ungauged basins in this study [28]. To analyze the future variability of the SHP potential under climate change, the discharge data until 2100 were calculated using the RCP 4.5 climate change scenario. Based on the discharge data, the SHP potential was predicted. The background of SHP potential calculation, climate model and climate change scenario are explained in section 2, respectively. The SHP potential is estimated under climate change and the variability of SHP potential is analyzed in section 3. The discussion and conclusions are provided in section 4.

2. Background

2.1 SHP potential calculation

The energy potential is data for estimating the total amount of energy resources available throughout an area, and the renewable energy potential is applied to the data for establishing the domestic renewable energy distribution plan and the energy basic plan. Currently, the regional distribution characteristics of hydropower and other renewable energy sources are analyzed in detail through the combination with geographic information. The potential of renewable energy resources generally starts from the theoretical potential and forms a stepwise pyramid structure. To calculate the potential, it is necessary to prepare standard coefficients for the amount of resources (natural environmental conditions), geographic conditions, technical elements (e.g. energy efficiency, operation rate, and collection rate), environmental performance, and technological progress through long-term data accumulation.

2.1.1 Hydropower potential

The hydropower potential is classified into the theoretical potential, geographic potential, and technical potential. The theoretical potential was defined as the total energy of the precipitation on the surface of all basins in the Korean Peninsula. The geographic potential was defined as the potential that considered the runoff ratio caused by the geographic characteristics of the basins in the theoretical potential. The technical potential was defined as the potential that considered the system efficiency and operation rate in the geographic potential. The hydropower potential was calculated for each water system and administrative district.

The SHP potential is widely applied not only to the SHP plants already developed but also in such areas as the selection of new suitable sites for SHP from the beginning stage of a policy to the site selection stage. The potential data are also used for the forecast of the future power market, establishment of future energy policies, selection of sites for power plants, development of communities, and construction of distributed power generation systems. As for the calculated potential, the theoretical potential, geographic potential, or technical potential is used depending on the purpose.

2.1.2 SHP potential calculation formula

The technical potential is calculated and used in this study. Assuming the water quantity used in the water turbine per unit time as Q(m^3/s), the head as H(m), the water density is ρ(kg/m^3), and the efficiency of the water turbine generator is η, the technical potential becomes P= $\rho \cdot g \cdot Q_d \cdot H_e \cdot \eta$ (kW). The g is gravity acceleration(m/s^2), and $Q_d(m^3/s)$ and H_e(m) indicate design discharge and effective head respectively[28].

2.2 Climate model and climate change scenario

2.2.1 Climate model

Climate models are computer programs created based on the mathematical equations that are used to quantitatively calculate the atmospheric temperature, air pressure, wind, vapor, clouds, and rainfall, which react to the ground surface and atmosphere due to solar heat [29]. Future climate change is forecasted using a climate model. It deals with a time scale longer than approximately two weeks, which is the limit of each weather simulation. Climate deals with phenomena with a long time scale, such as changes in oceans, glaciers, and ground surface. It can be affected by elements that occur slowly, such as changes in the chemicals in the atmosphere caused by human activities. Today, climate models under development worldwide are evolving into earth system models that combine biogeochemical modules beyond atmosphere-ocean-sea ice coupling. Models with different levels of complexity are being developed for various purposes. In general, an earth system model is constructed in a way that allows the solar energy supplied to the earth to act on the circulation of water, heat, and matter among the atmosphere-ocean-sea ice-land-hydrology areas. In addition, changes in GHG emissions, aerosols, and ground conditions caused by human activities are also considered a part of the earth system [30].

For the simulation of the future climate of South Korea, KMA(Korea Meteorological Administration) is preparing a global climate change scenario using Coupled Model Intercomparison Project phase 5 (CIMIP5), a circulation coupled model. It has introduced and used GCM(Global Climate Model) of HadGEM3-RA(Hadley Center Global Environment Model-Regional Climate Model) and HadGEM2-AO from the Hadley Center (UK Met Office), which have a horizontal resolution of 135 km for the atmosphere. The Hadley Center climate model is used for understanding climate change and to provide projections of future climate [31, 32].

2.2.2 Climate change scenario

A climate change scenario can be simply defined as the future carbon dioxide concentration in the atmosphere to be used as the forced condition of a climate change model. In other words, predictable scenarios, such as on whether the carbon dioxide concentration of the earth will sharply increase with the current slope, whether the present level will be maintained due to reduction efforts, and whether it will decrease with resilience, can be determined and used as the same boundary conditions in various models.

Future meteorological variability due to global warming and its impact on climate change are materialized through general circulation models (GCMs) and are used as the most general climate change forecast data. GCMs are global atmosphere-ocean circulation models based on complex interactions among various forces, such as solar radiation energy, volcanic eruptions, and greenhouse effects, and various conditions, including the atmosphere, oceans, and ground surface. Such models may vary depending on the time and country, and are classified according to the consideration of oceans, ground surface, and living organisms as well as the dimensions and factors. With the development of technology, climate change models have been developed so that more factors can be considered with higher dimensions and resolution.

The Intergovernmental Panel on Climate Change (IPCC) have been developing future climate change scenarios based on the GHG emission scenarios and evaluating climate change response strategies. In the IPCC fifth assessment report in 2014 (AR5), GHG concentrations were determined based on the radiation to the atmosphere caused by human activities. RCPs were newly presented to indicate that socio-economic scenarios may vary for one representative radiative forcing. In addition, in the Coupled Model Inter-comparison Project Phase 5 (CMIP5), a part of the World Climate Research Programme (WCRP) project, GCMs have been developed, compared, and verified using the RCP scenarios with other forcing scenarios since 2009 [33].

As for the future climate change scenarios produced for the Korean Peninsula, KMA has simulated the Korean Peninsula and nearby areas with a resolution of 1° x 1° using HadGEM2-AO, a global climate model. Based on these results, it has simulated the entire Korean Peninsula with a resolution of 12.5 x 12.5 km using HadGEM3-RA, a regional climate model. As for the RCP scenarios selected in conjunction with climate change response policies, RCP 2.6, 4.5, 6.0, and 8.5 scenarios are presented. This study used the future climate data that applied the RCP 4.5 scenario, which is mainly used for calculating the long-term runoff and considers the substantial realization of GHG reduction policies [34].

3. Estimation and Variability Analysis of SHP potential under Climate Change

3.1 Target basin selectin and data collection

3.1.1 Target basin selection

We have 5 large basins and one of them is Han river basin, then a large basin has medium basins and a medium has standard basins in Korea. In this study, Deoksong and Hanseok power plants in the Han River basin and Socheon power plant in the Nakdong River basin were selected in the same manner as in a previous study [28]. In the simulation of the runoff to calculate the power generation potential of the target SHP plants, the standard basins where the plants were located were analyzed. Deoksong SHP plant was located in the Jeongseon standard basin, and the nearby rainfall stations were Yeongwol and Daegwanryeong stations under the control of KMA. The discharge data of the Jeongseon streamflow station could be used. Hanseok SHP plant was located in the Saigokcheon junction standard basin, and the nearby rainfall stations were Yeongwol and Yeongju stations under the control of KMA. The discharge data of the Yeongchun streamflow station could be used. Socheon SHP plant was located in the Socheon streamflow station standard basin, and the nearby rainfall stations were Uljin and Bonghwa stations under the control of KMA. The discharge data of the Socheon streamflow station could be used.

Table 1 shows the information on the selected three SHP plants, including the effective head, power generation discharge, and power generation capacity. Tables 2, 3, and 4 show the general characteristics of each standard basin and the specifications of the nearby rainfall stations.

