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An Analysis of Water Security under Climate Change

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Summary

Water is a multidimensional issue, involving water availability, access to freshwater, spatial and temporal distribution of resources, competition among its uses, ecosystems conservation, climate-related disasters and risks and several other aspects. The water security approach manages such complexity and proposes a comprehensive view of human security in relation to the water-related issues. Consequently, the solutions developed in order to face this multi-faceted concept should reflect its thorough vision. The aim of the present work is to investigate the relationship between climate change and water security. Exploring such a relationship is truly important in order to help policy-makers in the development of adaptation and mitigation strategies. In the water context, this challenge is further complicated by the possible conflicts arising between climate and water policies. In order to carry out such an analysis, an indicator measuring water security, namely the Water Security Index, is created. In the present work, climate change is considered from four different perspectives but, as revealed by the econometric results, it always has a predominant (negative) effect on water security.

Keywords: Water Security, Climate Change, Water Security Index, Econometrics, Maps

JEL Classification: Q25, Q53, Q54, O13

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1. Introduction

Water is the element that allows life to begin and is essential for the survival of human beings and all other animal and vegetable species. On a global scale there is enough water, the main problem is how it is managed; however, the global average is not so relevant because the world's water is comparable to the world's wealth: "globally, there is more than enough to go around: the problem is that some countries get a lot more than others" (Human Development Report, 2006).

Indeed, most of the water-abundant countries often waste, misuse and overuse it (e.g. in rich countries, it is often used to water golf courses or to fill swimming pools). At the same time, there are many arid countries in which water is not even available to satisfy the drinking necessity of the whole population.

Water scarcity is firstly a poverty issue: about 1.2 billion people live in areas of physical water scarcity and it is estimated that in 2025, 1.8 billion people will live in a situation of absolute scarcity (UN Water, 2007).

Moreover, from 2010 to 2100, the population increase in the world is expected to be about 3 billion, of which 2.5 billion will be in Africa (FAO, 2012), hence enormously increasing pressure on water resources in the most arid continent of the world. Thus, "there is no development without water, but there is not enough water for development" (World Water Council, 2012).

Water is a multidimensional issue, involving water availability, access to freshwater, spatial and temporal distribution of resources, competition among its uses, ecosystems conservation, climate-related disasters and risks and several other aspects. The water security approach manages such complexity and proposes a comprehensive view of human security in relation to the water-related issues. Consequently, the solutions developed in order to face this multi-faceted concept should reflect its thorough vision.

The aim of the present work is to investigate the relationship between climate change and water security. Exploring such a relationship is truly important in order to help policy-makers in the development of adaptation and mitigation strategies which, in the water context, is further complicated by the fact that these two sets of options can sometimes conflict with water-related policies. This is the case, for instance, of hydropower generation: according to the International Energy Agency's projections more than 75% of the increase in energy use by 2030 will be met through fossil fuels (IEA, 2009). Consequently, the exacerbation of global warming will worsen water scarcity and affect food production. After 2030, hydropower generation is expected to increase sharply all over the world (IEA, 2009), but still more freshwater will be needed. Thus, if, on the one hand, hydropower generation is undoubtedly a valid mitigation option, on the other hand, it creates competition in water use, reducing its availability for adaptation purposes too. However, it is not only hydropower generation to look less sustainable when considered together with the water issue: for example, national policies aiming at reducing vehicle emissions designed incentives to promote biofuels. But the production of these fuels constitutes an unsustainable trade-off with respect to both water consumption and land use, since fields are converted to produce biofuels rather than food crops, demanding a much larger amount of water.

The present work is structured as follows: in the next section a brief literature review is presented; section 3 presents the concept of water security and its socioeconomic implications; section 4 deals with data, methodology and the related results obtained; finally, section 5 describes the implication of the results in the conclusion.

