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Water conflict vulnerability of regions

NILUPUL GUNASEKARA[1] & SO KAZAMA[2]

1 *Graduate School of Environmental Studies, Tohoku University, 6-6-6 Aramaki, Aoba, Sendai 980-8579, Japan*
nilupul@kaigan.civil.tohoku.ac.jp

2 *Department of Civil Engineering, Tohoku University, 6-6-6 Aramaki, Aoba, Sendai 980-8579, Japan*

Abstract A combined decision tree and multivariate analysis was utilized, also incorporating countries' water availability and their adaptive capacity to increasing water scarcity. Five country groups having the lowest adaptive capacity indicated by GNI per capita less than 13 195 International Dollars, were capable of addressing the whole Asian, African and South American continents' conflict vulnerabilities. Vietnam and Cambodia in the Mekong basin and the five most downstream countries of the Nile basin proved to be vulnerable to future conflicts due to climate change and population increase.

Key words water conflict vulnerability; adaptive capacity; decision tree; multivariate analysis; climate change

INTRODUCTION

Unreliable water availabilities and increased occurrences of extreme events due to the changing climate pose a great threat of conflict ignition to countries sharing rivers and groundwater systems throughout the world. Population change itself incurs a far greater threat for these countries (Vorosmarty *et al.*, 2000). Development will lead to more diversified and increased water needs among the water use sectors worsening the water scarcities, as in Asia. An increased need for food production will incur the highest demand on the water resources (Falkenmark & Rockstrom, 2006; Rijsberman, 2006), consuming as much as 6800 km^3/year (Falkenmark & Rockstrom, 2006), even now around the world. All these factors increase the competition for the shared water resources. It is more likely that the gradual decrease of water quantity and quality will affect the internal instability of these countries rather than develop into a violent conflict (Wolf, 2007). Nevertheless, on the verge of climate change, especially regions with booming populations will face worsened water scarcities, increasing the possibility of water conflicts.

A lot of research supports the water resource root of conflicts. Stahl (2005) explores the influence of hydroclimatology and socioeconomic conditions on international relations on shared waters. She finds that the hydroclimatic variability, together with population density, is most influential on international relations in arid to sub-humid basins. The consideration of precipitation, rather than the waters directly accessible by people, has moved it far from the actual. A clear relationship has been found between conflicting areas and the spatial distribution of river channel network in Africa (Ashton, 2002). Hauge & Ellingsen (1998) provide by far the most statistically significant relationship between conflicts and natural resources, although it does not aim at international conflicts or water conflicts in particular. Our research utilizes a classification of countries by a decision tree approach in combination with a multivariate analysis. A contrasting identification of upstream and downstream countries' conflict vulnerabilities is provided by the methodology. It classifies the countries based on their dependency on groundwater, external water resource dependence, water availability per capita, GNI per capita, and the population growth rates in view of developing a methodology to identifying countries vulnerable to international water conflicts. These countries are then compared with the recorded conflict occurrences to validate the parameter choices. Policy relevance of these findings to reduce the vulnerability to conflicts is also discussed.

METHODOLOGY

Water conflicts usually possess an ill-defined structure which makes them hard to predict, influenced by environmental, social, cultural, economic and political factors. Therefore,

identifying all possible conflict sources and their interrelations is required (Loucks & van Beek, 2005). Nevertheless, based on the overwhelming evidence for resource roots of conflicts (Hauge & Ellingsen, 1998; Ashton, 2002; Stahl, 2005), we develop a methodology to identify conflict vulnerabilities of countries with different water availabilities and different adaptive capacities to tackle water scarcities.

Identification of countries vulnerable to water conflicts

Gleick (1993) developed four indices of water resource vulnerability of countries; annual withdrawals to supply, per capita water availability, dependence of external surface water and hydroelectric production. The explanatory they are, they fail to address the adaptive capacity of countries to face water scarcity. We overcome this issue by considering Gross National Income (GNI) per capita of countries as reflecting the capacity of countries to solve water related issues. The near future demand for water was accounted for by taking countries' population growth rates. Glieck's (1993) Annual water availability per capita per year and the dependency of external water resources were adapted to this research as well. Groundwater dependency of a country is being introduced as an indicator as well, as groundwater resources cannot be considered as a sustainable resource in the face of booming populations. Therefore, groundwater dependant countries tend to seek increased access to shared waters with another country.