Table 1. Information on SHP plants of target basins(Reprinted from [28])

SHP plant	Standard basin	Commissioned time	Effective head [m]	Power generation flow rate	Installed power associated with the hydropower

				$[m^3/s]$	plant [kW]
Deoksong	Jeongseon	March, 1993	12.5	25.0	2,600
Hanseok	Saigokcheon junction	March, 1998	3.8	Avg.3.02 / Max.12.7	2,214
Socheon	Socheon streamflow station	August, 1985	22.5	12.5	2,400

Table 2. General characteristics of basins**(Reprinted from [28])**

Standard basin	Large basin	Runoff coefficient (C)	Runoff curve number (CN)	Basin area $[km^2]$	Cumulative basin area $[km^2]$
Jeongseon	Han River	0.56	58	179.6	1,834.7
Saigokcheon junction	Han River	0.56	64	128.7	4,898.0
Socheon streamflow station	Nakdong River	0.57	47	140.8	547.2

Table 3. Specifications of rainfall station**(Reprinted from [28])**

Observation station	Management agency	Coordinates (WGS84)		Start of observation
		Latitude	Longitude	
Yeongwol	Korea Meteorological Administration (KMA)	37.18	128.46	12/01/1997
Daegwallyeong		37.68	128.72	07/11/1971
Yeongju		36.87	128.52	11/28/1972
Uljin		36.99	129.41	01/12/1971
Bonghwa		36.94	128.91	01/01/1988

Table 4. Specifications of streamflow station**(Reprinted from [28])**

Observation station	Management agency	Zero of staff gauge (EL.m)	Benchmark elevation (EL.m)	Start of observation
Jeongseon	Ministry of Environment	296.79	312.42	01/01/1918
Yeongchun	K-water	159.97	177.63	08/30/1985
Socheon	K-water	250.08	262.03	07/16/1978

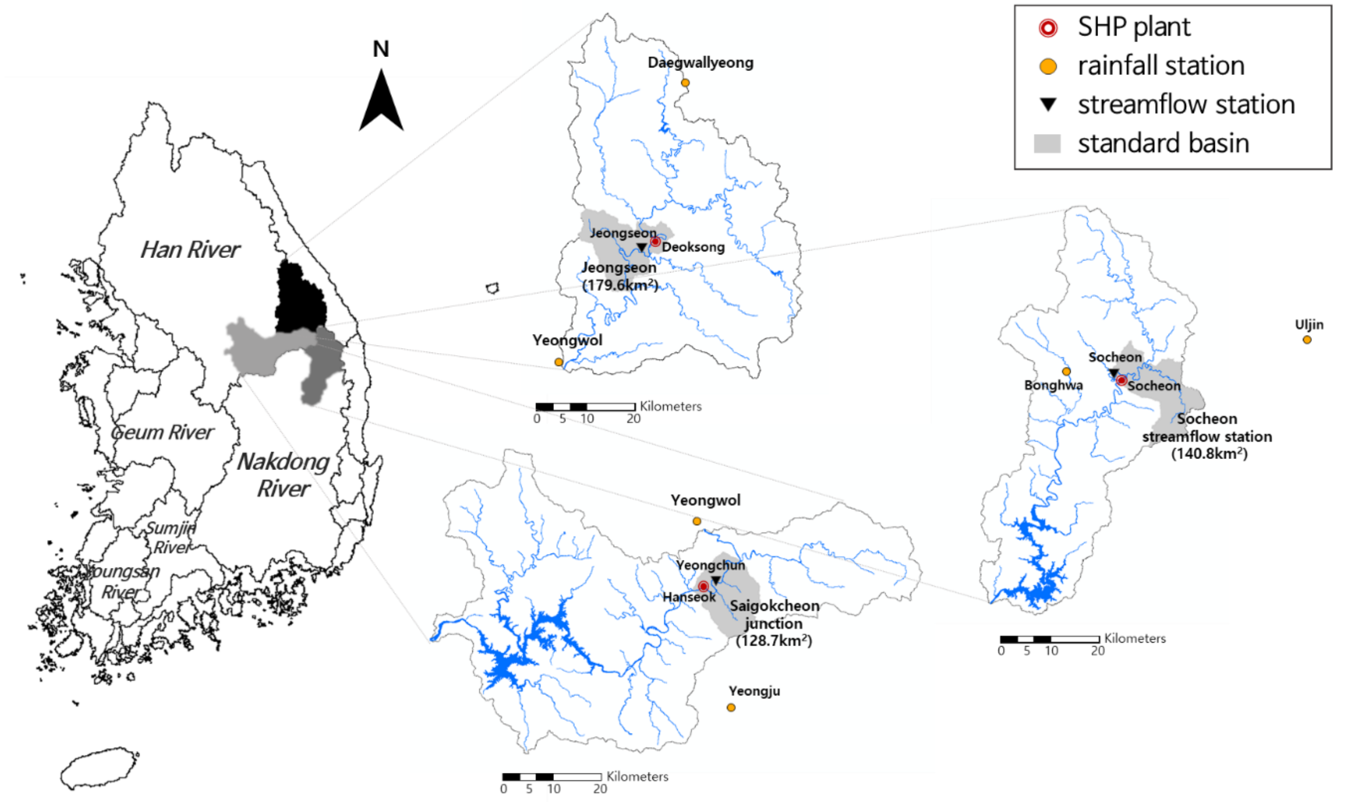


Figure 1. The study basins, basin area, locations of SHP plants, rainfall and streamflow stations (Reprinted from [28])

3.1.2 Climate change scenario data collection

To analyze the variability of the SHP potential under climate change, future climate data were collected using a climate change model and a scenario. In this study, the model and scenario of the CMIP5 phase were used. In addition, the future climate data that applied the RCP 4.5 scenario, which is mainly used to calculate the long-term runoff, were used. As for the climate change scenario data, daily data on the precipitation, average temperature, relative humidity, and average wind speed, were collected in the same way as the observation data, and future climate data from 2021 to 2060 were constructed.

The precipitation of the climate change scenario may exceed the outlier range because it tends to be underestimated than the observed precipitation. Therefore, outlier testing and bias correction through quantile mapping are required for the climate change scenario [35]. In this study, the climate change scenario data were also corrected through quantile mapping and outlier testing. The box plot method was used for testing outliers. In addition, when quantile mapping was performed, the monthly parameter values for each point were estimated and the probability distribution of the scenario precipitation data were corrected through that of the precipitation data observed in the past. In addition, the basin average value was calculated by assigning the Thyssen polygon area ratio of each meteorological observation network to the meteorological data by point collected through the climate change scenario as a weight in the same way as the observed meteorological data.

In this study, the entire period from 2021 to 2100 was divided into four periods as follows to analyze future climate change by period according to the climate change scenario data.

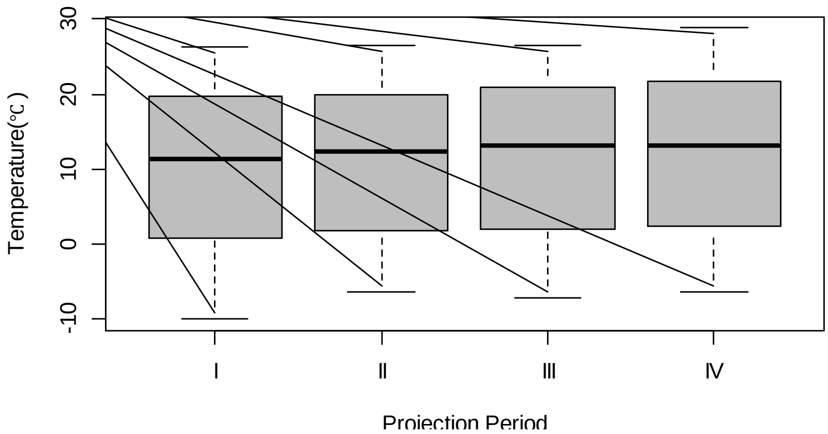
Projection Period 1: 2021 – 2040
Projection Period 2: 2041 – 2060
Projection Period 3: 2061 – 2080