2. Literature review

The main reasons why economics studies water are its physical scarcity and absence of substitutes. Economics is of critical importance in studying water as it can determine the allocation of the resource, both in efficiency (Shaw, 2005; Allan, 1998; Dinar & Tsur, 1995) and in equity terms (Veiga da Cunha, 2009; Perry et al., 1997; Perry, 2007; Seckler, 1996; Boelens & Vos, 2011). This issue raises the question of which kind of good water should be considered, and consequently which institutions should provide it. This aspect is very controversial and gave rise to a broad debate: in 1992, the *UN conference on Water and Environment*, held in Dublin, adopted the so-called *Dublin Statement*, which recognized water as an economic good. This implies the assignment of a price to water reflecting its scarcity and inducing to an efficient use of the resource. Nevertheless, water is not an economic good as many others (Veiga da Cunha, 2009), as it is essential, finite and non-substitutable: for these reasons, considering water as a pure private good, driven by free market forces, totally ignores the distribution of income in society, in which the rich will be able to acquire more water than the poor, even though it is a basic need for everyone (Perry et al., 1997; Veiga da Cunha, 2009).

On the other hand, the first principle of the 1992 Rio Declaration, which supplemented the Dublin Statement, implies that water is not only an economic good but also a social good (United Nations, 1992): it follows that humans are entitled to at least a minimum level of water, in terms of both quantity and quality, and from the point of view of both environmental and productive uses, under the responsibility of their respective governments (Dinar & Saleth, 2005). What is less clear is how to balance water management as an economic and a social good (Gleick et al., 2002).

Many authors consider water as a social good, arguing that it should be priced at well below market price, or subsidized, as it provides numerous ecological and environmental benefits, which everyone can take advantage of (Perry et al., 1997). In addition, a greater availability of water for certain groups favours social well-being at both individual and collective levels, while the consideration of water as a private good maximizes its value only for a certain group or region (Veiga da Cunha, 2009).

Nevertheless, there are some extreme conditions (such as during a drought or in a situation of extreme scarcity, when people are dying of thirst, and the marginal utility of water is approximately infinite), in which water, like other basic needs, is no longer an economic good, as there are no alternative uses anymore and the only remaining choice is to drink or die (Perry et al., 1997). For this reason, in recent times, access to water is being considered by many as a human right. According to Perry et al. (1997), water can be a basic human need, a merit good, or a pure private good, depending upon the quantities supplied to individuals, and consequently changes the authority which has to provide it.

Moreover, because of the delay, in the past, in acknowledging the consequences of a limited water supply and in decoupling economic development from water demand and supply, our growth model is now water-dependent (Dinar, 2012): as a matter of fact, business as usual scenarios reveal that economic growth both in developed and transition economies tends to increase water use.

Other issues concern conservation of natural resources and sustainability, as water is of critical importance to many ecosystem functions, and our decisions to withdraw water for particular uses can have relevant impacts on other uses now and in the future (Anand, 2007). Thus, economics can help in the study of water, as it determines both the dynamic allocation of the resource in several time periods and the existing level of water quality and quantity that needs to be purified from pollution originating from economic activities, keeping in consideration the cost of doing so.

In this context, global phenomena such as population growth and climate change will further exacerbate pressure on water resources, especially in dry countries. Indeed, climate, freshwater, environment and socio-economic conditions are all interconnected complex systems, thus a change in one of these systems generates a change in the others.

For a long time, water managers have assumed that the water resource base is mainly constant over time and, consequently, that past experience in water demand trend and management provides a reliable guide to future conditions. However, climate change trials this assumption and generates uncertainty in future water conditions, posing new challenges to water managers and making the achievement of water security reasonably more costly (IPCC,2008).

Water infrastructure and patterns of water use are shaped and developed in the context of past and current conditions (IPCC, 2008): any substantial change in water availability or in the frequency and intensity of floods and droughts will demand an adjustment that will allegedly be costly and have an impact both on society and on the environment (Miller et al., 1997).

