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INEQUALITIES IN WATER RESOURCES DISTRIBUTIONS AND WATER RELATED CONFLICTS

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It is anticipated that climate change will exacerbate the present water scarcities and widen the gap between the “Have” and the “Have not” with respect to water resources. In this stage of the progressing research, inequalities in GCM simulated river discharge distributions of the globe were quantified using the Gini Coefficient, and they were related to the existing water related conflicts to produce a model map of present conflicting regions of the earth.

Inequalities of all the river discharge distributions exceed 0.95, with increasing trends towards 2100, under scenario A1B even though the total water is increasing as well. The relationship between these inequalities and the water conflicts proved worthy of being improved into a robust methodology to predict on the future of the conflicts, by modeling the African water conflicts in 1990 well. This methodology underway is aimed at mitigating social issues due to climate change.

Key Words **:** *River discharge, Gini Coefficient, inequality, water conflicts, climate change, global scale.*

1. INTRODUCTION

Developing and managing river water resources have been a sensitive issue for the riparian parties, even since our early civilizations. At our times with much diversified needs for water, this is considered as “The” foreign policy issue in the 21st century by policy managers[1)].

This is braced by the findings of climate change studies revealing grim realities of water availability in the future over the even present scarcity regions as Western USA and South America, Southern and Northern Africa, Southern Europe, and Western Asia[2,3)], and the high confidence anticipations of induced water scarcities in Central, South, South –East and East Asian countries due to population increases together with enhanced quality of life[4)]. The increased occurrences of extreme hydrological events as droughts will further exacerbate the prevailing inequalities in these water availabilities. The Nile, Jordan River, and the Indus are only a few of which are centers for high tensions amongst the shared states even at present over sharing the waters. Even though early conflict researches saw internationally shared rivers as being capable of invoking enough social tensions even as to get matured into water wars[5)], by the present research they are seen as driving forces of social tension which may surface often as ethnic or related conflicts rather than as water wars, or as factors leading to cooperation[6,7)].

In resource conflict research, “Conflict” is defined as the clashing of interests over national values of some duration and magnitude between at least two parties which are determined to pursue their interests and achieve their goals[8)]. In water-related conflicts, the shared water resources befit the “National values”.

Only river water is considered in this research, as river abstractions consist of about 80 percent of all freshwater abstractions in the world [9)]. Having put aside the major ground water dependant regions;

Mexico, the Middle-East and within India, the other regions over the world are expected to be explained well enough for the global scale.

Although our pasts are considered as knowledge banks for the conclusions and decisions on conflicts, their driving factors, and resolution methods, this is a time researchers have begun to question their data sets to arrive into conclusions on future development especially of the existing water-related conflicts[6], due to the expected abruptness of the climate responses to global warming. This research's main focus is to explore the effects of climate change to the escalation of water related conflicts. Gleick[7] have suggested four collaborative indices of water resources vulnerability, namely the ratio of water demand to supply, per capita water availability, dependence on imported surface water and hydroelectric production (As a percentage of total electric production). Nevertheless, a country's decisions over its dependence on hydroelectricity are not possible to foretell in longer time lines under swift changes in water resource availabilities. Moreover, the dependence on imported water supplies doesn't clearly address the relative position of a country in the basin, with respect to its water needs, or the "equitable use" of water. Therefore, this research attempts to progress towards a methodology of identifying future conflict prone regions due to climate change. Under this phase of the research, the potentiality of the water resources and the inequalities in their distributions to explain water related conflicts in the past (1990), and the extent to which they could be articulated are being tested.

2. METHOD

The inequalities of potentially utilizable water resources of the world, assumed as river discharges were quantified using the Gini Coefficient (Gini, C., 1912)[10]. Their trends with time under climate change were observed. The river discharge data used were simulated annual average river discharges of the globe.

Next, the inequalities in water resources distributions were tested for its importance in water resources management, as a probable indicator for water related conflict prone regions, in a global scale. Moreover, its capacity and weaknesses were identified, for future development of this research.

