POTENTIALLY AVAILABLE WATER RESOURCES DISTRIBUTIONS OF EARTH UNDER CLIMATE CHANGE AND THEIR IMPLICATIONS FOR WATER RESOURCES MANAGEMENT

Tohoku University	Graduate Student	O Nilupul K. GUNASEKARA
Tohoku University	Fellow Member	So KAZAMA
University of Tokyo	Graduate Student	Dai YAMAZAKI
University of Tokyo	Fellow Member	Taikan OKI

1. INTRODUCTION

It is anticipated that water resources scarcity will surpass the present oil crisis and will become grounds for possible future wars. The Nile basin has been identified as the next probable domicile for a water war. One reason for the world water crisis is the anthropogenic agents and another one is the climate change. Innumerable researches on water resources bear evidence for worsened water scarcities in the near future, due to climate change.

These quantitative assessments of water scarcity exhibit the extent of scarcity in the future. The qualities of the water scarcity or the related social situations have not yet been addressed adequately. This research is in the primary stages of developing an index which enables one to measure inequality in water distributions as well as to relate it to the resulting social situations due to the water crisis, or the conflict situations. The potentiality of measuring inequality of water distributions of the index was evaluated on this phase of the research.

2. METHOD OF ANALYSIS

The potentially available water resources distributions over land of the globe, from 1970 to 2100 were analyzed for its inequality, using the Gini coefficient. The annual average river discharges were assumed as the potentially available water resources.

(1) Potentially Available Water Resources

The river discharge from a region, to the consecutive region, which is the combination of runoff from within the first region and the discharges from the regions upstream, was assumed as the potentially available water to the first region.

(2) The Gini Coefficient and Its Utilization in Inequality Measurement

The most prominent use of Gini is in the field of Economics, to measure inequality in distributions of welfare indicators of society. The Gini coefficient is defined as, the mean difference between every possible pair of individuals, divided by the mean size of the population (Gini, C., 1912).

$$Gini = \frac{1}{2n^2 \bar{y}} \sum_{i=1}^{n} \sum_{j=1}^{n} \left| y_i - y_j \right| \qquad (1a)$$

Here, n is the number of individuals in the sample, y_i and y_j are the incomes of individual i and j, while $i, j \in (1,2,...,n)$ and $\bar{y} = (1/n)\sum y_i$ is the arithmetic mean income (Litchfield, J. A.,1999). The Gini coefficient varies from 0 to 1. The closer the Gini is to 1, the more is the inequality.

This research occupies the graphical method of calculating Gini for its excellent clarity.

The Gini coefficient was applied to measure the inequality of the potentially available water resources distribution over land in the globe. First, the 0.5 degree horizontal resolution, annual average river discharge data of a year was sorted into order on the basis of water available per unit area. For the calculation of grid areas, Eq. (1*b*) below was employed. Then the Lorenz curve was plotted, and the Gini was calculated. The Gini coefficients were calculated at 10 year intervals from 1970 to 2100, for both the TRIP-routed CCSM and MIROC data.

a) Grid area Calculation

The area of each 0.5 x 0.5 degree grid of the globe was calculated as follows, as the surface area between two latitudes Φ_1 and Φ_2 ($S_{(\Phi 1,\, \Phi 2)}$) (Oki, T. et. al., 1998), per 0.5 degree of longitude.

$$S(\phi_1, \phi_2) = \left[\frac{\pi a (1-e^2)}{360 e} \left(\frac{e \sin\phi}{2(1-e^2 \sin^2\phi)} \right) + \frac{1}{4} \ln \left| \frac{1+e\sin\phi}{1-e\sin\phi} \right| \right]_{\phi_1}^{\phi_2} \qquad (1b)$$

Here, the radius of earth, a= 6378.136 km, and the ellipticity of earth, e^2 =0.00669447. Along a longitude, grid areas maximize at the equator to 3077.229 km^2, and minimize near the north and south poles to 13.609 km^2.

(3) The Data Employed

The data set utilized is a 0.5 x 0.5 degree horizontal resolution gridded annual average river discharge data of the globe from 1970 to 2100, produced by the Institute of Industrial Science, University of Tokyo, using Total Runoff Integrating Pathways (TRIP). The data from the following GCMs were exploited for this study.

(1) CCSM3 of the National Centre for Atmospheric Research, Colorado.
(2) MIROC3.2 of the Institute of Industrial Science, University of Tokyo, Japan.

The future projections have been done under three SRES marker scenario A1B.

3. RESULTS AND DISCUSSION

All the distributions of potentially available water

Key words: River discharge, unequal spatial distribution, Gini, climate change
Tohoku University, 6-6-20 Aoba Aramaki, Aoba-Ku, Sendai 980-8579, Japan. Tel & Fax: +81-22-795-7458

resources from 1970 to 2100 show extremely unequal water availability situations, exhibiting Gini coefficients higher than 0.95. The Gini coefficients also increase toward 2100, although inequalities appear to be eased in the mid- 21st century (**Fig.1**). This observation complements the predicted, pronounced occurrences of heavy and extreme events of precipitation and drought over the world (Parry, M.L. et. al., 2007).