Agriculture is by far the sector most harmed by climate variability, as water plays a crucial role in crop yields all over the world: more than 80% of food production comes from rain-fed agriculture, which forcefully depends critically on the spatial and temporal distribution of precipitation; the remaining 20% needs water as well for irrigation (IPCC, 2008). The primary sector, in developing countries, frequently suffers from historically low levels of investment in technology and weak institutions, thus the means to cope with climate change effects are often lacking (WEFWI, 2011).

The industrial sector, on the other hand, is usually considered to be less vulnerable to climate change, but there are some exceptions, such as industrial plants located in exposed areas and facilities dependent on climate-sensitive commodities (Ruth et al., 2004).

3. The concept of Water Security

The concept of water security has been gaining growing attention across various disciplines, ranging from natural to social sciences, in the past decade. Consequently, several definitions and approaches have been adopted by policy makers, scholars and international organizations such as UNESCO’s Institute for Water Education and Asia-Pacific Water Forum. The tendency to employ the water security concept to address water-related issues is contributing to foster the debate around this emerging paradigm.

The definition chosen in order to develop the present work is that of UN Water, the inter-agency of the United Nations which deals with freshwater issues, that defines water security as “the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability” (UN-Water, 2013).

From the above definition, the complexity and multidimensionality of the concept appears immediately evident, as it involves several intertwined fields of study. Four main dimensions of water security emerge from this definition: the first is, of course, the physical availability of water resources, which is a prerequisite for all the others; the second extremely important dimension is the population’s present and future physical and economic access to safe drinking water; the third dimension is the freshwater quality issue, which is strictly related to the ecosystem conservation; last but not least is the vulnerability to climate-related disasters and risks.

It is no doubt true that the concept of risk is extremely important in such a context, since the challenge is to achieve water *security:* the lack of any of the dimensions mentioned earlier represents a security risk for human livelihood and existence. Thus, a failure in achieving water security may have several adverse impacts on societies, representing a huge hindrance to development and growth. Among these harmful effects are food insecurity, health issues, conflicts over control of water resources, migrations, land grabbing, lost social and economic opportunities, loss of biodiversity and ecosystem degradation.

4. Methodology

From a methodological perspective, this work presents both a qualitative and quantitative analysis, which are carried out through several steps: firstly, the construction of a composite indicator measuring water security; secondly, the evaluation of the geographic distribution of water security and its dimensions, through GIS maps and a cluster analysis; finally, the regression models.

4.1. Dataset and variables

The dataset was built by combining data collected by several sources. The vast majority of these data comes from the World Development Indicators database by World Bank; the other databases exploited derive from the Climatic Research Unit (CRU) of University of East Anglia; the World Resource Institute; the Worldwide Governance Indicators by World Bank; the Socioeconomic Data and Application Center (SEDAC) by NASA.

Data used for the present work are aggregated at country level. The units considered for the econometric analysis are the 92 countries of the world for which all the necessary data were available, while for the map representation of the water security indicator and its four dimensions the countries examined are 189. Data are collected in an interval of years ranging between 2007 and 2014.

The independent variables can be divided in two categories: variables concerning climate change and control variables. Table 1 summarizes the independent variables chosen for the regression analysis:

Tab. 1: climate change variables and control variables

	Variables	Units of measurement	Data source	Variables names
Climate change variables	Daily mean temperature	C°	CRU University of East Anglia	temp
	Average annual precipitation	mm	CRU University of East Anglia	prec
	Flood occurrence	Ranges between 0 (low) and 5 (extremely high)	World Resource Institute	flood
	Drought severity	Ranges between 0 (low) and 5 (extremely high)	World Resource Institute	drought
Control Variables	Electricity production from hydroelectric sources	Kwh	WDI – World Bank	Hydropower
	Population density	People per km^2 of land area	WDI – World Bank	pop.dens
	Water productivity, total	Constant 2005 US$ GDP per m^3 of total freshwater withdrawal	WDI – World Bank	water.prod
	Political stability and absence of violence/terrorism	Ranges from -2,5 (weak) to 2,5 (strong)	WGI – World Bank	pol.stab
	Regulatory quality	Ranges from -2,5 (weak) to 2,5 (strong)	WGI – World Bank	reg.qual
	GDP per capita, PPP	Constant 2011 international $	WDI – World Bank	GDP.pcap
	Rural population	% of total population	WDI – World Bank	rur.pop
	Agricultural raw material imports	% of merchandise import	WDI – World Bank	agri.imp
	Agricultural raw material exports	% of merchandise export	WDI – World Bank	agri.exp
	Environmental Performance Index	Ranges between 0 and 100	SEDAC - NASA	EPI
	Agricultural land	% of land area	WDI – World Bank	agri.land
	Fertilizer consumption	Kg per hectare of arable land	WDI – World Bank	fert.cons
	Terrestrial and marine protected areas	% of land area	WDI – World Bank	prot.areas
	Industry, value added	% of GDP	WDI – World Bank	industry

4.2. An indicator measuring water security

In order to conduct both the qualitative and the quantitative analysis, I developed an indicator measuring water security, namely the Water Security Index (WSI), since a widely accepted indicator was lacking in the literature. The vast majority of the existing indicators does not include all the dimensions of the concept as indicated in the definition by the United Nations. Moreover, from different definitions and approaches, different scales of analysis descend and this contributes to make further distinctions among the existing indices and indicators. Indeed, in the development of the WSI a major concern was given by the scale of analysis, since the water realm is by nature heterogeneous, as variations in physical water availability and water quality often occur at basin level. Certainly, country-level indices may hide differences existing among regions, urban and rural populations and genders. However, considering the challenges it poses and how integrated these are, water security is by definition a national issue; consequently, a certain level of integration among policy makers and the engaged institutions is also requested to address it. Moreover, the choice of the scale of analysis is also constrained by data availability, which is far broader at country level rather than at basin level; in addition, for policy purposes, an index measured at national level allows comparisons among countries, forming a meaningful management tool.

The indicator proposed is an outcome indicator that includes the four dimensions of water security individuated by the United Nations, each corresponding to a variable of the indicator:

- *Water availability per capita*, expressed in cubic meters (data source: WDI database by World Bank);
- *Percentage of population with access to improved water source* (data source: WHO-UNICEF Joint Monitoring Programme);
- *Water Quality Index*, ranging between 0 and 100 (data source: UNEP GEMS/Water programme);
- *Water Score*, measuring freshwater vulnerability to climate change and ranging between 0 and 1 (data source: University of Notre Dame – Climate change adaptation program).

The variable *Water availability per capita* does not need to be explained, while a drinking-water source is improved if it is protected from outside contamination; it includes piped water on premises and other improved drinking water sources, such as public taps or standpipes, tube wells or boreholes, protected dug wells, protected springs and rainwater collection. With respect to the variable *Water Quality Index* (WQI), it is a proxy for both water quality and ecosystem conservation, as UNEP defines it as an “assessment of the overall quality of inland surface water resources as it relates to both human and aquatic ecosystem health”. Finally, the variable *Water Score* measures the vulnerability of a country’s fresh water supplies to climate change, and includes projected change of annual runoff, projected change of annual groundwater recharge, fresh water withdrawal rate, water dependency ratio and dam capacity.

The equation that links the variables is the generalized mean, used by Anand and Sen (1997) in the definition of the Human Poverty Index. The generic formula of the generalized mean is the following:

$$M_\alpha(x_1, \dots, x_n) = \left(\frac{1}{n} \sum_{i=1}^{n} x_i^\alpha\right)^{1/\alpha}$$

