The impacts of climate and population change on water conflicts estimated by the inequalities in water resource distributions

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論文内容要旨

The rationale of this research is to assess the vulnerability and impacts of climate change and population change to the society. The social impact of climate change considered under this study is the increasing risk of water conflicts. The future vulnerability to the increased risk of water conflicts under climate change was assessed in terms of sensitivity and adaptability of countries to the risk of water conflicts. As employed in this research, a water conflict is a conflict which necessarily has its root causes in water related issues. However, the use of the term "Conflict" ranges from the situation commonly referred to as an argument, also to armed situations as well.

Water availability was assumed as the simulated annual average river discharges of horizontal resolution 0.5 degrees, which is the potentially available water for the use by the population in the 0.5 degree grid. Data were obtained from the University of Tokyo, from the Total Runoff Integrating Pathways (TRIP) global river routing scheme under four climate scenarios, 20c3m for the present climate until 1999, and for future scenarios A1b, B1 and A2 until 2100, under four GCMs: CCSM3, MIROC3.2, CGCM2.3.2 and UKMO. The countries with different adaptabilities to the increased risk of water conflicts were first identified using a classification method (Table 1), which considers economic, social and physical parameters other than simple water availability directly affected by climate change.

Table 1 The employed classification to identify different adaptabilities of countries to the increased risk of water conflicts

Classification parameter	Water Availability per Capita	Economic Capacity (GNI /ppp)	Population Trends (Growth rates)	External Resources Dependability	Ground Water Dependability
Classification level	1st level (Multivariate classification)			2nd level	3rd level
Data source	FAO Aquastat	World Bank	World Bank	FAO Aquastat	FAO Aquastat

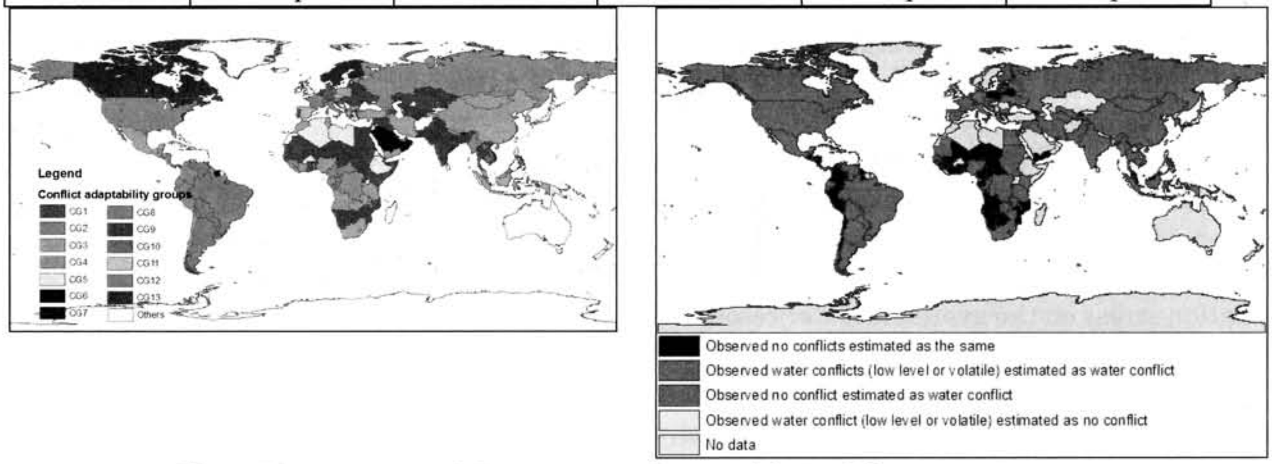


Fig. 2 The accuracy of the water conflict models in different regions.