FAO Aquastat 2005 database provided the water related data of 136 continental countries (nations sharing at least one border with another country) for the classification. For large aquifers like the Nubian aquifer shared by Tunisia, Algeria and Libya, the external groundwater flow has been utilized in calculating water resources originating outside the country. For other countries, only the shallow groundwater resources have been considered. Actual external water resources have been utilized in calculating external water resources, after accounting for the flow reserved by an upstream country with any existing water agreements. All values provide annual estimates. Population growth rates were obtained from the US Census Bureau and the GNI per capita were from the World Bank. All utilized data sets belong to the period 1998–2005. The conceptualization of conflict vulnerabilities are shown in Table 1.

First, multivariate analysis was conducted for the water resources per capita, GNI per capita and population growth rates of countries. All possible plots between the three variables were explored and five apparent groups could be identified in the water resources per capita to GNI per capita plot. Classification rules were developed from this plot. Population growth rates did not exhibit a clear pattern with any of the other two variables. The above identified groups were utilized for the clustering, to estimate the strength of the classification rules. Due to the high variances of data, statistical distances between the points were used for the classification.

Statistical distance $d(P, Q)$ between two points P and Q with coordinates $P(x_{1i}, x_{2i}, x_{3i})$ of group i and $Q(y_{1j}, y_{2j}, y_{3j})$ of group j belonging to multivariate parameters 1, 2 and 3 (here x and y are parameter values at P and Q, respectively) (Johnson & Wichern, 2007):

$$d(P,Q) = \sqrt{\frac{(x_{1i} - y_{1j})^2}{(s_{1i}.s_{1j})^{0.5}} + \frac{(x_{2i} - y_{2j})^2}{(s_{2i}.s_{2j})^{0.5}} + \frac{(x_{3i} - y_{3j})^2}{(s_{3i}.s_{3j})^{0.5}}} \quad (1)$$

where, s_{kl} is the sample variances of parameter k (k = 1, 2, 3) and of group l ($l = i,j$).

The clustering produced a good agreement with the classification rules developed (Table 2).

The two methods agreed with each other by more than 80% for all groups, with class 1 agreeing over 90%. The classes 4 and 5 could not be distinguished separately by the clustering using statistical distances. However, 80% of the elements of both classes could be identified as classified into one distance class. Then the classification of countries into conflict vulnerability groups was carried out using the decision tree first and second levels of groundwater dependency and external resources dependency, in combination with the multivariate groups as the third level of the decision tree (Table 1).

Table 1 Conceptualizing the influence of parameters to water conflicts.

Parameter	Water conflict vulnerability when the parameter is		Contribution to the classification
	High	Low	
Groundwater dependency >50%	High	Low	Decision tree first level
External resource dependency >30%	High	Low	Decision tree second level
Water resources per capita (m^3/year)	Low	High	Multivariate analysis
GNI per capita (PPP, International Dollars)	Low	High	Multivariate analysis
Population growth rates (%)	High	Low	Multivariate analysis

GNI is the Gross National Income measured in the purchasing power parity terms.

Table 2 Simple classification rules compared to multivariate analysis clustering.

Country classes by classification rules	Parameters		Agreement with the cluster analysis (%)
	Water resources per capita per year (m^3/year)	GNI per capita (PPP, International Dollars)	
1	< 17 610	< 13 195	91
2	< 17 610	> 13 195, <23 085	86
3	> 17 610	< 13 195	81
4	< 17 610	> 23 085	80
5	> 17 610	> 13 195	

Comparison of conflict vulnerabilities of countries with actual water conflicts

The 136 countries classified into the conflict vulnerability classes using the simple classification rules were compared with the present conflicting or conflicted countries. We adapted the definition of water conflicts of Ohlsson (2000) as when two countries who are sharing the same waters at the same time are involved in relations over water and are not cooperating to solve the problem. Non-cooperative international relations were taken as indicating water conflicts. The water event database of the Transboundary Fresh Water Dispute Database of Oregon State University was employed for the comparison. For a particular year of concern, all countries sharing an international river may not be involved in conflicting events or cooperative efforts. Therefore, the latest international relations were occupied from the period 1990–2000. Countries were again grouped into conflicting countries and countries with cooperation efforts. The shared groundwater aquifers could not be compared as those events are not adequately covered by this database.