Projection Period 4: 2081 – 2100

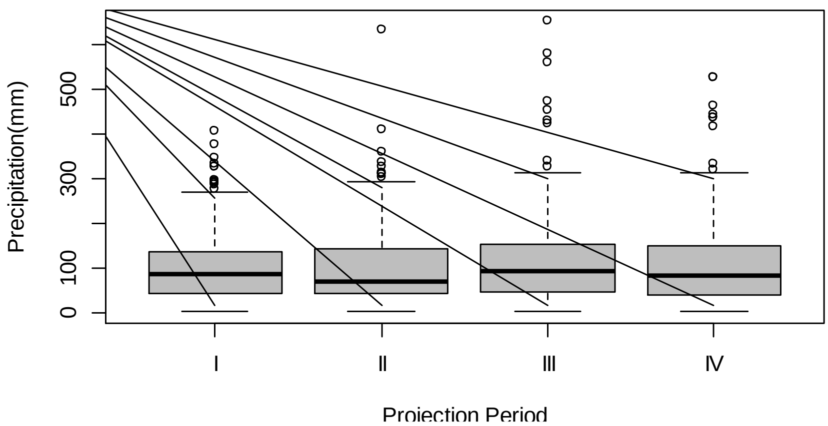
When the average value of the future monthly average temperatures was compared with that of the data during the observation period (2008-2017) for the Jeongseon basin, it was found to decrease by 0.5℃ in Project Period I but increase by 0.2, 0.7, and 1.0℃ in Project Period II, III, and IV, respectively. In the case of the future monthly precipitation, the average value of the monthly precipitations was expected to increase by 4.6, 6.3, 18.9, and 11.7% in Project Period I, II, III, and IV, respectively, compared to the present level.

When the average value of the future monthly average temperatures was compared with that of the data during the observation period (2008-2017) for the Saigokcheon junction basin, it was found to decrease by 0.7 and 0.1℃ in Project Period I and II but increase by 0.5 and 0.8℃ in Project Period III and IV. In the case of the future monthly precipitation, the average value of the monthly precipitations was expected to increase by 5.2, 6.1, 19.0 and 13.7% in Project Period I, II, III, and IV, respectively, compared to the present level.

When the average value of the future monthly average temperatures was compared with that of the data during the observation period (2008-2017) for the Socheon streamflow station basin, it was found to increase by 1.0, 1.6, 2.1, and 2.3℃ in Project Period I, II, III, and IV, respectively. In the case of the future monthly precipitation, the average value of the monthly precipitations was expected to increase by 27.6, 22.4, 35.6 and 47.2% in Project Period I, II, III, and IV, respectively, compared to the present level, indicating that the future precipitation will significantly increase compared to the present level.



(a) Monthly average temperature (Jeongseon basin)



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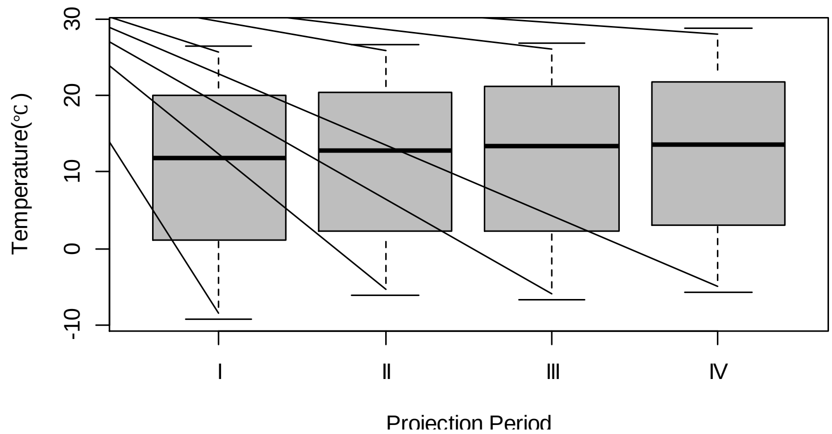
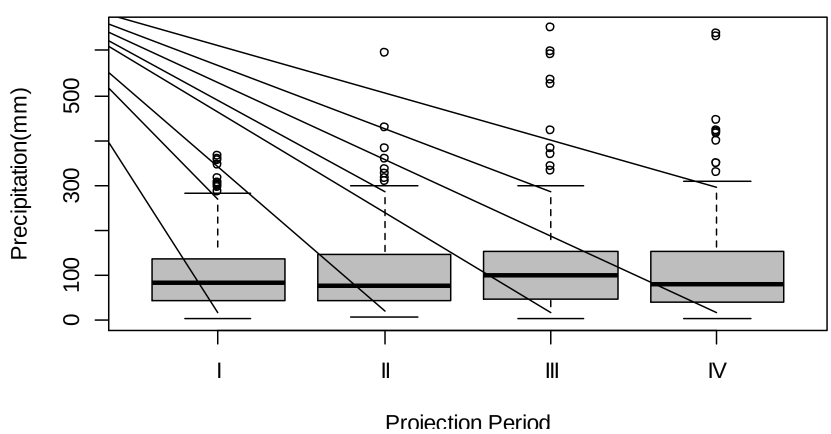
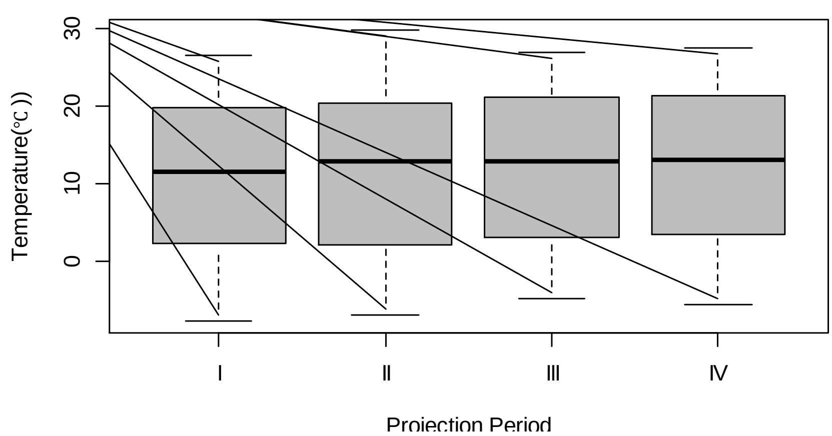
(b) Monthly precipitation (Jeongseon basin)



(c) Monthly average temperature (Saigokcheon junction basin)



(d) Monthly precipitation (Saigokcheon junction basin)



(e) Monthly average temperature (Socheon streamflow station basin)

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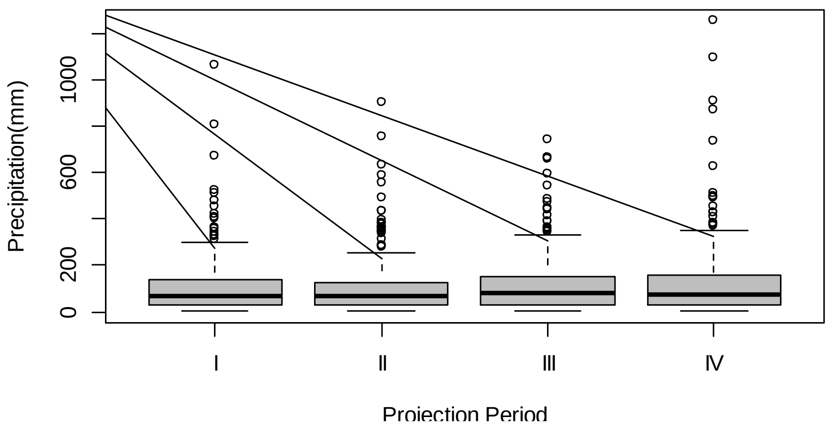


(f) Monthly precipitation (Socheon streamflow station basin)