(1) Measuring inequality in water distributions

The Gini Coefficient[10] serves as the tool to measure inequality in river discharge distributions over space. This method was elaborated in Gunasekara, N. K., et. al., 2009[11]. The use of Gini

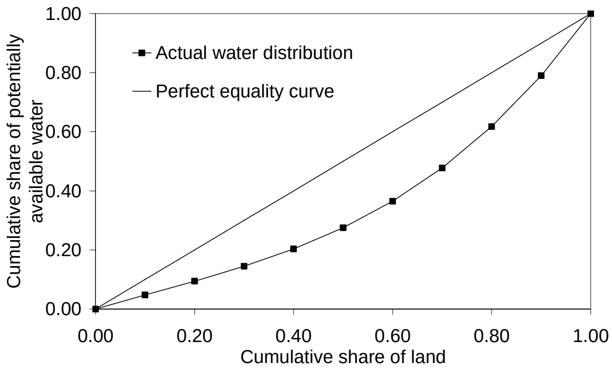

Fig.1 Inequality measurement of water resources distributions using the Gini Coefficient

Coefficient in this research is as follows:

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

Here, n is the number of individual grids in the sample, y_i and y_j are the discharges out of individual grids i and j, while $i, j \in (1,2,...,n)$ and $\overline{y} = (1/n)\sum y_i$ is the arithmetic mean discharge.

The data utilized were 0.5^o x 0.5^o gridded average annual river discharges of the globe. The discharge out of a grid was averaged to take the discharge of 1 km^2 for that grid. This unit area is being considered as *i* or *j* here. For this purpose, the 0.5^o x 0.5^o grid areas were calculated as the surface area between two latitudes Φ_1 and Φ_2 per 0.5 degrees of longitude[11].

The **Fig. 1** clearly shows the perfect equality curve, and a general Lorenz curve for an actual inequality situation (An example for a curve that could be seen practically). The minimum inequality is zero, when the water distributions are perfectly equal, which is practically a non-existent condition, and its maximum is when the Gini reaches unity.

(2) Assessing water-related conflict intensity

The reason for adopting a conflict intensity scale is that there is no other way to interpret conflicts. The basic and sole aim of this is to explain the strengths and weaknesses of the inequalities in water resources distributions in water management to explain, or model the existing water-related conflict areas around the world.

Two conflict intensity scales were reviewed; the Water Event Intensity Scale (Or the BAR scale)[12] and the conflict intensities of the Heidelberg Institute for International Conflict Research[8]. Both scales give random numbers for the conflict events, as well as for cooperation events, numbers increasing from -7 to +7 through zero, where minus means conflicts while plus means cooperation. The other scale considers only conflicts, from 1 to 5; 1

Table 1 The adopted international water conflict intensity scale.

Intensity	Event description
1.0	Formal declaration of war.
0.8	Political-military hostile actions.
0.5	Diplomatic-economic hostile actions.
0.3	Mild verbal expressions displaying discord in interaction.
0.2	The dispute tempting country not having any existing or historical water agreements / An adequately appropriate solution is not given by the existing agreements. Nevertheless, present actions display cooperation.
0.1	The tempted country not having any existing or historical water agreements / An adequately appropriate solution is not given by the existing agreements. Nevertheless, present actions display cooperation.
0.0	Neutral or non-significant acts for the inter-nation situation.

being "Latent conflict" and 5 being "War".

For this stage of the research, the "cooperation" portion of the scale was disregarded, considering the roughness of the applied scale – the global scale, and this application's aim. The below (**Table. 1**) scale was adopted for the research, by modifying the above said conflict scales.

Considered the water conflicts in the Mekong, or the Salween, even with prior water agreements, the problems in the basins in sharing water did not seem to have solved, although they do not belong even to the lowest possible conflict intensity groups of the above reviewed scales. The risks exist of the prevailing debates on sharing the resource to exacerbate in the future as well. Therefore, two more intensity groups were introduced (0.1 and 0.2), to overcome this.

3. DATA UTILIZED

(1) River discharge data

The data set utilized is a 0.5^o x 0.5^o horizontal resolution gridded annual average river discharge data of the globe, produced by the Institute of Industrial Science, University of Tokyo. The annual discharges have been produced by runoff inputs from the following five climatic models, routed by Total Runoff Integrating Pathways (TRIP).

- CCSM3
- MIROC3.2
- ECHAM5-OM
- CGCM2.3.2
- UKMO

Total Runoff Integrating Pathways (TRIP) is a global river routing scheme developed in University of Tokyo. The TRIP converts runoffs from the above General Circulation Models (GCMs) into river discharges[13)].

