Journal of Global Environment Engineering, Vol.10, pp.53-63, 2004

Full Paper

STUDY ON THE IMPACTS OF GLOBAL WARMING ON RIVER FLOWS THROUGHOUT JAPAN

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Abstract

The effect of global warming on river flows is considered to have great impacts on water resources that have strong links with our social and economic activities. In this paper a method for assessing river flows throughout Japan is proposed. Moreover, a simulation of future river flows using IPCC climate scenario data is attempted. As a result, a striking change in seasonal flow patterns are predicted in the selected representative blocks.

KEYWORDS: *global warming, river flows, hydrological model*

1. Introduction

The effect of global warming on river flows is considered to have great impacts on water resources that have strong links with our social and economic activities.

The IPCC and other organizations, therefore, have been promoting international research programs, which include forecasting of river flows using the global climate models (IPCC, 2001, NAST, 2001). However, it shall not be very reasonable to apply global-scale models to Japan, merely a small area in the Far East, to assess the river flows within the nation.

Meanwhile, local-scale studies of specific domestic regions are also being conducted. Those include the studies in which an analogical method is used to estimate future river flows referring to recorded climatic and hydrological data and those in which a river flow is simulated applying a long-term hydrological model (MOE, 2001). Although such local-scale studies enable more precise estimation than global-scale studies, local-scale modeling is not necessarily suitable for a nationwide assessment because a comprehensive understanding of various factors of each river basin such as inflow and outflow of water is required.

Therefore, this paper, as an intermediate-scale study, attempts to assess the impacts of global warming on river flows throughout Japan using commonly available data.

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2. Analytical methods

Observed river flow data is essential for evaluating impacts of global warming on river flows as baseline data. However, it is difficult to obtain these data for every river in the country. Therefore, in light of the limited amount of data available, a means of compensating for information insufficiencies needs to be considered. Thus in this study, a long-term hydrological model with volumetric river flows extrapolated from meteorological and other data was produced for each of several representative river basins for which volumetric flow data were available. These models are presented as a means to assess the river flows throughout Japan.

2.1 Process flow

As shown in Figure 1, Japan's land was divided into several blocks, and a river basin was selected to represent each block. A long-term hydrological model was then produced for each river basin. Next, each model was applied to the river flow assessment within the respective blocks. To put it concretely, the river flow within a block is estimated by putting the climatic data of the block into the model built for the river basin on the assumption that relation between climate and river flow in the block shows the same relation between those in the representative river basin.

For example, for Kanto block, Tama River basin was chosen as a representative river basin. A long-term hydrological model for Tama River basin was produced using observed river flow and meteorological data. This model was then applied to assess the river flows within whole Kanto block.

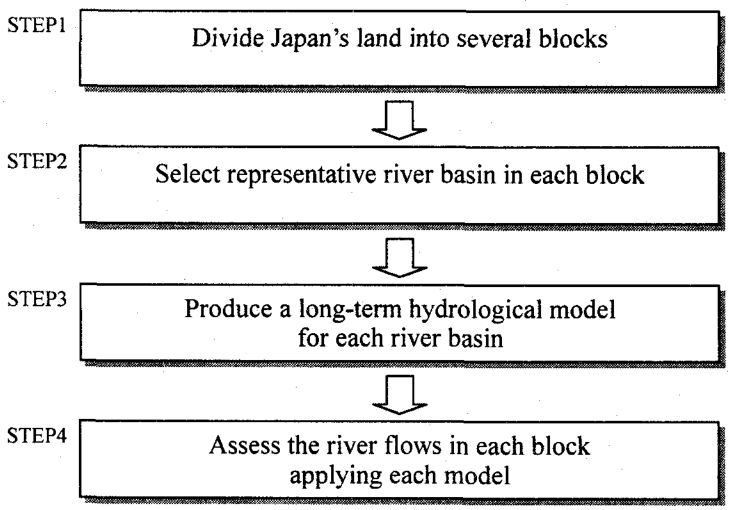

Figure 1 Analytical Methods

2.2 Hydrological model

In this study, WatBal, supplied by International Institute for Applied Systems Analysis (IIASA), was used as a long-term hydrological model.