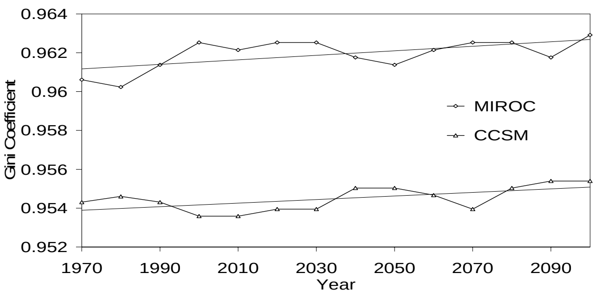

Fig. 1 The trends of global Gini coefficients in time.

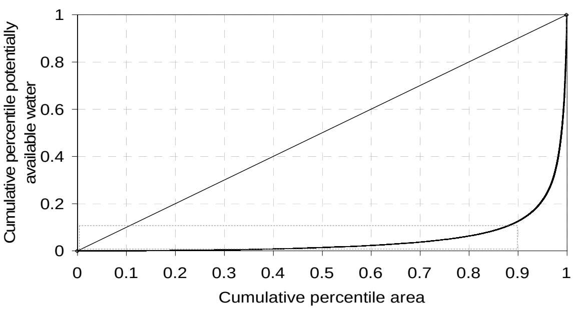

Fig. 2 The Lorenz curve for 1980 (CCSM data) potentially available water distribution.

The Lorenz curve also provides a clear picture of how the water resources are distributed over the land (**Fig.2**). The marked region of the Lorenz curve refers to the 90% of the land area, which is having only 10% of the total water available for potential use. The wetter regions possess about 90% of the world fresh water resources. The Lorenz curves for all the years analyzed exhibit approximately the same distribution. It is expected that climate change will worsen these conditions. The increasing Ginis of **Fig.1** provides evidence for this. In the Lorenz curve for 2100, regions of Canada, China, Southern Asia and North-Western USA are in the marked region of the curve. This agrees with other studies as IPCC showing high water scarcities in those regions.

(1) Sensitivity Analysis

The sensitivity of the Gini coefficient to the changes in the discharges is very low and does not possess a clear relationship. Consideration of all land area, inclusive of all the desert regions, and regions having year-through ice, which do not contribute in significant discharge, might have resulted in very high Gini coefficients. When those areas are neglected, it is expected that the Gini will significantly reduce, and the sensitivity of Gini will increase.

(2) Uncertainties

Uncertainties of the data could be accounted to the future scenarios used for projections. According to IPCC, the largest contributions of uncertainty in future river discharges are given by the variations between the climatic models used for the projections.

In this research, water fluxes which are used for human activities other than river discharge were not considered as potentially available water resources. If ground water resources also were considered, this study would be very comprehensive.

4. CONCLUSIONS

The inequalities in the river discharge distributions of the world were evaluated using the Gini coefficient from 1970 to 2100. The future projections of runoff had been done under the IPCC SRES scenario A1B.

The distributions of potential water availability from 1970 until 2100 exhibit very high inequalities of Gini coefficients more than 0.95. The results exhibit eased inequalities of water around 2050, even though the inequality increases towards 2100 in general. This result well agrees with other studies on fresh water resources such as IPCC. The examination of the Lorenz curves provides important information about the inequality of the water distributions for water management as well. On the average, a 90% of the land area lack fresh water, while the other 10% of the wetter regions enjoy 90% of the totally available fresh water. In the Lorenz curve for 2100, regions of Canada, China, Southern Asia and North-Western USA seem to have high inequality conditions.

The method of analysis of this research is expected to be developed further to relate inequality of water due to climate change to the resulting social inequity. The quantitative application of the index to inequality measurement of water resources was done in this phase of the study, and appears to be a success.

ACKNOWLEDGMENT: The authors would like to thank the Global Environment Research Fund (S-4) of Ministry of Environment, Japan, and the Mitsubishi UFJ Trust Scholarship Foundation, Japan, for their immeasurable assistance in this research.

REFERENCES

(1) Litchfield, J. A., Inequality: Methods and Tools, 1999.
(2) Oki, T., and Sud. Y. C., Design of Total Runoff Integrating Pathways (TRIP) - A global river channel network, *Earth Interactions*, Vol.2, Paper no. 1, 1998.
(3) Parry, M.L., Canziani, O. F., Palutikof, J. P., van der Linden and Hanson, C. E., Eds., et al, Climate Change 2007: Impacts, adaptation and vulnerability, contribution of Working Group II to the Fourth Assessment Report of the IPCC, Summary for policy makers, Assessment report of IPCC, Cambridge University Press, 2007.