RISK BASED ASSESSMENT OF WATER AVAILABILITY ALONG THE TONE RIVER AND TOKYO METROPOLITAN AREA UNDER CLIMATIC CHANGES

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Tone river supplies most of its water requires for the Tokyo Metropolitan Area (TMA). Lowering of Tone flow and its fluctuation, however, is causing water shortage along TMA nowadays. An integrated modeling approach considering the dominating factors affecting Tone flow and TMA water supply was developed to investigate the condition of water availability along the Tone and its effect on TMA that is expected under some future climatic scenarios. Several risk indices were introduced to quantify the changes in this case. For an average future climatic condition, the reliability of the Tone river system was not expected to be changed significantly due to presence of a robust reservoir system at the upstream with eight multi-purpose reservoirs.

INTRODUCTION

Even though, there are a large number of studies available since the last decade on the topic climate change impact assessment on the water resources sector; most of them were actually concentrated on natural hydrological balance and its sensitivity to some expected range of future climatic changes derived from GCM or hypothetically assumed. In an actual catchment, however, the condition is quite different, which is complicated by a number of anthropogenic factors like water withdrawal and artificial structures. Only a few studies have examined climate change impact including those factors in an integrated way to the water resources—such as the reliability of a water supply system or the risk of flooding and drought—and even fewer explicitly have considered possible adaptation strategies (IPCC [1]).

In this study, a risk based assessment of climate change impact on the water availability scenario along the Tone river and its ultimate effect on the TMA water supply system was made. Tone is one of the largest river in Japan, with a catchment area of 15,628.7 km². TMA collects most of its water supply (80%) from the adjacent Tone River and is suffering from water shortage almost once in every 2-3 years, especially due to low flow along Tone. A historical assessment of trend in climatic attributes along the Tone river basin again confirmed the fact that the yearly average value of temperature along the basin is increasing steadily and precipitation is getting more chaotic (Islam et al. [2]).
The Kurihashi point of the river was taken for investigation, as it was considered important for water management in TMA. Due to presence of eight multipurpose reservoirs at the upstream of Kurihashi, as well as varied land uses and water uses, it is also considered as one of the most complex river basin in Japan (Figure 1). Careful judgment was thus required to simplify the system and develop a water balance model in a way so that it reduces complexity in calculation with reasonable accuracy. A conceptual framework for addressing the entire problem was first envisaged. Both the demand and supply sides were included in the analysis in an integrated way. It is to note that at the downstream of Kurihashi, other than domestic water demand, there are several other water users as well like the agricultural water users, industrial and commercial water users. Several risk indices were introduced to quantify the water availability, compare to that of its demand. The entire system was defined as reliable when the available water supply was enough to meet all the downstream demand. Four different GCM scenarios were used to investigate the future changes in risk indices, which can give an insight about the overall water availability picture of Tone and TMA.

CONCEPTUAL FRAMEWORK

To address climate change impact on the overall water resources system along the Tone basin and its relevance to TMA, a research protocol was first postulated as shown in the flow diagram in Figure 2. It starts with a historical assessment of some hydro-climatic attributes in the study area to identify their interrelationships and trends. This paper mostly covers the portion application of the water balance model for some future GCM climate scenarios and investigates the changes in risk indices.
Selection of governing sectors might be affected by climate change

- Climate change scenario
  - Hypothetical
  - GCM based

- Land use / social / economic change scenario

Development of suitable Water balance model

Model application under future changes

Impact on Social, economy and infrastructure

Impact on Regional Hydrology

- Demand
  - Agriculture
  - Domestic / urban
  - Others

- Water system
  - Water resources development
  - Change in management, operation rule

- Natural system
  - Hydrologic cycle
  - Water availability

Robustness of the system

Uncertainty, fluctuation

Figure 2. A protocol for risk base integrated assessment of climate change impact in the water resources sector
DEVELOPMENT AND APPLICATION OF WATER BALANCE MODEL

The water balance model was mainly developed to apply at the upstream of the Kurihashi station. Upstream of Kurihashi is less populated so that domestic and industrial water uses were considered negligible. However, significant percentages (25%) of the catchment cover with cropland, so that irrigation water requirement is important to be considered. The Water Balance model was finally composed of three major components as:

- Natural hydrological cycle
- Irrigation water use
- River regulation

Figure 3 shows the schematic diagram of the interaction between different components. Irrigation water demand was estimated by using CROPWAT model, which is sensitive to both temperature and precipitation changes (FAO[3]). Standard reservoir regulation rule was adopted to simulate Reservoir outflow. Climate sensitivity of the natural hydrological balance was mainly expected through snow accumulation-melting and evapotranspiration processes. Degree day equation for snow melt and Hamon’s temperature based equation for evapotranspiration was used. For detail description of the natural water balance part of the model, please refer to Islam et al. [1].