The conceptual diagram of WaBal is shown in Figure 2. To derive the relations between climatic factors and river flows, four parameters (Smax, Zi, eps, alpha) in the figure are calibrated by applying a type of regression methods. Evapotranspiration is estimated referring to several factors such as average air temperature, average daily precipitation, average amount of daily sunlight and relative humidity, applying Priestly-Taylor method. For details in this model, please refer to the original article (Yates, 1994).

3. Simulation analysis

3.1 Determination of target blocks and representative river basins

Japan was divided into 8 blocks: Hokkaido, Tohoku, Hokuriku-Chubu, Kanto, Kinki, Chugoku, Shikoku, and Kyushu, and the basins of Tokachi, Omono, Jintsu, Tama, Yamato, Gouno, Shimanto, and Chikugo Rivers were selected to represent these blocks respectively (Figure 3). While block divisions could be based more on regional and climatic characteristics, for our study standardized geographical divisions were chosen. Moreover, the representative river basins were chosen on the assumption that there were no missing flow data in chronological tables of rivers and streams for each river in the years 1995 to 1999.

3.2 Development of the data set

As mentioned in the section 2.2, the data set was prepared as the input data of hydrological model to extract monthly data values from 1995 to 1999 for the five parameters of average air temperature, average daily precipitation, and average amount of daily sunlight (from AMeDAS observational data); daily average river flow (from chronological tables of rivers and streams); and relative humidity (normal value from chronological scientific tables 2001).

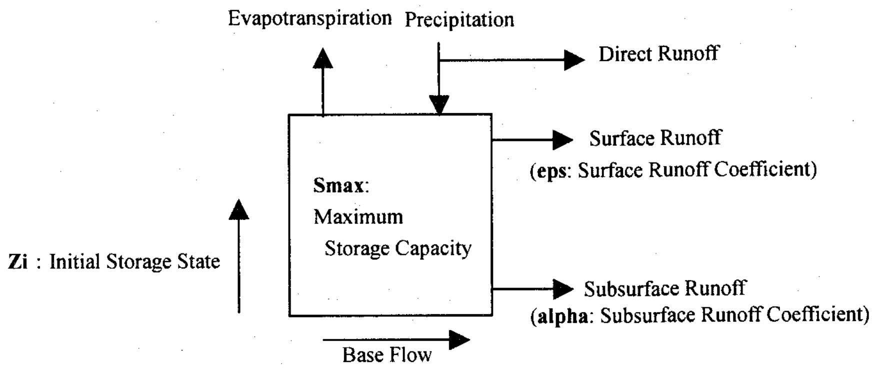

Figure 2 Conceptual diagram of WatBal (Yates, 1994)

3.3 Production of the long-term hydrological model (Calibration)

The long-term hydrological model was produced after calibration performed using the prepared data set for the three-year period of 1995 to 1997. The calibration results are shown in Figure 4. Since observed river flows for Tama River were extremely small when viewed against observed precipitation, making it impossible to properly calibrate the corresponding Kanto block model, this model was excluded. For the other modeled blocks, the predicted river flow values roughly coincided with the observed values, leading to the conclusion that the models sufficiently reflect the characteristics of each corresponding block. The 1998 to 1999 data set was used for validation of the models. Though the data is not shown due to space limitations, the validation produced good results on the whole.

3.4 Prediction of future river flows (Simulation)

Based on the long-term hydrological models of representative river basins obtained via calibration, decennial monthly river flows for whole Japan from 2000 to 2099 were calculated by the block. The data for average air temperature and average daily precipitation were taken from the climate scenario data (made by downscaling the GCM supplied by the IPPC to 10-km mesh cells) produced by the National Institute for Agro-Environmental Sciences (MOE, 2002). In this study, the simulation was performed with five types of climate scenario data: ECHAMA4 (Germany), HadCM2 (England), CSIRO (Australia), CCCma (Canada), and CCSR/NIES (Japan). In order to save space, only the results for the years 2000-2009 and 2070-2079 based on the CCSR/NIES scenario data are shown (Figure 5). In this scenario the amount of CO_2 is assumed to increase by 1% yearly and reaches twice as much as that of 2000 by the year 2070. It should be noted that GCM data was prepared for analysis on global level, so when the data within Japan is focused, the values of climatic factors may differ from actual values.