In the specific case with $\alpha=1$ the formula is that of a simple arithmetic mean: in this case, a high value of one component can be compensated by a low value of another component. On the opposite, the generalized mean with $\alpha>1$ allows to avoid compensation effects among the variables, thus letting unbalances emerge. The formula of the generalized mean with $\alpha=2$ has been used for the development of the Water Security Index. In order to obtain an indicator ranging between 0 and 100, some of the variables included in the WSI underwent some modifications, so as to range between 0 and 100. In addition, as for the variable *Water Score* a value of 0 corresponds to the minimum vulnerability level, while the value of 1 corresponds to its maximum level, in opposition to the rest of the variables considered and to the meaning of the overall indicator itself, I considered its complementary value. The final formula is the following:

$$WSI = \left[\tfrac{1}{4} (\text{water availability per capita}/\textstyle\sum \text{water availability per capita})^2 + \tfrac{1}{4}\, \text{access to water}^2 + \tfrac{1}{4}\, \text{water quality index}^2 + \tfrac{1}{4} (100 - \text{water score}*100)^2 \right]^{1/2}$$

4.3. Geographic distribution of water security

A first level of analysis is conducted on a geographical dimension, in order to have an idea of the geographic distribution of water security across countries, through the use of two different tools: the software QGIS, used to obtain a map representation of the Water Security Index and its dimensions, and a cluster analysis, aiming at achieving a statistical division of the countries in groups according to their level of water security.

4.3.1. GIS maps of water security and its dimensions

A first kind of investigation is given by a geographical representation through maps of the Water Security Index and its dimensions: water availability per capita, percentage of population with access to improved water sources, quality of water and vulnerability to climate change. The plotting of water security on maps is extremely useful to highlight differences among different countries and regions in an easily understandable way. The tool used to obtain the maps is the free software QGIS.

Fig. 1 shows the percentage of population having access to improved water sources: it appears immediately evident that the totality or the almost-totality of the population in developed countries has full access to safe water resources, while in developing countries the situation is far more desperate. More in detail, most African countries, together with Papua New Guinea, Afghanistan, Haiti, Mongolia, Turkmenistan, Laos and Cambodia present the worst conditions.

Fig. 2 represents the global distribution of freshwater availability per capita. As we can see, this information is not only conditioned by climatic factors proper of a given geographical area, but also by population density: indeed, countries like Canada and Russia, which have a far more extended territory compared to their population size, have a much greater water availability per capita. Of course climatic factors are extremely relevant, as the Middle Eastern and Northern Africa countries, characterized by a high prevalence of desert, confirm, being among the most arid areas of the world.

Fig. 3 depicts the different levels of freshwater quality, measured through the Water Quality Index. This map shows a wider variability compared to the two previous ones, since countries with a very low level of clean water can be found all over the world. The vast majority of the African countries show a worrying level of water pollution, and the same happens in Central Asia, Eastern Europe, Greenland and in some countries of Latin America and Oceania.

Fig. 4 describes the vulnerability of countries' freshwater resources to climate change. We can notice a great disparity between the North, where vulnerability is almost inexistent, and the South of the world, which is far more vulnerable, with the exception of Australia. This is due, on the one hand, to geographical characteristics, which include the different climatic conditions and availability of fresh water resources; on the other hand, to the economic capacity to cope with climate change, which enables the creation of proper infrastructure to mitigate and adapt to the effects of climate change. In particular, the moderate vulnerability of European countries is likely attributable to the first class of reasons, while vulnerability characterizing Africa, Southern Asia and Latin America is attributable to both geographical characteristics and the lack of economic means.

Fig. 5 illustrates the distribution of the Water Security Index, which is composed of all the dimensions observed before, across the world. The net difference between developed and developing countries is easily discernable. Great disparities in the water security level are observable in all of the five continents. In particular, the situation is rather desperate in some countries of Sub-Saharan Africa, South Asia and Oceania, including Somalia, Papua New Guinea, Turkmenistan, Mauritania, Eritrea, Chad and Afghanistan. In contrast, the most virtuous countries, as we could expect, are Iceland, New Zealand, Canada, Norway and Sweden.