For validation of the model, reservoir regulation and diversion effect was eliminated from the observed flow and the corrected flow was then compared to the simulated natural flow, coupled with agricultural water withdrawal as estimated by CROPWAT. It was because, the parameters to be calibrated were mostly from the natural water balance part and because of the practical impossibility of simulating reservoir outflow, it might cause for unrealistic values of those calibrated parameters. Figure 4 shows the simulated
and observed flow on a monthly basis without regulation, for the period between 1984-91.

![Graph showing comparison of observed and simulated flow](image)

**Figure 4. Comparison of observed and simulated flow**

### RISK ANALYSIS

Once the water balance model for the upstream of Kurihashi had been validated against natural flow, the reservoir regulation rule was re-imposed to generate actual flow. In this case, no attempt had been made to validate the regulated flow. A target flow at Kurihashi was estimated based on the water requirement at the downstream, as shown in Table 1.

<table>
<thead>
<tr>
<th></th>
<th>Domestic ($10^4$ m$^3$/d)</th>
<th>Industrial ($10^4$ m$^3$/d)</th>
<th>Agriculture ($10^4$ m$^3$/d)</th>
<th>Ecological ($10^4$ m$^3$/d)</th>
<th>Total ($10^4$ m$^3$/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High (June)</td>
<td>1100</td>
<td>100</td>
<td>2000</td>
<td>4900</td>
<td>8100</td>
</tr>
<tr>
<td>Medium high (May, July, Aug)</td>
<td>1000</td>
<td>100</td>
<td>1500</td>
<td>4900</td>
<td>7500</td>
</tr>
<tr>
<td>Medium low (Apr, Sep)</td>
<td>950</td>
<td>100</td>
<td>500</td>
<td>4900</td>
<td>6450</td>
</tr>
<tr>
<td>Low (Other)</td>
<td>900</td>
<td>100</td>
<td>0</td>
<td>4900</td>
<td>5900</td>
</tr>
</tbody>
</table>

Four risk indices were defined to quantify water availability from Tone to meet the target flow level as Risk, Reliability, Resiliency and Vulnerability (Hashimoto et al. [4]). For daily simulation, a particular day is in failure or in Risk when the actual regulated flow at Kurihashi is below the target flow level. Reliability is just the opposite of risk as the state of the system in success or able to supply adequate target flow. Resiliency is the index applies to define how quickly the system can recover from a failure. Vulnerability defines the magnitude of failure below the target flow level.
CLIMATE CHANGE SCENARIOS

GCM selected
Four GCM climate projections were selected to estimate the future climate change expected along the study area. They are;

1. CSIRO-Mk2 : Australia
2. CGCM1 : Canada
3. CCSR-98 Japan
4. ECHAM4 : Germany

The original projected data by the above four GCM for temperature and precipitation were based on the emission scenario IS92a. National Institute of Agricultural Science (NIAS) further downscaled the data to a smaller spatial scale up to 20km x 20km through statistical technique Inverse Distance method (NIAS [5]). The temporal scale of the data was still on a monthly basis.

Temporal Downscaling
For use in the water balance model with daily time step, the NIAS monthly GCM data was required to be temporally downscaled to daily values. To downscale precipitation data, second order Markov chain model was used to generate rainy and non-rainy day sequences. Log-normal distribution was adopted to estimate the depth of precipitation for rainy days.

RESULTS AND DISCUSSION

Change in monthly natural flow
Figure 5 (a) compares the future monthly variation of Kurihashi flow compared to that of the present observed flow 1984-91, without downsampling. Percent change in monthly average values of precipitation and absolute change in temperature was added to the 1984-91 observed daily precipitation and temperature to use as input to the water balance model. Figure 5(b), on the other hand directly uses the temporally downscaled daily GCM values.