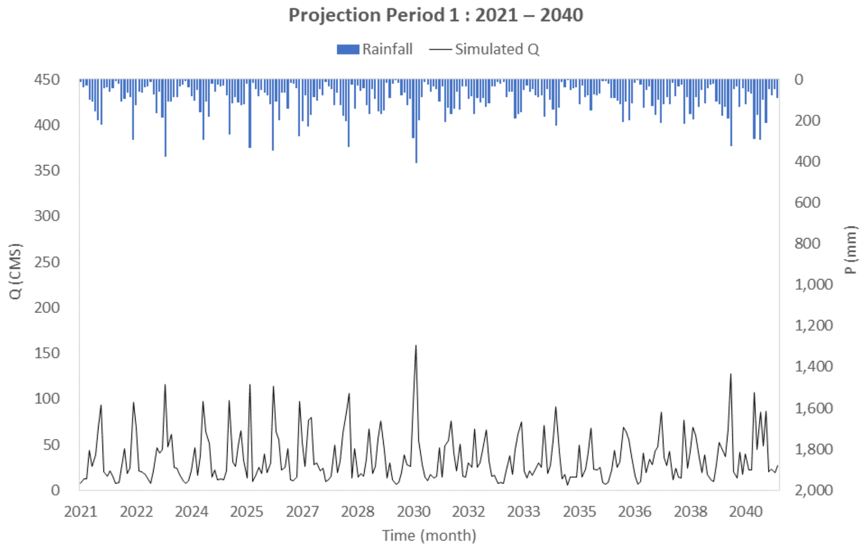
Figure 2. Changes in future monthly average temperatures and monthly precipitations

3.2 SHP potential estimation under climate change

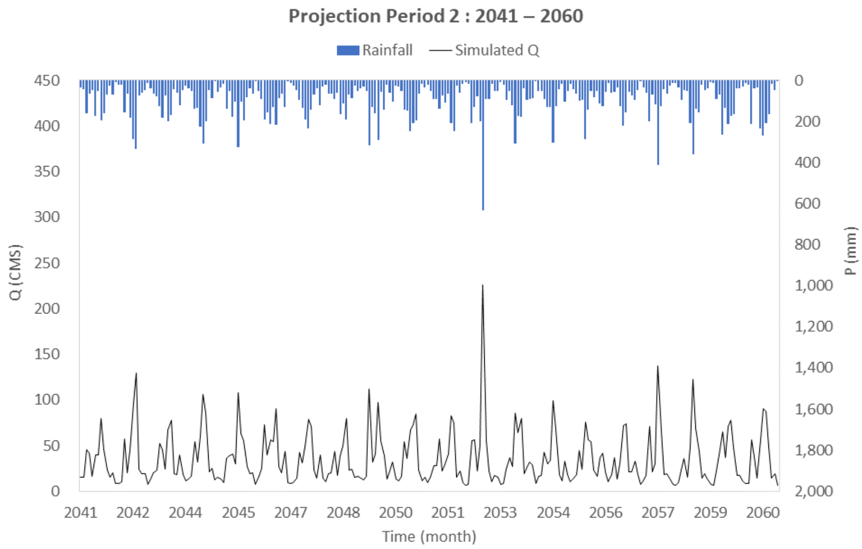
A previous study (Jung et al., 2021) confirmed that it is possible to estimate the reliable SHP potential through the application of the discharge simulation and blending technique that uses meteorological data even in ungauged basins without discharge data [28]. In the same manner, it is possible to estimate the SHP potential that considers climate change by collecting the future meteorological data of the target basin from the climate change scenario data. In this study, the method proposed by Jung et al. (2021) was applied [28], and the SHP potential was calculated using the climate change scenario data . In other words, the runoff was simulated by applying flow duration characteristics model, Kajiyama formula, and modified-TPM. In addition, the future runoff by basin was simulated by applying the MSE blending technique to the discharge simulation results.

For the future prospect in consideration of climate change, the entire period from 2021 to 2100 was divided into four periods with 20 years. Figure 2 shows changes in annual average discharge and monthly average discharge by period for the runoff simulation results by SHP plant.

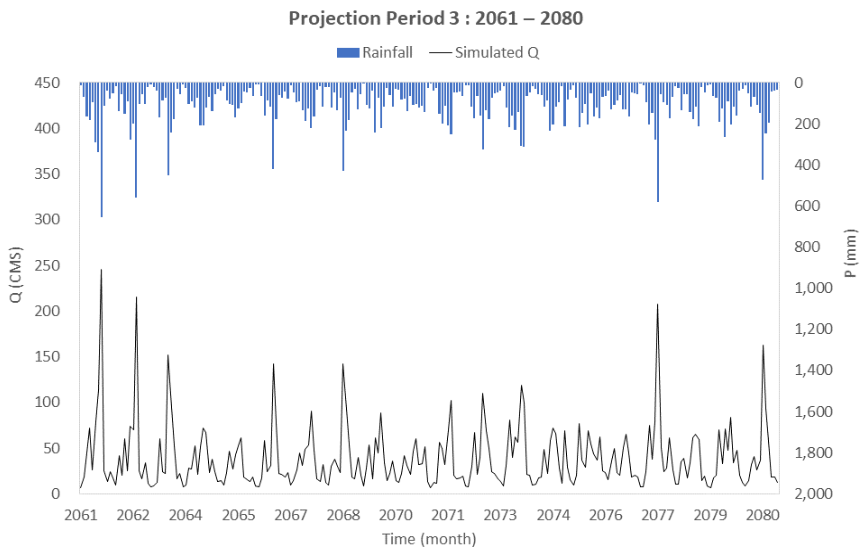
The future runoff forecast results of the Deoksong SHP plant basin show that the runoff tends to increase as the precipitation increases due to future climate change. In particular, the annual average runoff was simulated to be largest in Projection Period III, indicating that the meteorological data that considered climate change were reflected well in the simulation because the same pattern as the average precipitation of the Jeongseon basin was observed (Table 5 and Figure 2).



(a) Monthly average discharge: Period I (2021–2040)



(b) Monthly average discharge: Period II (2041–2060)



(c) Monthly average discharge: Period III (2061–2080)

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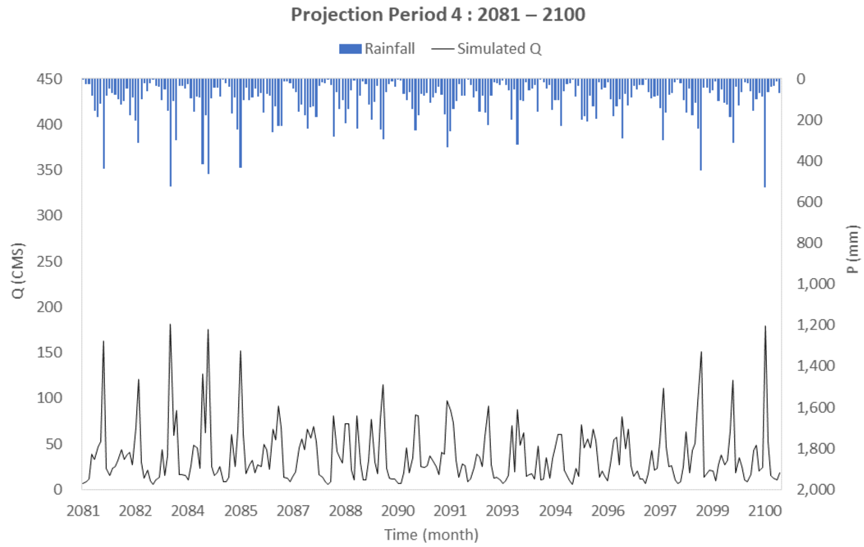
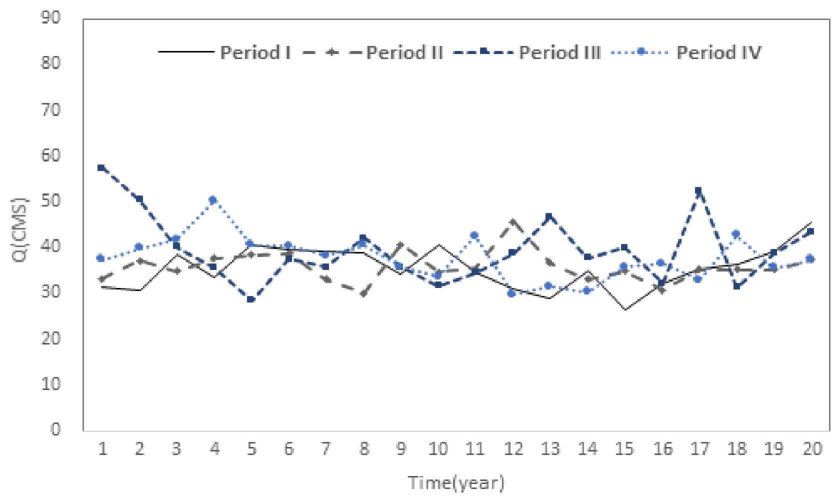