RESULTS AND DISCUSSION

The water conflict vulnerability groups of countries indicated by our classification are shown in Fig. 1. Out of 136 countries taken for the classification, 108 belong to five major water conflict vulnerability groups. The most vulnerable among all the vulnerability groups is the groundwater dependency less than 50% and dependency on external water resources greater than 30%, and belonging to multivariate class 1, of which water availability per head and GNI per capita are both the lowest (LT50GT301). They are poor in water and the adaptive capacity to cope with the water scarcities. Hence they are the most vulnerable for water conflicts. The South Asian water conflicting basins; the Indus and the Ganges and the Nile basin conflict vulnerabilities could all be explained. Out of 10 Nile basin countries, four most downstream countries belong to this group. These are the most vulnerable countries to climate change, as even a subtle decrease in water availability could cost comparatively higher economic losses due to the high agricultural dependency of these countries.

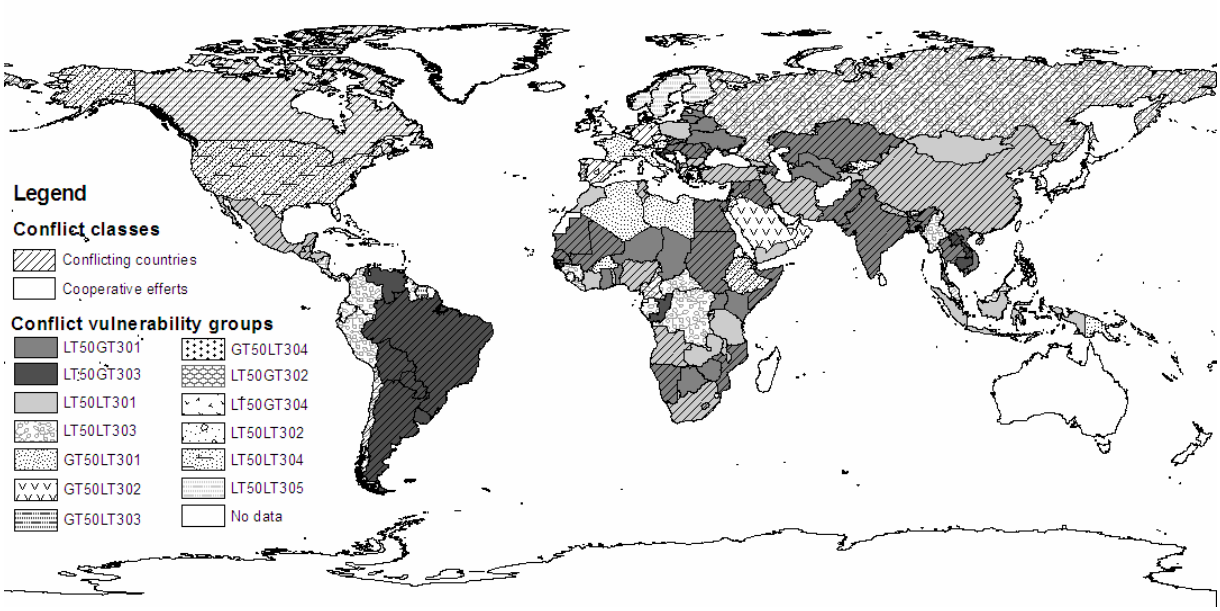

Fig. 1 Water conflict vulnerability country groups identified by our classification. The group codes follow this format; the first four letters; GT50 or LT50 stand for groundwater dependency greater than 50% and less than 50%, respectively. Next four letters; GT30 or LT30 are for external water resource dependency greater than 30% and less than 30%, respectively. The last digit (1–5) stands for the country class resulted by the multivariate analysis of water resources per capita per year, GNI per capita and population growth rates.

The next vulnerability group LT50GT303 only differs from LT50GT301 by their water availability. They have higher water availability, but the same range of adaptive capacity (GNI per capita PPP less than 13 195 International Dollars). These two groups are the most vulnerable to demand management conflicts (Ohlsson, 2000), related to water quantity and the inequity of its distribution.

The next vulnerabilities exist for the groups LT50LT301 and LT50LT303, both groundwater dependence and external water resources dependence do not pose a direct threat to the countries, as both are low. Nevertheless, they have low GNI per capita values, indicating low adaptive capacity against water related issues. Even though they show higher annual water availabilities per capita the spatial and temporal water distributions and water quality may be serious issues in these countries. As water availability is the highest in these countries, the neighbouring countries with low water availability (countries in LT50GT301 and LT50GT303) depend on the water resources from these countries. They might be expected to cooperate with the neighbouring countries' water development programmes. These countries are therefore having vulnerability to conflicts imposed by the surrounding countries. Nevertheless countries such as China, which are large in extent, could also possess additional vulnerabilities as they share borders with many countries. China might experience more water stress due to its population concentration in only some regions to the east (Fig. 2), and the agricultural dominance of the western and southern arid regions.