Within these conflict adaptability country groups, the inter-relation of water availability and the inequality of the water resources distribution, which are factors directly affected by climate change with the probability of water conflicts was investigated. Water conflicts models were derived and were validated for each water conflict adaptability country group, aiming to estimate the probability of water conflicts and the change in the likelihood of water conflicts

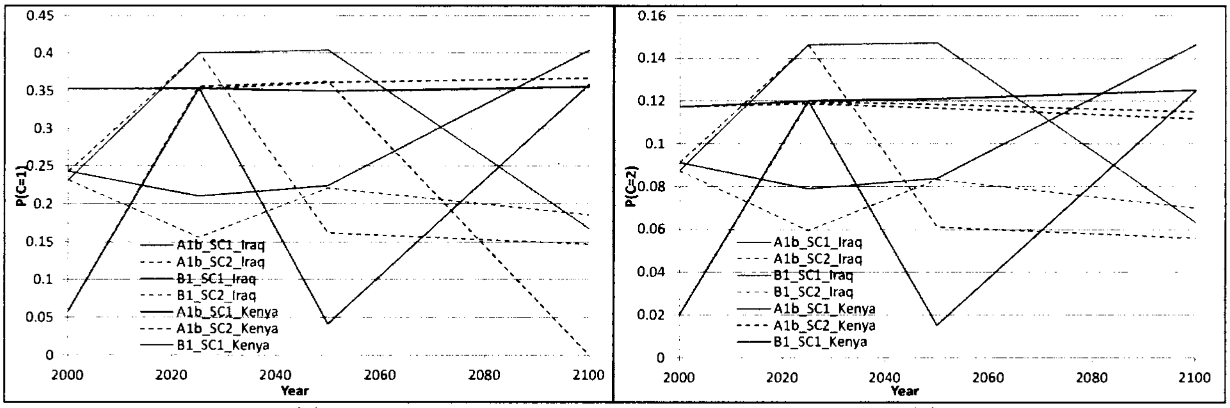
thereby, because of climate change. Utilizing the validated water conflict models, the future vulnerabilities of countries to the increased risk of water conflicts were estimated. The plausibility of the results was confirmed across scenarios and in confirmation with the IPCC terminology for the classification of likelihood of an event.

Within the 136 countries classified, only 116 countries of the classification could be confirmed, with a comparison to present conflict occurrences. Thirteen water conflict adaptability groups were identified (**Fig. 1**). The two highest conflict adaptability 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 adaptability groups with lowest water conflict adaptability have a total ability to address water conflicts in south and Southeast Asia, Africa and South America. Inside the country groups similar in adaptability to the increased risk of water conflicts, the inter-relation of per capita water resources of a country and the inequality in distribution of the resource was explored. Conflict model derivation was conducted for 1990, and validation was conducted for the year 2000. Country groups with the lowest adaptability to water conflict incidence, the CG1, CG2, CG3 and CG4 groups, showed significant associations with model coefficients for Logit regressions on the near-future water-conflict indicators 5-year conflict and 5-year conflict risk. Inequality in per capita water distributions was highly associated with these two water-conflict variables. Country groups classified as having both the lowest economic capacity (per capita GNI (ppp) lower than 13195 International Dollars) and the lowest per capita water availability (CG1 and CG3) showed an increasing probability of low-level and volatile water conflicts with increasing inequalities. Inequalities were highly significant in estimating volatile water conflicts in these two adaptability groups, whereas the odds of low-level conflict incidence were higher than those for the incidence of volatile water conflict. In indicating the incidence of water conflicts, the interactive country groups CG10, CG11 and CG12 were the best modeled (**Fig. 1** and **Fig. 2**), with an overall accuracy of 85.7% and a false-negative rate of 0.0%, whereas CG2 had the most modeling errors (a false-negative rate of 66.7% and a false-positive rate of 87.5%). However, CG2 produced an overall accuracy of 74.0%. The overall modeling of the incidence of water conflicts had an accuracy of 54.1% along with a false-positive rate of 34.0% and a false-negative rate of 11.9%.