(d) Monthly average discharge: Period IV (2081–2100)



(e) Annual average discharge

Figure 3. Future discharge simulation results of the Deoksong SHP plant basin

Table 5. Future runoff statistics in the Deoksong SHP plant basin

[Unit: m^3/s]

Projection Period	I (2021–2040)	II (2041–2060)	III (2061–2080)	IV (2081–2100)
Mean	35.6	35.9	39.5	37.6
Standard deviation	4.7	3.5	7.5	4.9

The future runoff forecast results of the Hanseok SHP plant basin also showed that the runoff increases as the precipitation increases due to future climate change. In addition, the annual average runoff was simulated to be largest in Projection Period III due to the influence of the precipitation change in the Saigokcheon basin (Table 6 and Figure 3).

Table 6. Future runoff statistics in the Hanseok SHP plant basin

[Unit: m^3/s]

Projection Period	I (2021–2040)	II (2041–2060)	III (2061–2080)	IV (2081–2100)

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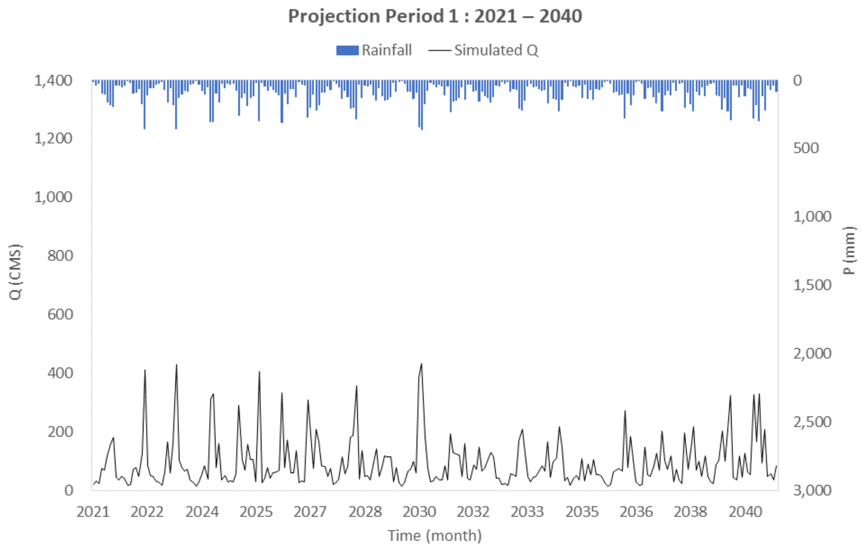
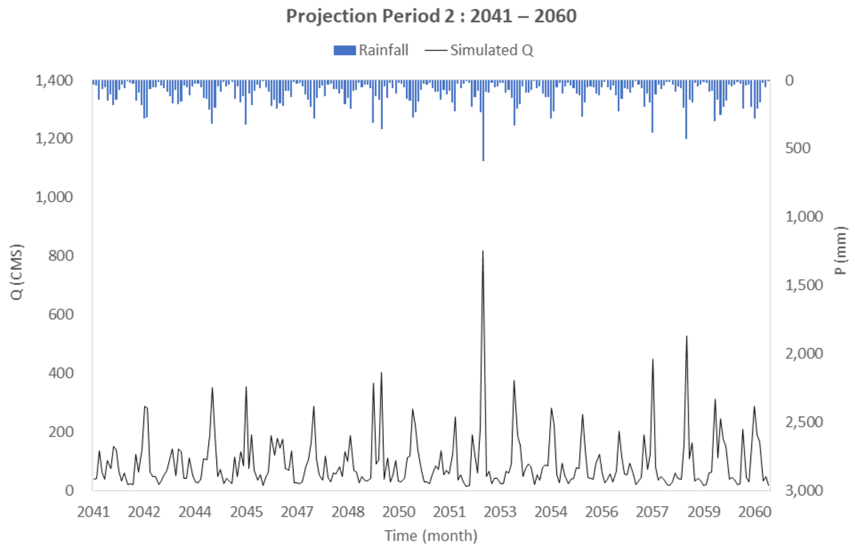
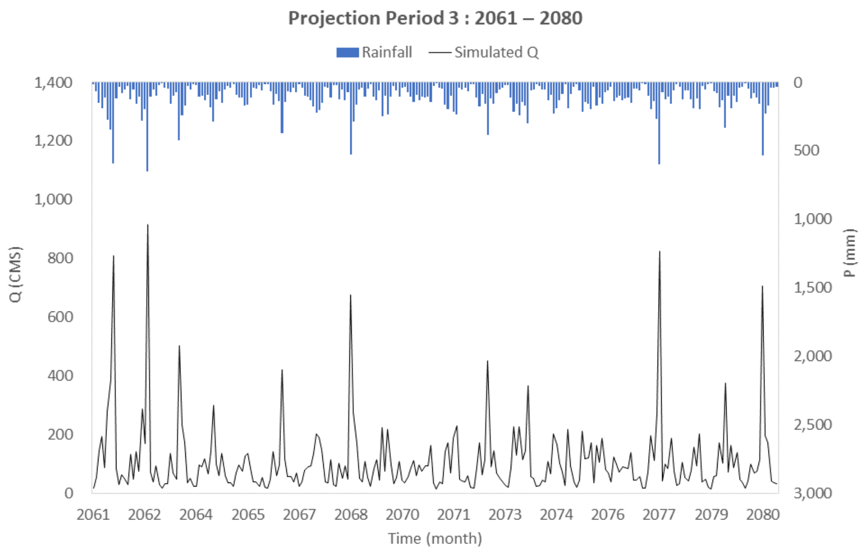
Mean	94.9	96.2	111.8	107.2
Standard deviation	19.0	15.4	32.4	25.3



(**a**) Monthly average discharge: Period I (2021–2040)



(**b**) Monthly average discharge: Period II (2041–2060)