Fig. 1: Improved water source (% of population with access)

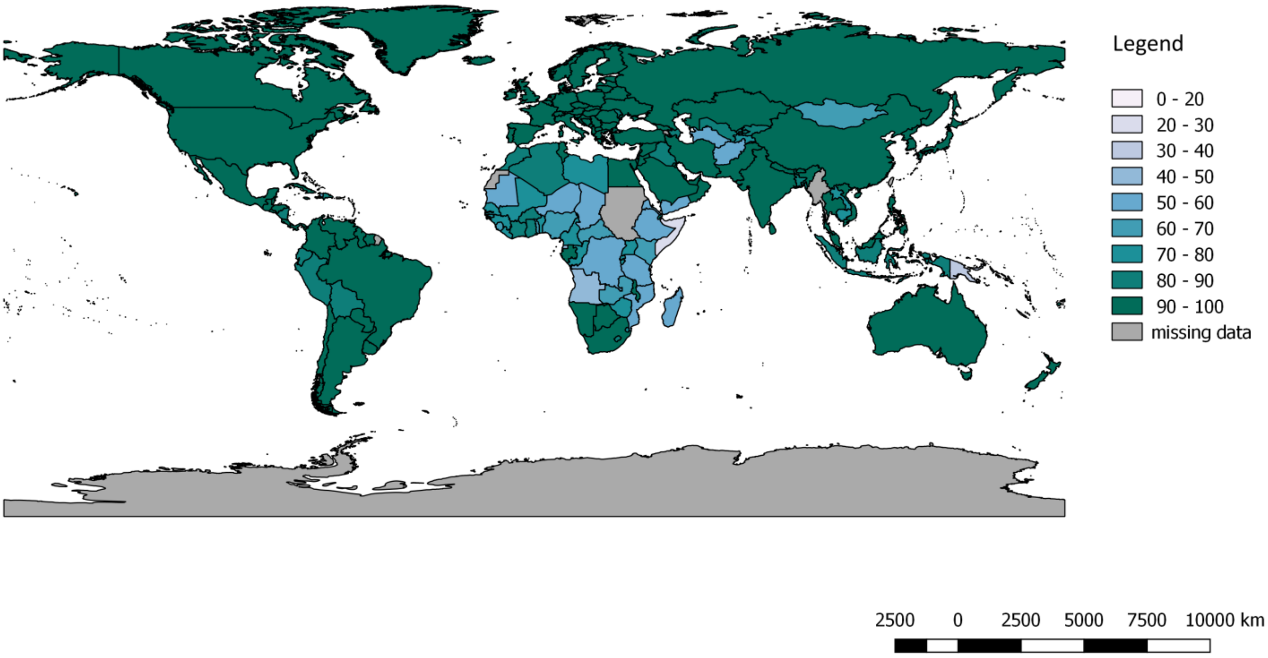


Fig. 2: Water availability per capita (cubic meters)