The least vulnerable of the five major country groups considered is the GT50LT301, of which member countries predominantly depend on groundwater resources, with a low dependence on external water resources. Nevertheless, these countries are economically less-capable. Therefore, when they aim for their development goals, they are likely to seek increased access to the external water resources from their neighbours. Of the nine states in this conflict vulnerability group, five are in the African continent, surrounded by the most vulnerable (LT50GT301, Fig. 1) countries to water conflicts. Therefore, these neighbour countries are unlikely to cooperate with them to solve their increased water needs. Therefore, any water resources decrease due to climate change and the population stress will most likely increase the instability of these countries, making them more vulnerable to internal conflicts such as ethnic conflicts.

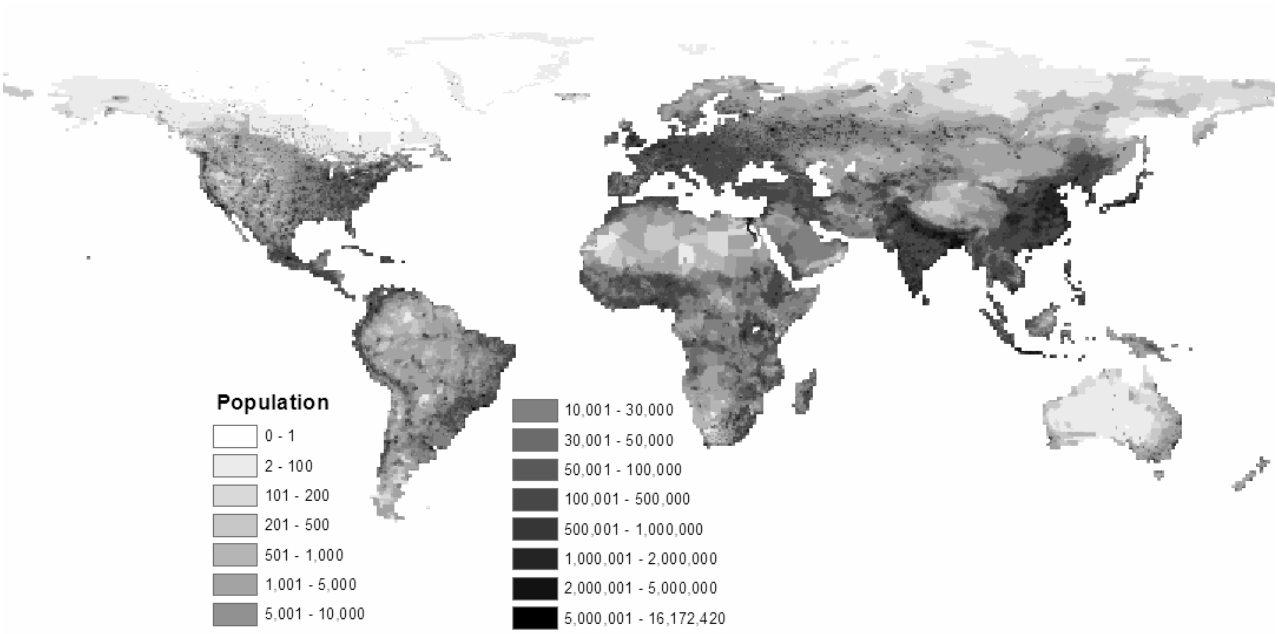

Fig. 2 Population distribution of the year 2000 of horizontal resolution 0.5° (data courtesy CIESIN).

Having discussed these five major conflict vulnerability regions, all the African, Asian and South American water conflicts could be discussed.

If we focus on the Nile basin again, Ethiopia, surrounded by the most conflict-vulnerable countries in the basin, Sudan, Uganda and Kenya, is likely to reply to climate changes and population increases by ethnic conflict, which in turn cripples the social and economic systems of a country. This fact stands true for Burkina Faso (western Africa) sharing the Volta basin. Even though Rwanda (central Africa) could be vulnerable to conflicts due to the immediate downstream nation Uganda, other external water resource options exist upstream, e.g. Burundi. In southern Africa, the downstream countries sharing the Orange and Zambezi basins (Namibia, Botswana, Zimbabwe and Mozambique) are also vulnerable. Two of them are at present in conflict. The whole African continent exhibits a very high vulnerability for water conflicts due to climate change and population change.