The sensitivity of the countries utilized for the classification to the parameters governing the water conflict models were explored next. The effectiveness of population policy to reduce the stress on per capita water was also explored. The risk of low-level water conflicts is more sensitive to the population changes than the risk of volatile water conflicts (**Fig. 3**). In reducing the population stress on the available water resources, population policy was proposed as a low-regret adaptation measure in the study. The fertility-reduction policy assumed (SC2) was very effective in reducing water stress in the countries suffering from water scarcity. They were effective in reducing the area stressed inside countries as well. By reducing the population stress on the available water resources, the risk of water conflicts, especially the risk of low-level water conflicts can be reduced (examples shown in **Fig. 4** for Iraq and Kenya). The sensitivity of the countries to climate change impacts on water resources is lower than the sensitivity to population stress.

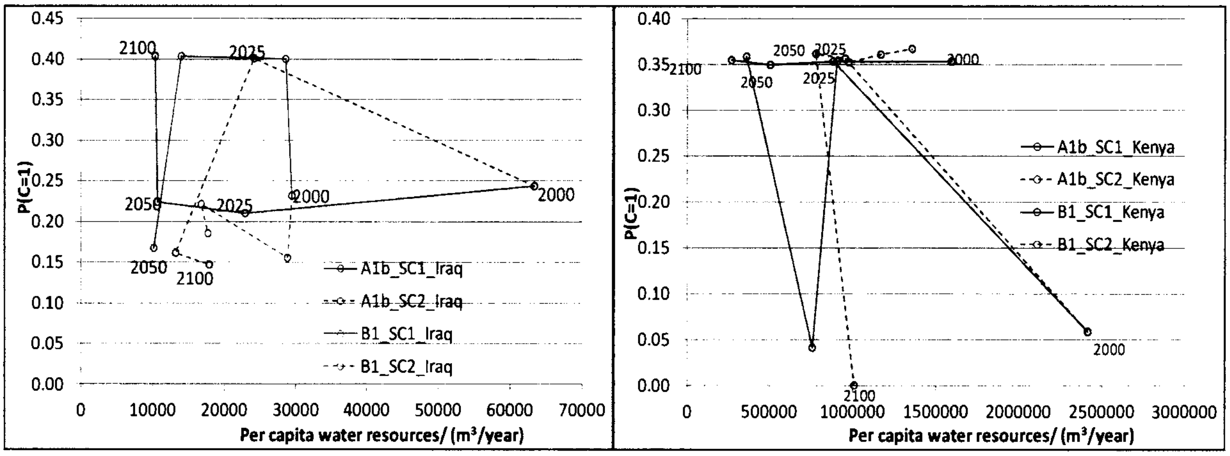
By combining the adaptability of countries and the sensitivity to climate change impacts on water resources, the future vulnerability of countries to the increased risk of water conflicts resulted by climate change was assessed. The plausibility of the future vulnerability estimates were assured by using the standard likelihood classification of the IPCC and by seeking confirmation in all scenarios used: A1b, B1 and A2. Volatile water conflicts are virtually certain for Indonesia, and for Angola, they are very likely to virtually certain to occur from 200-2100, under all the considered climate scenarios: A1b, B1 and A2. Nevertheless, for China, climate change increases the likelihood of volatile water conflicts significantly, from about as likely as not in the year 2000, to virtually certain in the year 2100, under all the three climate scenarios. Low-level water conflicts are not estimated to be virtually certain in conformity with all the three scenarios, A1b, B1 and A2. However, for the Russian Federation, it is very likely under all the scenarios. For all the other countries, where low-level water conflicts are not unlikely (probability of conflict>33%), the likelihood stays below likely and does not increase more than under climate change. However, the estimations confirm across the scenarios very well. Nevertheless the water conflicts changing in intensity is not shown to be a possibility under the effects of climate change.

This research used a combined multivariate and decision tree approach to identify the countries similar in adaptability to the risk of water conflict. Within these adaptability groups, the influence of climate change in increasing the risk of water conflicts was investigated. The method proved effective in estimating the risk of volatile water conflicts in most countries, in South American and African countries, the accuracy of models were low. However, the methodology used in the research will prove to have increased applicability with the improvement



(a) (b)

Fig. 3 (a) The variations of the risk of low-level (C5R=1, C5=1) and (b) the variations of the risk of volatile (C5R=2), for the water conflict adaptability country group CG1 under the climate scenarios A1b, B1. SC1 is the no-policy population scenario, while SC2 assumes population reduction policies resulting in uniform population growth rates across each country.