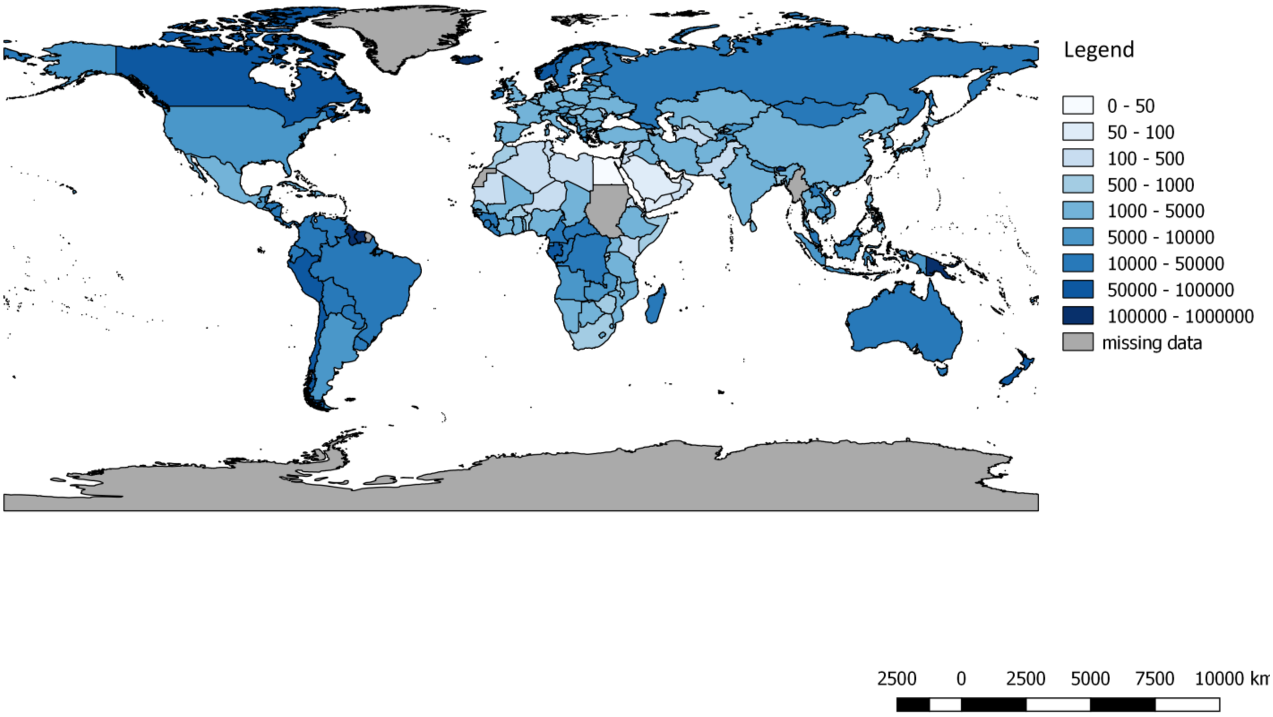


Fig. 3: Water Quality Index

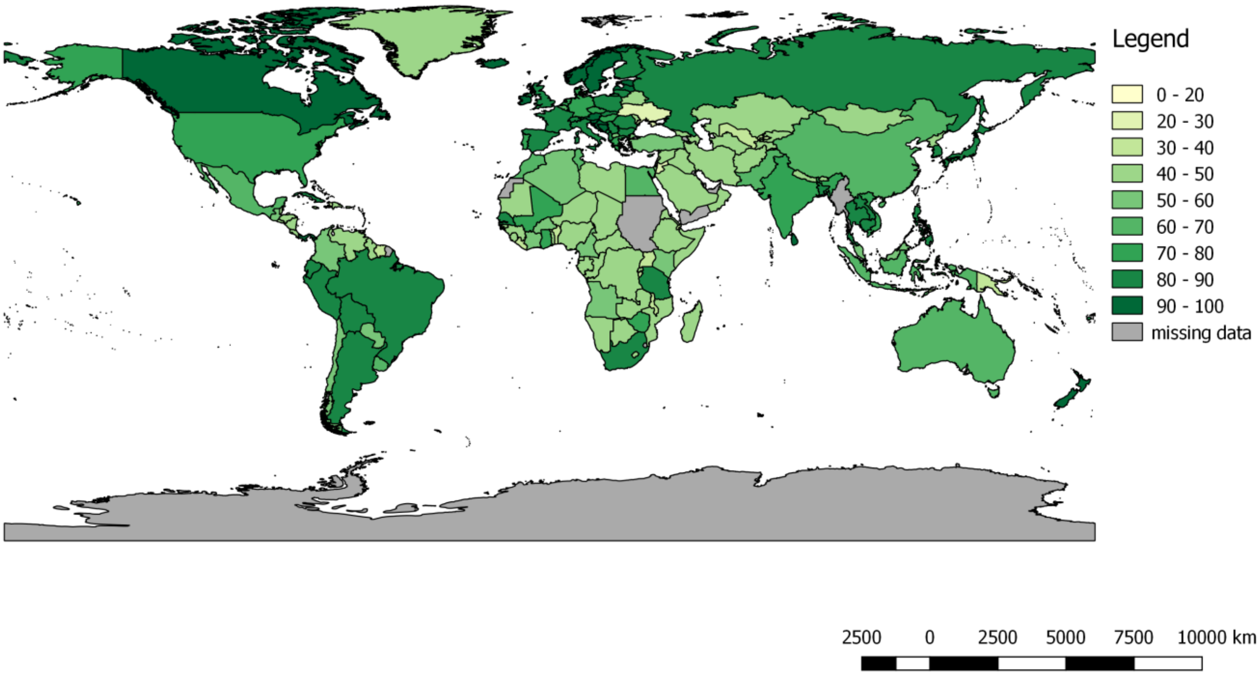