NIAS spatially downscaled GCM values for different GCM calculated same values of monthly precipitation and temperature for the present scenario, but differed in future projections. Even though the figures for different GCM predicted different monthly patterns for 2xCO₂ scenario, however, in general all of them showed higher flow for the summer periods between June-Sept, mainly due to higher precipitation projected. Winter flow was almost unaffected or slightly decreasing. Lowering of flow was observed mostly between Apr-May, due to lowering of snowmelt water and increased agricultural demand. The monthly pattern between Figure 5(a) and 5(b) showed the quality of temporal downscaling, which sounds good enough. The difference in magnitude was mainly due to the bias between GCM present and observed present (1984-91) climate.
Predicted future flow after downscaling as shown in Figure 5(b) was regulated to reservoir effect. As shown in table 1, among the components of water withdrawal, agricultural and domestic water demands are climate sensitive so that need to be predicted for future climate scenarios as well. CROPWAT model was used to predict the future agricultural water demand downstream of Kurihashi. A temperature based regression model was developed for domestic water demand based on the water use data along TMA for the years 1973-98. The risk indices calculated after reservoir regulation for the four GCM are shown in Table 2. Here the term peak season defined as the season May-Aug, due to increase water demand for domestic as well as agriculture.

The table implies that the reservoir system at the upstream of Kurihashi is quite robust to withstand future changes, so that no major changes in risk indices were observed. However, it might be due to the fact that all the four GCM predicted a higher average yearly flow, especially during peak season. Only for the case of CCM, the average yearly risk was considerably increased due to lowering of flow during winter. For peak season flow, the change in risk was negligible, but resiliency was observed to be decreased significantly. It means delay in recovery from failure in future is expected.

The analysis however, having limitation by the fact that simply observing future average monthly changes is not enough for a risk analysis. Based on the historical mean and standard deviation, it is possible to generate a set of monthly flow series through
Monte-Carlo simulation so that it can account for the future fluctuating behavior of Tone flow in different months in more realistic way.

Table 2. Risk indices for different future climate scenarios

<table>
<thead>
<tr>
<th>Future</th>
<th>Present</th>
<th>ccm</th>
<th>ccsr</th>
<th>csiro</th>
<th>mpki</th>
</tr>
</thead>
<tbody>
<tr>
<td>risk (%)</td>
<td>6.95</td>
<td>13.01</td>
<td>5.07</td>
<td>6.16</td>
<td>5.99</td>
</tr>
<tr>
<td>Average reliability(%)</td>
<td>93.05</td>
<td>86.99</td>
<td>94.93</td>
<td>93.84</td>
<td>94.01</td>
</tr>
<tr>
<td>Yearly resiliency(%)</td>
<td>5.42</td>
<td>4.21</td>
<td>7.43</td>
<td>9.44</td>
<td>6.29</td>
</tr>
<tr>
<td>Vulnerability (% shortage/day)</td>
<td>0.39</td>
<td>0.68</td>
<td>0.25</td>
<td>0.28</td>
<td>0.29</td>
</tr>
<tr>
<td>risk(%)</td>
<td>0.73</td>
<td>2.08</td>
<td>0.00</td>
<td>2.60</td>
<td>1.77</td>
</tr>
<tr>
<td>Peak reliability(%)</td>
<td>99.27</td>
<td>97.92</td>
<td>100.00</td>
<td>97.40</td>
<td>98.23</td>
</tr>
<tr>
<td>Season resiliency(%)</td>
<td>42.86</td>
<td>20.00</td>
<td>NA</td>
<td>24.00</td>
<td>11.76</td>
</tr>
<tr>
<td>Vulnerability (% shortage/day)</td>
<td>0.04</td>
<td>0.15</td>
<td>0.00</td>
<td>0.14</td>
<td>0.09</td>
</tr>
</tbody>
</table>

CONCLUSION AND RECOMMENDATION

A comprehensive risk based approach for assessment of water availability along the Tone river and Tokyo Metropolitan Area was developed. Appropriate methodology was adopted to address the water resources system as a whole including all the relevant sectors. Based on some future GCM scenarios, the future water availability scenario was quantified with several risk indices and was found to be not significantly changed. Further improvement of the study was proposed adopting a Monte-Carlo simulation.

REFERENCES

[5] NIAS, Data collected through personal contact, 2003