The discharge data includes annual average river discharges of the globe from 1970 to until 2100, of which future projections are done under three SRES marker scenarios of A1B, A2 and B1, from the year 2000, up to 2100.

(2) Water conflict event data

Transboundary Fresh Water Dispute Database[14)], a collection of news releases from 1948 to 2005, with news event summaries and their BAR (Basins at Risk) scales, was utilized to assign the conflict intensities to inter- country relations over water in internationally shared river basins, for the sample basins took for the primary analysis.

The year 1990 was focused for this analysis. The nearest past or future news event from the above database around 1990 was regarded relevant in the absence of such an event in 1990. Moreover only one news event was considered adequate enough to demonstrate the inter-relationship on sharing the international river of concern in that time.

Along with the above data, the template of major river basins on TRIP 0.5^o version and the National Identifier Grid GPWv3 (2.5' res.) of the Socioeconomic Data and Applications Center (SEDAC) were occupied to delineate the river discharge data to international river basins and countries as well, in the sample river basin analysis.

4. RESULTS AND DISCUSSION

(1) The global analysis of inequality in water resources distributions

The global potentially available water resources distributions, which were assumed to be the river discharges, were analyzed to examine the behaviors of their inequalities under climate change, towards

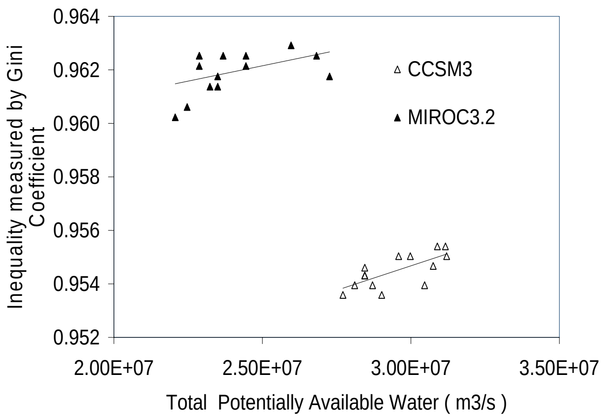

Fig.2 The variation of inequalities of water distributions with total available water for the earth towards 2100.

2100.

The discharges out of a 0.5°x0.5° grid could be considered as the water resources available for the potential use by the inhabitants of that grid. This definition stands for the potentially available water resources throughout this article.

The annual average river discharges from the two GCMs, CCSM3 and MIROC3.2 only were utilized for this analysis, future projections for the SRES A1B scenario. SRES A1B characterizes a future world with a rapid economic growth, population peaking around 2050, and a balanced consumption of fossil intensive and non-fossil intensive fuels, and with introduction of efficient technology as well.

The inequalities of global river discharge distributions measured by the Gini Coefficient were more than 0.95 and were increasing towards the year 2100. The GCMs, CCSM3 and MIROC3.2 agreed with the trends towards the end of the century, although they did not exactly match quantitatively. The total potentially available water for a year, which is the summation of discharges out of all land grids, was increasing towards 2100 as well, exhibiting the agreeing trends along with similar quantitative disparities between the two GCMs. The **Fig. 2** illustrates the aggregate result of the above two observations. The inconsistency between the two GCMs (0.0074 for Ginis and $5.5\text{x}10^6$ m^3/s for total potentially available water) seems to be larger than the variation ranges for the Ginis and for the total water as well. Nevertheless the differences in the Gini ranges (0.0027 for MIROC3.2 and 0.0018 for CCSM3) and those of total potentially available water ($5.1\text{x}10^6$ m^3/s for MIROC3.2 and $3.5\text{x}10^6$ m^3/s for CCSM3) fairly correspond, and their trends also match. Therefore, the results should be realistic, even with higher discrepancies among the two GCMs.