(a) (b)

Fig. 4 (a) The reductions in the risk of low-level water conflicts in Iraq and (b) the reductions in the risk of low-level water conflicts in Kenya resulted in by the applied population reduction policy scenario SC2, over the no-policy scenario SC1.

of global or regional ground water data bases and the improvement of runoff data considering reservoir operations as well. At present, the primary spatial scale considered in the research is the country level, which is the basic decision-making unit in terms of international relations over water. Therefore, the results could be readily utilized in the international river basin management. Even though at this level, the method has limited applicability in the finer spatial and temporal scales because of inadequate data, with finer data, the applicability increases.

The methodology utilized in this research employed the ground water dependency of a country as a local variable which enables the correct identification of outliers in regression analyses in water conflict research. It also utilizes the Gini Coefficient to indicate the inequality in the water resource distributions over the traditional comparative resource use employed by water conflict research. For climate impact assessments and climate modelers, the population scenarios used in the research provides an important feedback of considering societal adaptation to climate policy and the significance of population growth in assessing future vulnerability of water resources.

論文審査結果の要旨

人口増加に伴う社会環境変化と気候変動によって水資源の需要と供給の不安定が顕在化しており，将来の水紛争の増加が懸念されている．食糧問題との関連から水紛争が本格的な紛争に発展することも国際機関において危惧されている．このような背景から，本論文は，全球規模の様々なデータベースを利用して，水配分の不公平性と人口を地域毎に解析し，水紛争リスクを推定する手法を開発したものである．

第 1 章は序論である．

第 2 章は，全球規模の水の偏在性や水紛争に関する既往研究を収集し，本研究の独創性と新規性について言及している．

第 3 章では， 解析に利用した全球のデータセットについて説明している．

第 4 章では，地下水依存性，外部からの水の依存性，人口あたりの水資源量，経済発展度，人口増加率を用いて，世界各国を水紛争リスクによって 13 段階に分類した．108 か国が水紛争の高リスク 5 段階に位置し，そのうちの上位 3 段階の 48%の国に実際に水紛争が 1990 年から 2000 年に存在した．本章で得た成果は，水紛争のリスクを定量的に評価した初めての知見である．

第 5 章は，水紛争リスクを推定するモデルを開発した．モデルの中核として，水資源量，人口，一人あたり水資源量のジニ係数を変数として持つ様々な関数を 1990 年のデータを用いて検討を行い，logit 関数が最も優れていることを示した．2000 年のデータによってモデルの検証を行い，良好な結果を得た．全球の水紛争を水の観点から推定するモデルは過去になく，極めて重要な成果である．

第 6 章では，得られたモデルを用いて各国の水紛争に与える影響の感度分析を行った．その結果，最も水紛争のリスクが高く分類される国において，人口当たりの水資源が最も感度の高いことが理解された．最もリスクの高く分類される国においてジニ係数が 0.8 以上の場合は，将来に水紛争リスクが急激に上昇することが示された．これらの結果は，気候変動と人口変化について考察されており，世界の水資源の偏在性をもたらす要因を特定した．これは世界の安全保障上，重要な知見である．

第 7 章では 6 章を踏まえて，将来の気候モデルシナリオと人口変化シナリオを用いて，全球の将来の水紛争リスクの全球分布を示した．特に中国は将来の水紛争リスクが高く，ロシアは逆に低いと推定された．本章で得られた水紛争リスク地図は，将来の各地域の水紛争リスク情報を与えると同時に，各国の水資源計画と水資源管理の政策に指針を与えるものであり，極めて有用性の高い成果である．

第 8 章は結論である．

以上要するに本論文は，様々な社会環境と水文情報のデータを用いて全球の水紛争リスクを推定する手法を開発し，将来シナリオによって将来の水紛争リスク分布図を示すことに成功した．本手法の成果は，世界各国の水資源計画立案と将来の水資源管理に大きく貢献できる成果である．

よって，本論文は博士（環境科学）の学位論文として合格と認める．