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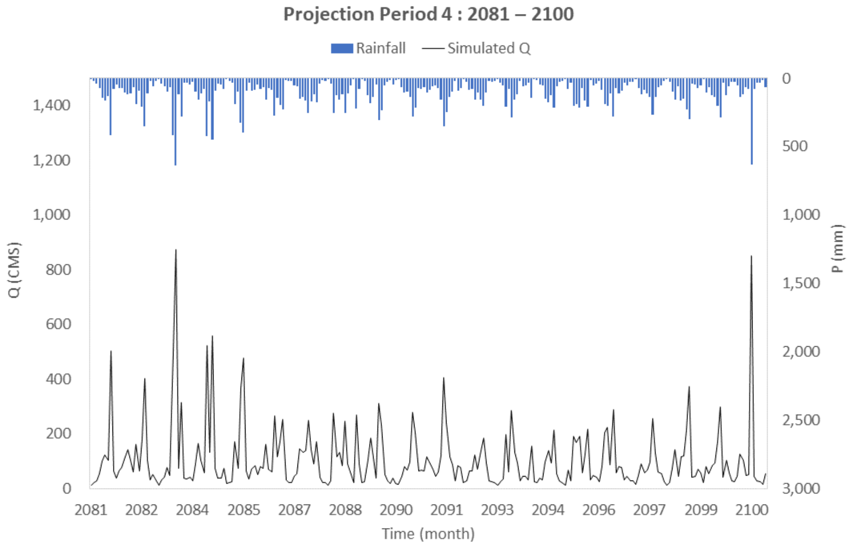
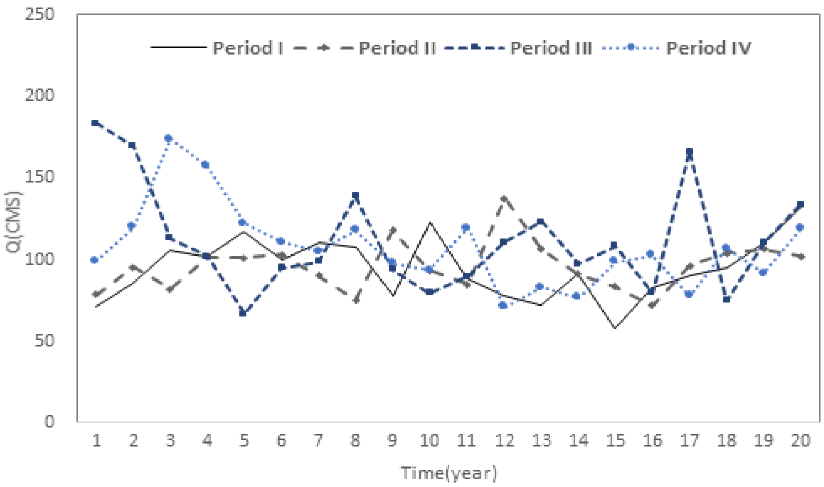
(c) Monthly average discharge: Period III (2061–2080)



(d) Monthly average discharge: Period IV (2081–2100)



(e) Annual average discharge

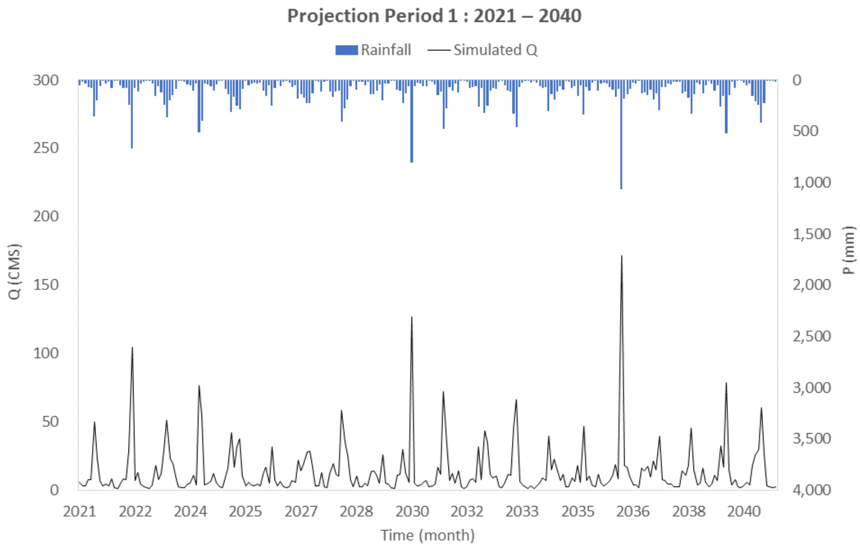
Figure 4. Future discharge simulation results of the Hanseok SHP plant basin

The future runoff forecast results of the Socheon SHP plant basin also showed that the runoff will gradually increase. In particular, in Projection Period IV, the average value of the monthly average runoff increased to 16.7 and the standard deviation also significantly increased to 26.3. This indicates that the runoff will increase in the same pattern as the increase in precipitation due to the influence of climate change (Table 7 and Figure 4).

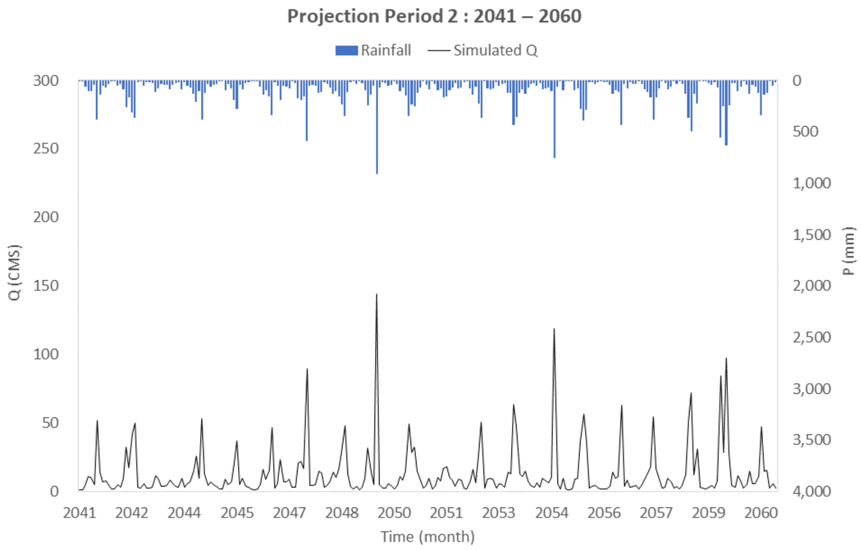
Table 7. Future runoff statistics in the Socheon SHP plant basin

[Unit: m^3/s]

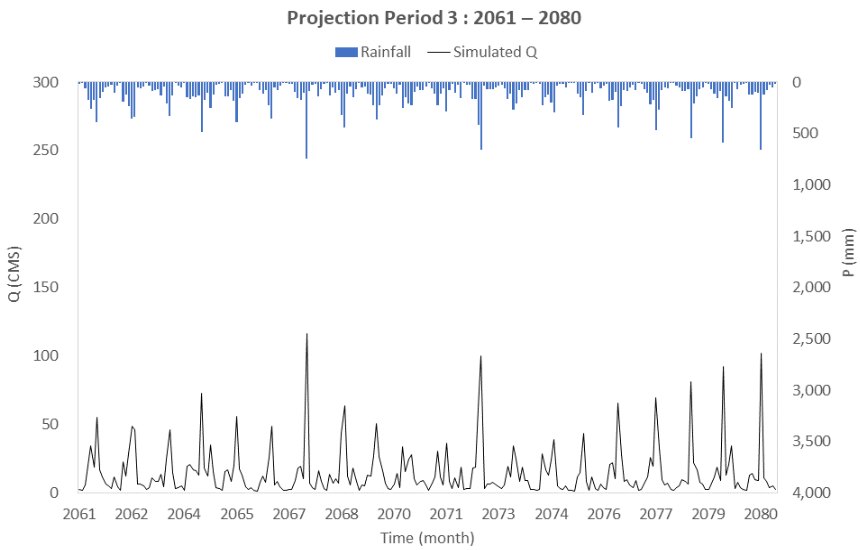
Projection Period	**I (2021–2040)**	**II (2041–2060)**	**III (2061–2080)**	**IV (2081–2100)**
Mean	14.0	13.4	14.8	16.7
Standard deviation	3.5	4.0	3.0	5.9