This result deems us to conclude that even though there will be plenty of water for human use

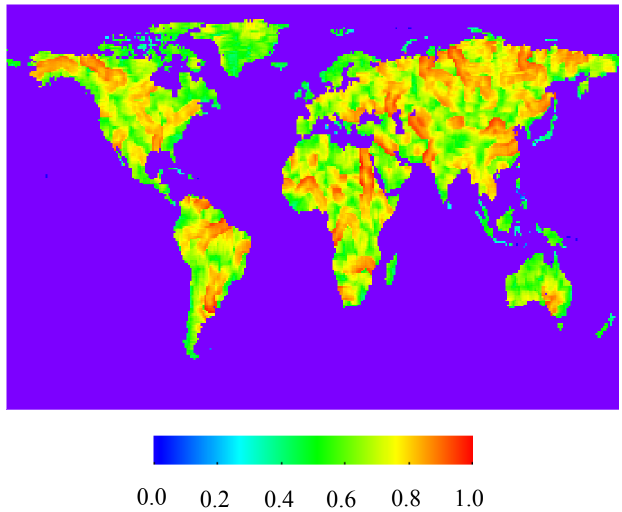

Fig.3 Inequalities of potentially available water in 1990 measured by Gini, varying from 0 to 1.

when considered the whole earth, their distribution will become more and more unequal. Therefore in the sense of water management in internationally shared river basins, worsened inequalities may dampen the cooperative management efforts.

This observation led the path to the next analysis of investigating on the relationship between water-related conflicts and the inequalities in river water distributions, and on its strength in water resources management.

(2) Inequalities in water resources and water related international conflicts

The relationship between international water related conflicts and the prevailing inequalities in water resources distributions were explored.

The year 1990 was selected for this analysis since the GCM performance is better after 1970 due to data availability, and by consideration of the other data as well. To minimize the possible errors induced by each GCM, the averages of the grid discharges were taken of all the five GCMs, CCSM3, MIROC3.2, ECHAM5-OM, CGCM2.3.2, and UKMO. As the year selected was 1990, the runoff simulations have been done under the present climate scenario, 20C3M.

The Gini Coefficients were calculated for 4.5° x 4.5° grids and were assigned to the middle 0.5° grid to produce an inequality map of the world for 1990 of horizontal resolution 0.5° (**Fig. 3**).

The inequalities of discharge distributions are higher along the rivers, along the Nile, the Indus, Ganges, the Amazon for example, than in dessert areas as Sahara, or in Central Australia. This is due to the natural concentration of water along the river valleys, and to the fact that, compared to the surroundings, the river itself contains a higher discharge; the inequality between the two places are

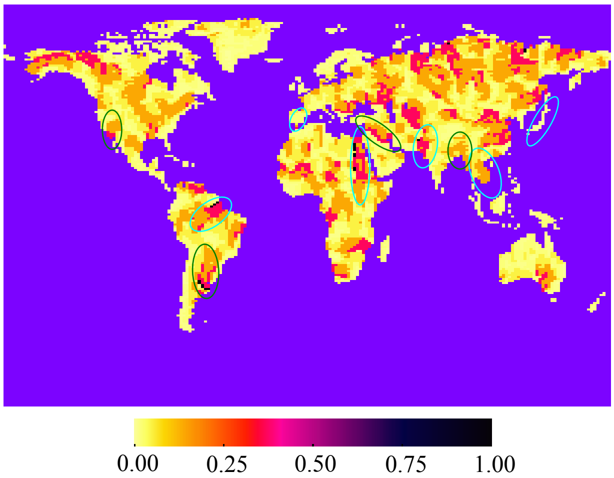

Fig.4 The Conflict Proneness Scale; varying from minimum 0 to maximum 1 (For year 1990).

high. But, if two regions on a dessert are concerned, the availability of water is almost comparable. Hence, those two regions do not exhibit higher inequalities.

It is also worthwhile to notice that all the islands do not exhibit any inequalities. This could be partly due to the fairly distributed precipitations caused by the effect of the surrounding oceans, and to some extent, it could be due to the inability of the chosen scale (4.5^{o} x 4.5^{o}) to convey such details as well.

This map was then employed to establish the relationship of the shown inequalities in water resources distributions with the water-related international conflicts. Only conflicts between nations or regions in internationally shared river basins were considered for this phase, as in different geographical scales as international, inter-provincial or inter-community, the base factors leading to conflicts, and therefore their treatment as well, should be different[15].

A sample of tensed international river basins, together with internationally sound basins and regions were chosen as to represent water availabilities adequately, to establish the relationship of water conflicts with inequality in water distributions. The Nile, Amazon, Guadiana, The Indus, Mekong and Japan were the chosen sample regions. The international water conflict intensities were judged according to the adopted conflict scale (**Table 1**), using basically only one water event from the Transboundary Fresh Water Dispute Database[14] on or around 1990.