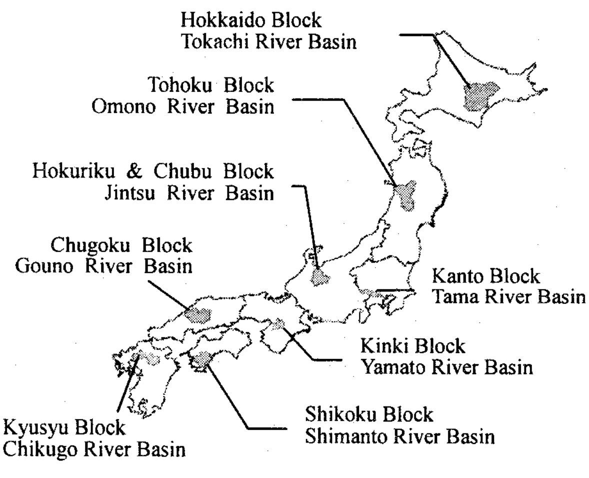

Figure 3 Target blocks and representative river basins

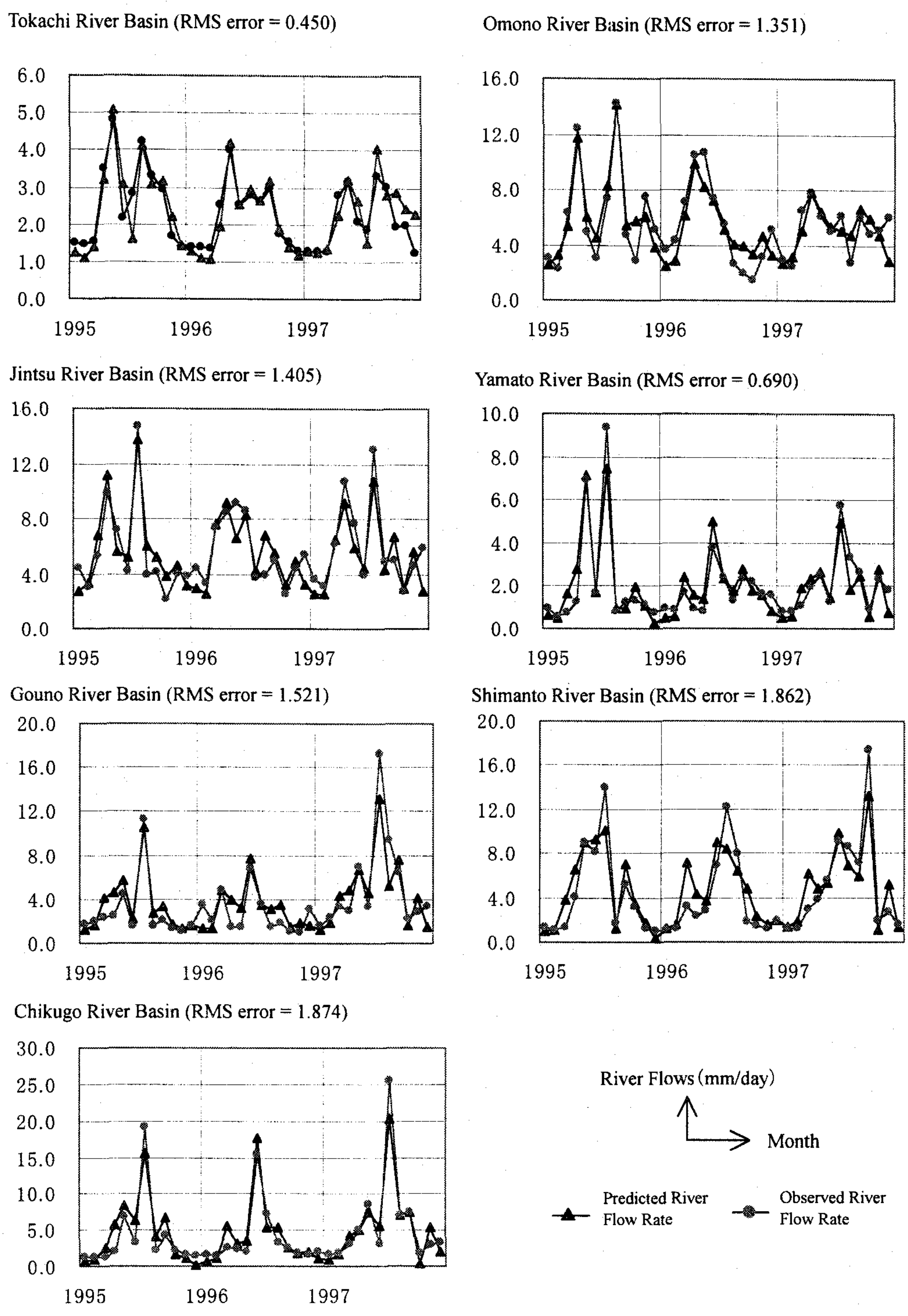

Figure 4 Calibration results

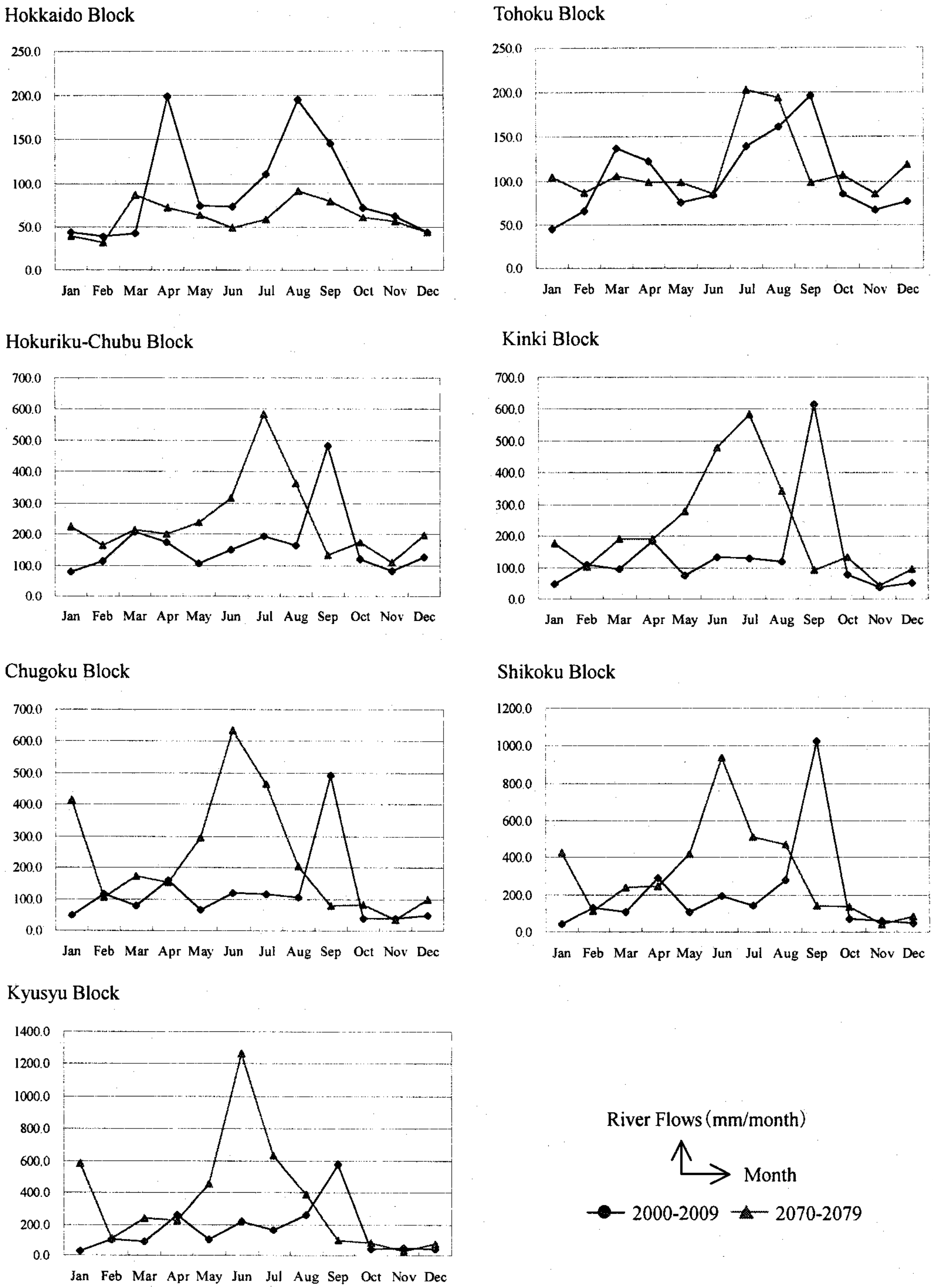

Figure 5 Simulation results: River flows for the years 2000-2009 and 2070-2079

4. Discussion

4.1 Analysis of changes in local climates and river flows

For further analysis, the simulation result for the Tohoku block was selected as an example because it demonstrates striking changes in river flow patterns due to global warming. The computed average air temperature, average monthly precipitation, monthly evapotranspiration, and predicted river flows are described below. Figures 6 show the results for each pattern for the years 2000-2009 and 2070-2079.

(1) Changes in air temperature

Average yearly air temperature rose approximately 3.2°C, from 10.5°C to 13.7°C. The distinctive feature about this is the large range in the rise in winter compared with that in the