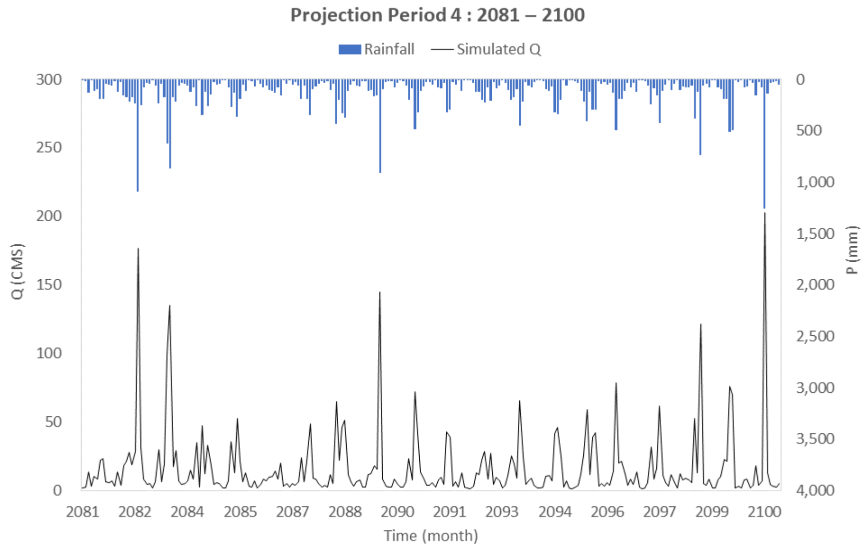
(**a**) Monthly average discharge: Period I (2021–2040)



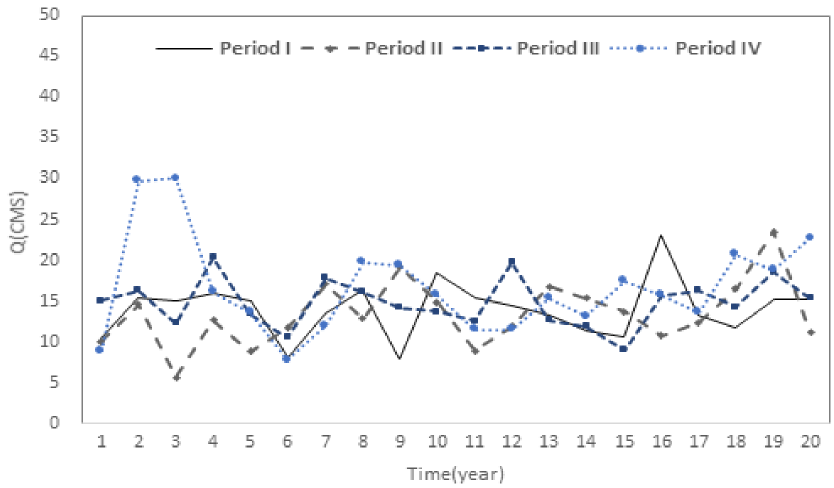
(**b**) Monthly average discharge: Period II (2041–2060)



(**c**) Monthly average discharge: Period III (2061–2080)



(d) Monthly average discharge: Period IV (2081–2100)



(**e**) Annual average discharge

Figure 5. Future discharge simulation results of the Socheon SHP plant basin

The future runoff change in each basin under climate change was analyzed. Based on the results, the SHP potential of each plant was calculated. In this instance, the plants were assumed to operate until 2100 for the analysis even though the average lifespan of SHP plants is approximately 50 years. Table 8 shows the results of estimating the annual SHP potential of each SHP plant.

Table 8. Estimated annual SHP potential by SHP plant (2021-2100)

[unit: MW h]

Year	Deoksong	Hanseok	Socheon	Year	Deoksong	Hanseok	Socheon
2021	9,261	7,847	6,451	2061	10,361	20,363	8,216
2022	9,336	9,490	6,422	2062	10,419	18,722	8,369
2023	10,348	11,661	8,534	2063	8,985	12,529	8,201
2024	9,305	11,178	7,109	2064	10,751	11,293	10,864
2025	9,841	12,889	8,201	2065	9,591	7,385	8,272
2026	11,140	10,997	6,236	2066	9,853	10,543	6,496
2027	10,409	12,232	9,091	2067	10,313	10,937	7,929

 doi:10.20944/preprints202103.0290.v1

2028	9,442	11,816	9,103	2068	10,384	15,513	8,779
2029	10,172	8,556	6,489	2069	10,432	10,388	8,365
2030	9,532	13,655	7,608	2070	10,518	8,755	9,311
2031	10,001	9,708	8,220	2071	9,328	9,961	8,553
2032	10,260	8,556	8,509	2072	10,172	12,288	7,441
2033	9,196	8,021	6,151	2073	10,050	13,550	8,726
2034	10,231	9,997	8,044	2074	10,337	10,682	7,117
2035	9,499	6,388	7,363	2075	10,931	11,948	6,301
2036	9,549	9,183	8,479	2076	10,739	8,783	8,576
2037	10,686	9,870	9,207	2077	10,655	18,440	8,199
2038	10,629	10,433	8,020	2078	9,345	8,233	7,448
2039	10,053	12,253	7,541	2079	10,226	12,127	8,963
2040	11,443	14,635	7,084	2080	10,051	14,859	7,752
2041	10,383	8,690	6,672	2081	9,698	11,038	7,173
2042	8,886	10,567	7,027	2082	10,876	13,244	10,213
2043	10,564	9,075	5,670	2083	8,876	19,216	8,811
2044	9,708	11,263	7,978	2084	10,825	17,352	8,957
2045	10,635	11,236	6,143	2085	9,755	13,475	7,664
2046	10,263	11,370	7,476	2086	10,318	12,181	7,083
2047	9,546	9,944	8,663	2087	9,953	11,566	7,340
2048	10,036	8,304	8,150	2088	9,986	13,062	8,604
2049	10,266	12,985	6,477	2089	9,022	10,848	7,649
2050	9,141	10,326	8,551	2090	10,097	10,358	7,426
2051	10,443	9,319	8,166	2091	11,325	13,143	6,817
2052	9,250	15,317	7,344	2092	9,364	7,887	8,171
2053	10,535	11,731	9,354	2093	8,506	9,095	8,321
2054	9,753	10,083	6,516	2094	9,303	8,493	6,964
2055	10,417	9,198	6,217	2095	9,759	10,829	7,762
2056	10,105	7,949	6,394	2096	10,320	11,258	8,694
2057	8,827	10,677	7,989	2097	9,738	8,606	7,690
2058	9,229	11,525	6,827	2098	9,501	11,779	8,284
2059	9,473	11,832	7,898	2099	10,485	10,178	7,260
2060	8,941	11,324	7,675	2100	9,151	13,214	6,501

3.3 Analysis of the variability of SHP potential under climate change

The variability of SHP potential under climate change was analyzed. First, the annual SHP potential forecast results of the Deoksong SHP plant showed that the power generation potential tends to increase during the entire projection period (Figure 5(a)). When the variability was analyzed for each future projection period, the annual potential was expected to increase by 1,776, 1,580, 1,931, and 1,603 MWh in Projection Period I, II, III, and IV, respectively, compared to the present level (Table 9).