This established relationship was then used to produce a conflict map for the year 1990, using the inequality map in **Fig. 3**. The conflict map is shown in **Fig. 4**.

This produced conflict scale will be referred to as the Conflict Proneness Scale hereafter in this text. It differs from a minimum of zero to a maximum of one. **Fig. 4** illustrates very high possibilities for international water conflicts in the Nile, Indus, Amazon, and The La Plata basins. It doesn't show higher conflict proneness in the Euphrates Tigris, Ganges, Colorado and Mekong basins, despite of the well-known[7] water conflicts in these basins. In addition, the low populated, northern most territories of North America (Alaska) and Russia are displaying comparatively high proneness for water conflicts. These observations correspond to the high and low inequalities in the inequality map (**Fig. 3**). The areas with highest inequality display the highest conflict possibilities, while low inequality areas are shown free of conflicts. Nevertheless, population is an important factor which decides the proneness of conflicts, although lacking in this stage of the study. The Middle East, Mexico and European countries also seem to be not explained well enough. If ground water resources were considered, these regions could have been modeled more accurately.

If focused only on the African continent in **Fig. 4**, in spite of all the above observations, the Nile, the Sahelian region, Zambezi and the small basins around it, Orange and Congo basins are shown complying with the conflict situations prevailing. This result well agrees with the observation of Ashton, P.[15], who found a solid correspondence of the distribution of perennial rivers to the conflicted or disputed or threatened regions (Not only water related conflicts) in Africa.

In the African continent, there exists a unique behavior in climatic factors and therefore of the population centers. Although the average annual rainfall across the continent lies far below that for the whole world (650mm and 860 mm respectively), runoff in the equatorial wet regions in Africa consists of above 30-40% of the mean annual rainfall, while for the northern and southern regions it is below 10% of the mean annual rainfall on a general view[15]. This along with the high temperatures may have made the populations to settle in wetter areas or along river banks as in the Nile resulting in coincided river discharge and population distributions in Africa. This partly explains the success of this conflict proneness index in Africa. This link is again verified by Stahl's[16] findings of hydroclimatologic factors and population density having a greater influence on water related international relations of more arid regions over the wetter climates.

5. CONCLUSIONS

The inequalities in spatial distribution of potentially available water resources, assumed as the annual average river discharges, were calculated using the Gini Coefficient to explore the variations due to climate change to the world water resources. TRIP routed annual average river discharges of CCSM3 and MIROC3.2 were exploited, under the scenario SRES A1B.

All the inequalities towards 2100 exhibited Ginis higher than 0.95, with increasing trends towards 2100 for both GCMs, even though the total available water is increasing towards 2100 as well. This deemed us to conclude that although more water will be available, they will be for wetter regions, and the drier regions will get drier, increasing the disparity of water availability.

Following the above observation, the relationship of these inequalities in water resources distributions with water related conflicts in internationally shared basins was investigated, to assess the significance of the inequalities to water resources management. 0.5^{o} horizontal resolution water resources inequality map of the Earth was produced employing average of the 5 GCMs, CCSM3, MIROC3.2, ECHAM5-OM, CGCM2.3.2, and UKMO for 1990. Along the major river basins as the Nile and Amazon, the inequalities were the highest. This is caused by the natural concentration of water in the river valleys. This map was occupied to establish the relationship of inequalities in water distributions with international water conflicts, by analyzing 6 sample regions. A global map illustrating the conflict prone regions was produced using the above relationship.

The water conflicted regions in the African continent was modeled well, although only natural river water distributions were the base for this modeling. This is due to the coinciding of the population centers with the river discharge distribution. The Nile was shown as the hottest region for water conflicts over the world. However, other regions as Mekong, Ganges and the Northern most regions of continents were poorly modeled. This proves the significance of the population to this analysis. The Middle East and Mexico, European countries also seem to be not explained well enough. If ground water resources were considered, these regions could have been modeled fairly well.

This methodology seems promising as to be improved into a powerful tool which enables the water resources mangers to look into the future of water related conflicts. Nonetheless, there exist limitations in the present stage, due to the dedication of the analysis only to the natural river discharges of the earth.

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