summer. Computing the difference in average air temperature for the half-year period from October to March resulted in a temperature rise of approximately 4.1°C, from 2.9°C to 7.0°C. In particular, for January and February, the value shifts across 0°C, suggesting such changes as reductions in snowfall frequency and accumulation as well as earlier snowmelt.

(2) Changes in precipitation

Precipitation was suggested to increase by approximately 12%, from 1863 to 2083 mm/year. The distinctive feature here is the shift of the peak in the rainy season from autumn to summer. In the range of this change, the predicted 54% rise (from 245 to 386mm) in July stands in contrast to the predicted 64% reduction (from 386 to 135mm) in September.

(3) Changes in evapotranspiration

Evapotranspiration was found to increase by approximately 13%, from 611 to 692 mm/year, showing good accordance with the rate of increase in precipitation. However, the shift of the peak point in the evapotranspiration pattern, which was seen in the case of precipitation, was not identified. The maximal change was found to be increased during winter, and the highest value in summer, the period in which evapotranspiration peaked, was also found to increase. The rise in evapotranspiration was in agreement with the rise in air temperature.

(4) Changes in predicted river flows

The total yearly flow tended to increase by approximately 10%, from 1255mm (84.3 x 10^3 m^3) to 1385mm (93.1 x 10^3 m^3). A large change was confirmed when each month was analyzed separately: -50% (from 196 to 98mm) in September to +132% (from 45 to 105mm) in January. Moreover, the maximal difference was –98mm (-6.6x$10^3 m^3$). For the change in flow pattern, particularly significant is the flow rate increase in winter and the reduction in river flows in spring, arising from the above-mentioned situation change in winter. In addition, the changes in rainfall patterns make a shift in the peak flow, from autumn to summer.