In the case of the Hanseok SHP plant, the annual SHP potential showed a tendency to increase during the projection period (Figure 5(b)). When the average annual potential was estimated for each projection period and compared with that of the current period, the annual potential was expected to

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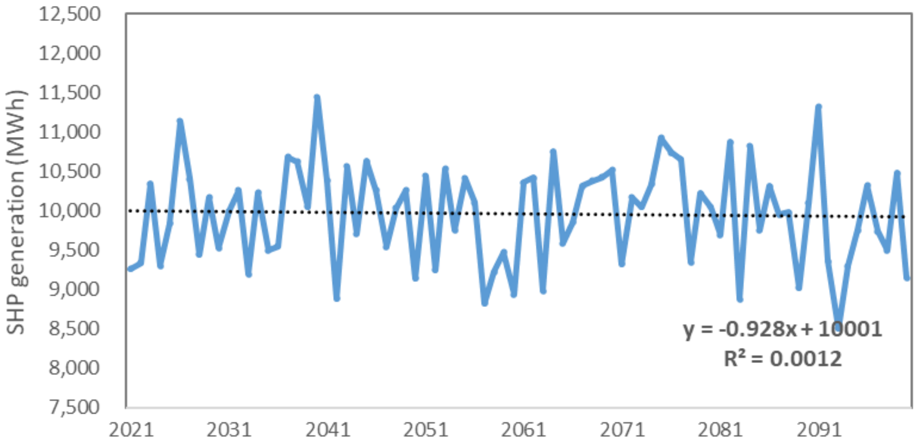
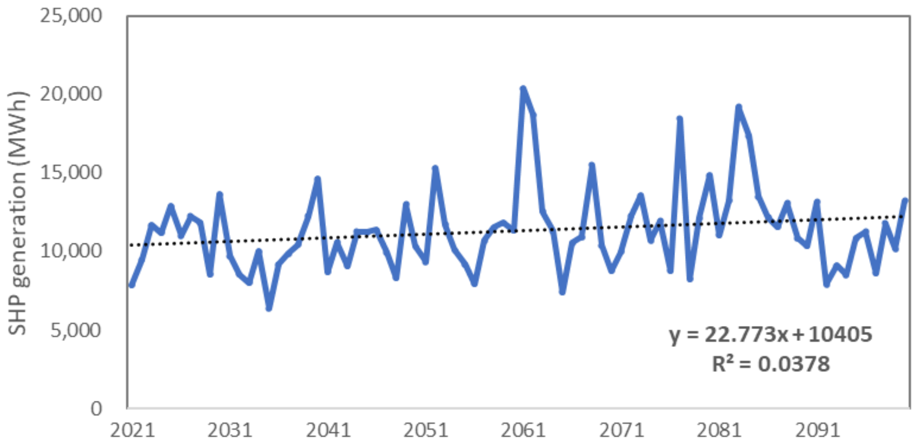
slightly decrease by 176 and 9 MWh in Projection Period I and II, respectively, but increase by 1,720 and 1,197 MWh in Projection Period III and IV, respectively, compared to the present level (Table 9).

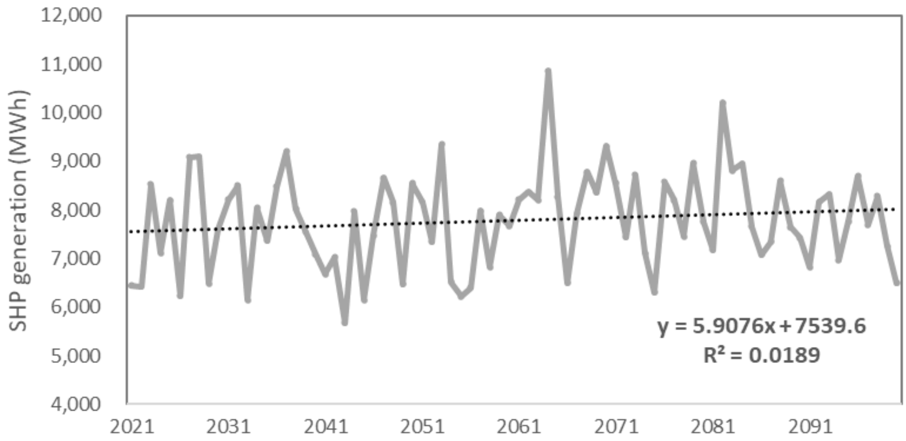
The annual SHP potential forecast results of the Socheon SHP plant showed that the potential tends to increase noticeably over time (Figure 5(c)). Compared to the present level, the annual potential was expected to increase by 485, 151, 986, and 661 MWh in Projection Period I, II, III, and IV, respectively (Table 9).



(**a**) Deoksong SHP plant



(b) Hanseok SHP plant



(c) Socheon SHP plant

Figure 6. Annual SHP potential by SHP plant

Table 9. Analysis of the variability of annual SHP potential by SHP plant

[unit: MW h]

SHP plant	Period			Average annual potential	Variation compared to the present level
Deoksong	Present		2008 - 2017	8,241	-
	Future	I	2021 – 2040	10,017	1,776 (↑21.6%)
		II	2041 – 2060	9,820	1,580 (↑19.2%)
		III	2061 – 2080	10,172	1,931 (↑23.4%)
		IV	2081 – 2100	9,843	1,603 (↑19.4%)
Hanseok	Present		2008 - 2017	10,645	-
	Future	I	2021 – 2040	10,468	-176 (↓1.7%)
		II	2041 – 2060	10,636	-9 (↓0.1%)
		III	2061 – 2080	12,365	1,720 (↑16.2%)
		IV	2081 – 2100	11,841	1,197 (↑11.2%)
Socheon	Present		2008 - 2017	7,208	-
	Future	I	2021 – 2040	7,693	485 (↑6.7%)
		II	2041 – 2060	7,359	151 (↑2.1%)
		III	2061 – 2080	8,194	986 (↑13.7%)
		IV	2081 – 2100	7,869	661 (↑9.2%)

When the annual SHP potential was forecasted during the period from 2012 to 2100 by applying the climate change scenario, it was expected to significantly increase for all of the three target SHP plants compared to the present level. This appears to be due to the influence of the increase in discharge caused by climate change.

4. Discussion and Conclusion

In this study, the future small hydropower (SHP) potential under climate change was predicted using the method proposed in a previous study [28]. The SHP potential from 2021 to 2100 was calculated using the RCP 4.5 climate change scenario data. It is uncertain and difficult to forecast the climate change on the projection period III and IV(2061 to 2100). For the future work, the long term river dynamics also could be considered through the Computational Fluid Dynamics(CFD) or Cellular Automata to improve the forecasts. Because of the uncertainty, it is desirable to focus on the SHP potential during first two periods and to see the tendency of the SHP potential during last two periods.

The SHP potential for all three SHP plants showed a tendency to increase over the entire period. This appears to be due to the increase in precipitation and discharge under the influence of climate change. In this instance, the design discharge was considered for the calculation of the power generation potential, and the river discharge above the design discharge did not contribute to the calculation of the potential. Therefore, if the theoretical power generation potential is calculated considering only the increase in discharge caused by climate change without considering the existing design discharge, it is expected that larger SHP potential can be used. This indicates that the hydropower generated can be efficiently used if the design discharge is calculated to be larger considering the discharge increased by climate change when new SHP plants are designed in the future.

Through the results of this study, the applicability of the proposed methodology for estimating the SHP generation potential in an ungaged basin in which no measured discharge data exists. In addition, as a result of prospecting the potential for future SHP generation taking into account climate change of the three target SHP plants, the prospect of future SHP generation potential is expected to increase from the present. The results of this study are expected to be used not only as a procedure for calculating the existing SHP potential but also for the planning of SHP plants in the future. Especially, if the future facility capacity is calculated more accurately based on the future prospect of the energy potential derived in this study, it will be possible to minimize loss in terms of initial facility investment and maintenance cost. In addition, it is expected to play an important role in supporting decision-making when energy policies are established in the corresponding areas.

Author Contributions: Conceptualization, H.K.; methodology, S.J.; software, J.L. and J.J.; validation, M.L.; formal analysis, J.J.; investigation, J.L.; resources, S.J.; data curation, S.J.; writing—original draft preparation, J.J.; writing—review and editing, S.J. and H.K.; visualization, J.J.; supervision, H.K.; project administration, M.L.; funding acquisition, J.J. All authors have read and agreed to the published version of the manuscript.

Acknowledgments: This research was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIT) (No. 2017R1A2B3005695).

Conflicts of Interest: The authors declare no conflict of interest.

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