The Mekong in southeast Asia is shared by China and Myanmar as the most upstream countries (Fig. 1). The downstream Laos, Cambodia (LT50GT303) and Thailand, Vietnam (LT50GT301) possess very high vulnerabilities for conflicts due to both water quantity and water quality in particular. All these basin countries are of the lowest GNI per capita class (1 and 3); therefore adaptive capacity to water scarcities is also minimal. Therefore this basin could be considered a hot spot for future water conflicts. Having two of the four downstream nations in conflict, the other two (Vietnam and Cambodia) also tend to renounce their cooperative efforts.

The South American continent is gifted with water resources compared to the other continents, having per capita water availabilities above 17 610 m^3/year. The upstream countries of Ecuador, Peru and Colombia are heavily populated (Fig. 2). Therefore, water quality issues could dominate rather than water quantity problems in these basins. Furthermore, their adaptive capacity to water scarcity is lower (GNI per capita lower than 13 195 International Dollars, PPP). Therefore, with further increases in population and development, these countries possess a similar threat of water conflict occurrences, although compared with south and southeast Asia, it is low.

European countries especially possess a high adaptive capacity indicated by a GNI per capita higher than 13 195 International Dollars (Spain and Portugal) and most other countries are rich in water resources and the adaptive capacity. Nevertheless, the population and its density are equally high over the whole of Europe (Fig. 2). Furthermore, a further population increase could be

considered slower than in Asian and African situations. Therefore, the existing development and industries are particularly vulnerable to climate change. Nevertheless, cooperative efforts govern Europe. The bordering countries of Europe and the countries sharing the Aral Sea basin, most of which were newly emerged after the collapse of the USSR, are highly vulnerable to conflicts as population pressure and low adaptive capacity are dominant in these basin countries.

The Jordan basin countries, Israel, Syria, Turkey and Jordan possess very high vulnerability to conflicts, being one of the conflicts considered as having water resource roots. Nevertheless Israel's groundwater dependency has not been adequately incorporated in the FAO Aquastat database. Therefore, Israel's conflict vulnerability has been under-grouped. Also, the conflict vulnerabilities of USA and Canada could not be discussed, as they are very large countries with high variations in population distributions (Fig. 2), even though they are capable of adaptation measures (GNI per capita higher than 13 195 International Dollars, PPP).

The comparison of these conflict vulnerability groups with actual conflict accounts (Table 3) reveals a fair agreement with each other, considering the complexity of water conflicts. Countries with low adaptive capacity indicated by GNI per capita (PPP) of less than 13 195 International Dollars in combination with high (>50%) external water resources dependencies show increased vulnerability for water conflicts.

Table 3 Conflict vulnerability groups compared with actual water conflict occurrences.

Vulnerability group	Total number of countries	Percent of conflicting countries (%)
LT50GT301	37	54
LT50GT303	11	55
LT50LT301	31	48
LT50LT303	19	21
GT50LT301	10	30

CONCLUSIONS

Countries' vulnerability to water conflicts was identified by a combined decision tree and multivariate analysis approach of classifying countries. Groundwater dependency, external resources dependency, annual water availability per capita, GNI per capita (PPP) and the population growth rates were employed for the classification. GNI per capita was assumed to indicate a country's adaptive capacity to water scarcity due to climate change and population increase. Consideration of shallow groundwater resources, and accounting the external groundwater flow in the Nubian aquifer was made possible by the FAO Aquastat database. Within the 136 countries classified, only 116 countries of the classification could be confirmed, with a comparison to present conflict occurrences. The two highest conflict vulnerability groups, with countries of low groundwater dependency (<50%) and high external water dependency (>30%) together with the lowest adaptive capacity (GNI per capita < 13 195 International Dollars, PPP) were classified with above 54% accuracy. The five vulnerability groups have a total ability to address water conflicts in south and southeast Asia, Africa and South America.

The most vulnerable to future water conflicts are the Mekong basin countries, with a possibility of both water quantity and water quality issues. In the African continent, five out of the 10 Nile basin countries are critically vulnerable to water conflicts.

The countries grouped into the most vulnerable two groups do not possess many water resources options from their neighbouring countries, even though virtual water import as a solution for booming food needs has a capacity to reduce the conflict vulnerabilities of these countries. Nevertheless, these developing countries having the highest demands for food are only being traded with 5–10% of the world food production (Falkenmark & Rockstrom, 2006). Therefore, international food trade opportunities should be more open for these countries.

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