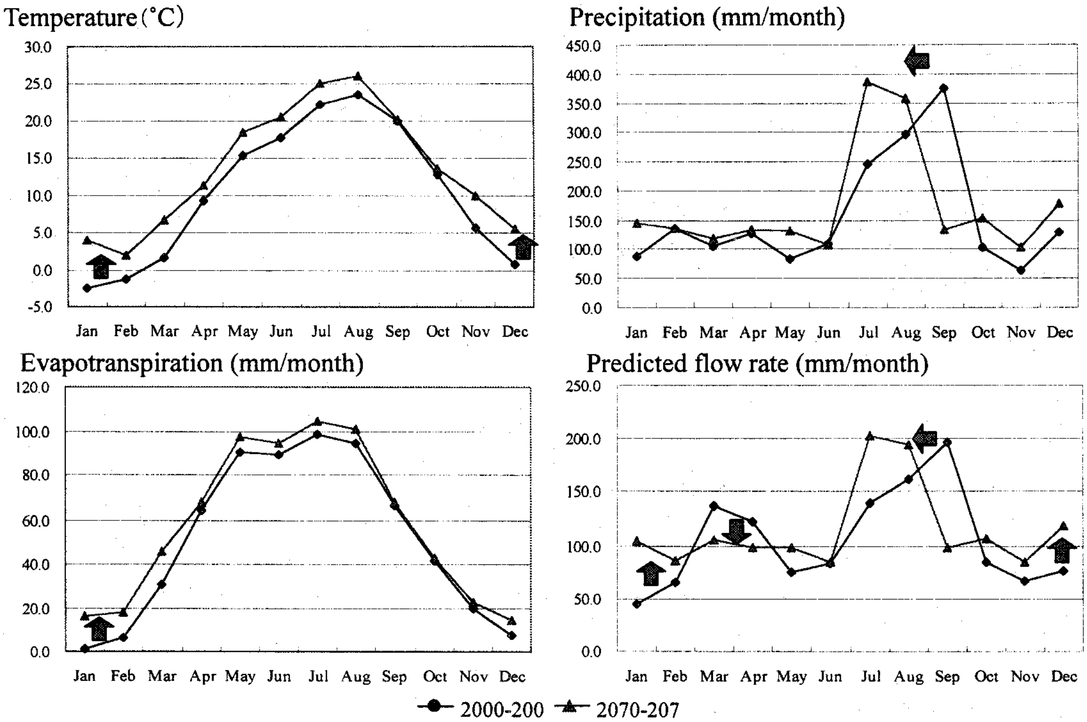

Figure 6 Changes in local climates and river flows in Tohoku block

4.2 Interregional comparison of changes in climate and river flows

To analyze the regional impacts of global warming, the change in temperature, precipitation, evapotranspiration, and predicted river flow values (annual average, summer average, and winter average) for 2070-2079 against those in 2000-2009 are shown in Table 1 for each block, and the changes are discussed below.

(1) Changes in temperature

All blocks tended to show an elevation of approximately 3°C in average annual temperature. The rise was greater in winter than in summer, a characteristic that was more pronounced in blocks located further north. For example, in the Hokkaido block the summer average rose 2.2°C and the winter average 4.9°C (range 2.7°C), whereas in the Kyushu block the summer average rose 2.3°C while the winter average rose only 3.1°C (range 0.8°C).

(2) Changes in precipitation

The increasing rate of precipitation was higher as the blocks were further south. In the Kyushu block the annual change was +88%, and in winter only +179%, reaching nearly three-fold (although this is affected by the fundamentally small absolute precipitation amount in winter). In the Hokkaido block, on the other hand, summer precipitation decreased by 34% and annual precipitation also decreased by 22%.

(3) Changes in evapotranspiration

Similarly to the elevated air temperature and increased precipitation, evapotranspiration tended to increase across the board. Specifically, the high increasing rate in winter in northern blocks (Hokkaido block +96%, Tohoku block +48%) corresponded to the rise in winter temperature.

(4) Changes in predicted river flows

The predicted river flows will rise as precipitation increases; that is, precipitation decreased in the Hokkaido block, the predicted river flows also showed a decrease. In blocks located south of Hokuriku-Chubu block, there are a fair number of cases showing increases of more than 50% in the annual, summer, and winter predicted river flows. In particular, the increasing rate of river flows rises with locations further south, which corresponds with the increasing rate of precipitation. The Kyushu block had the highest predicted rate of increase, and recorded changes of nearly 2-fold (+93%) in summer, more than 3-fold (+216%) in winter, and more than 2-fold annually (+116%).

Table 1 Interregional comparison of changes in climate and flow rate

(Summer: Apr, May, Jun, Jul, Aug and Sep, Winter: Oct, Nov, Dec, Jan, Feb and Mar)

Hokkaido Block

	Annual average	Summer average	Winter average
Temperature	+3.6°C	+2.2°C	+4.9°C
Precipitation	-22%	-34%	+7%
Evapotranspiration	+5%	-3%	+96%
Predicted river flow	-34%	-49%	+5%

Tohoku Block

	Annual average	Summer average	Winter average
Temperature	+3.2°C	+2.2°C	+4.1°C
Precipitation	+12%	+1%	+33%
Evapotranspiration	+13%	+6%	+48%
Predicted river flow	+10%	0%	+28%

Hokuriku-Chubu Block

	Annual average	Summer average	Winter average
Temperature	+3.0°C	+2.2°C	+3.8°C
Precipitation	+40%	+35%	+52%
Evapotranspiration	+17%	+12%	+31%
Predicted river flow	+47%	+45%	+50%

Kinki Block

	Annual average	Summer average	Winter average
Temperature	+2.9°C	+2.1°C	+3.6°C
Precipitation	+44%	+38%	+63%
Evapotranspiration	+10%	+9%	+12%
Predicted river flow	+62%	+57%	+76%

Chugoku Block

	Annual average	Summer average	Winter average
Temperature	+2.8°C	+2.1°C	+3.5°C
Precipitation	+68%	+50%	+121%
Evapotranspiration	+17%	+16%	+20%
Predicted river flow	+93%	+73%	+150%

Shikoku Block

	Annual average	Summer average	Winter average
Temperature	+2.7°C	+2.2°C	+3.3°C
Precipitation	+45%	+29%	+122%
Evapotranspiration	+17%	+17%	+19%
Predicted river flow	+51%	+34%	+130%

Kyusyu Block

	Annual average	Summer average	Winter average
Temperature	+2.7°C	+2.3°C	+3.1°C
Precipitation	+88%	+68%	+179%
Evapotranspiration	+18%	+18%	+21%
Predicted river flow	+116%	+93%	+216%

5. Conclusions

In this paper a method for assessing river flows throughout Japan was proposed. Moreover, a simulation of future river flows using IPCC climate scenario data was attempted. The achievements and problems revealed in this study, as well as future tasks, are discussed below.

5.1 Achievements of this study

This study was successful in addressing the foremost question, "What will happen to river flows in the future?" This was accomplished by focusing on a method to assess the impacts of global warming on river flows throughout Japan, something that has remained unaddressed thus far despite the importance of such an assessment to our lifestyles. The results showed a striking change in seasonal flow patterns in the selected representative blocks, thus indicating the impacts of global warming on river flows.

1) River flows in winter increased, while those in spring decreased.
2) The peak river flows shifted from autumn to summer.
3) The further south a block, the larger the increase in river flows.

5.2 Problems

When attempting to analyze river flows impacts using a simple long-term hydrological model, the assumption is made to some extent that the model is not influenced by human activity but "natural". However, the limitations in utility of models were revealed, as represented by the Tama River example. These limitations stem from the large number of parameters complicating the relation between rainfall and river flows, such as when river flows is modified by water storage facilities such as a dam or when a large amount of river water is redirected for industrial, agricultural, or domestic (non-commercial) purposes in metropolitan regions contain river basins.

5.3 Tasks for the future

In this paper the assessment area was simply divided into eight regional blocks. If, however, local geographical characteristics such as climate conditions are considered, it can be seen that this is not necessarily the most suitable way to divide the target area. Moreover, the representative river basins chosen for each block may not fully represent the characteristics of the original block. A means to reflect the spreading of the effect of human activity is also needed. Based on these points, more detailed research was planed to expand the presently limited information to represent more of the country. In addition, the climate scenario simulation presented here was originally produced to study the effects of global warming on a global scale; thus, the accuracy is undeniably insufficient for evaluating the much smaller area of Japan. Regarding this insufficiency, the results of a regional-scale climate model (MLIT, 2002), which is planned for limited release, are anticipated.

Acknowledgements

The authors would like to express thanks to the National Institute for Agro-Environmental Sciences for providing the climate scenario data, and also to Ms. Naoko Koyasu from Pacific Consultants Co., Ltd. for her cooperation to complete this paper.

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