Fig. 4: Vulnerability of freshwater resources to climate change

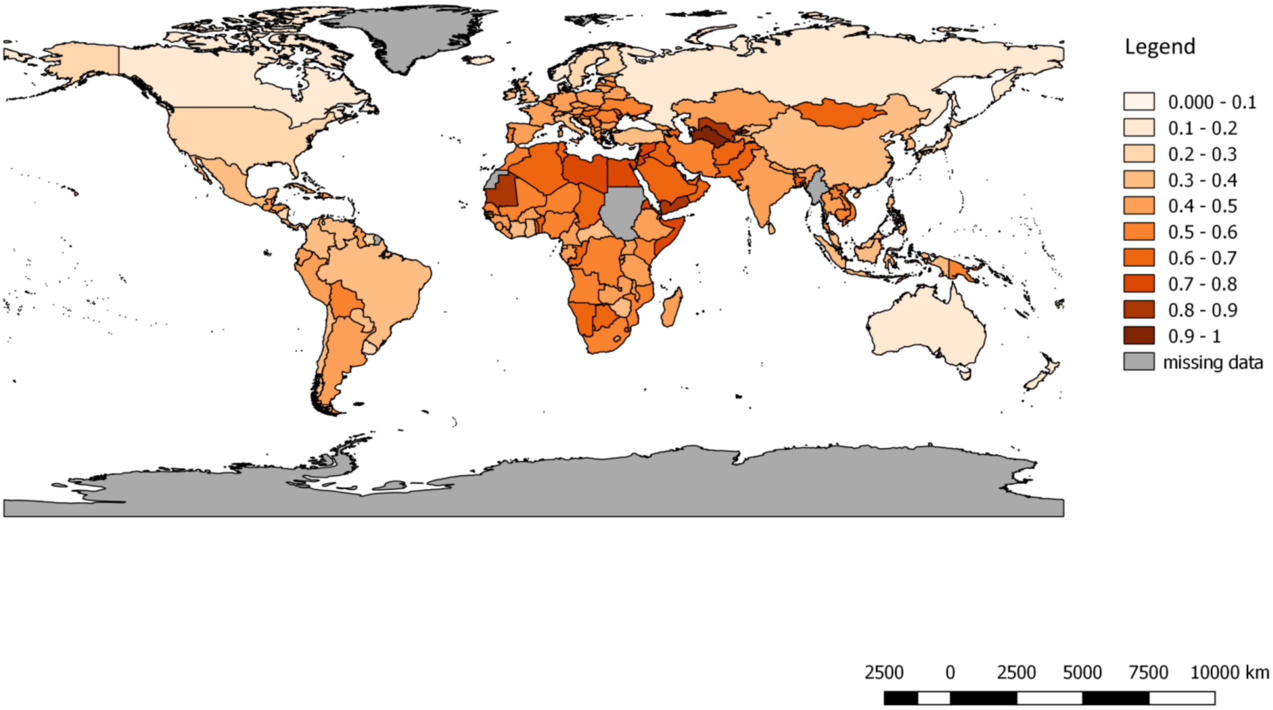
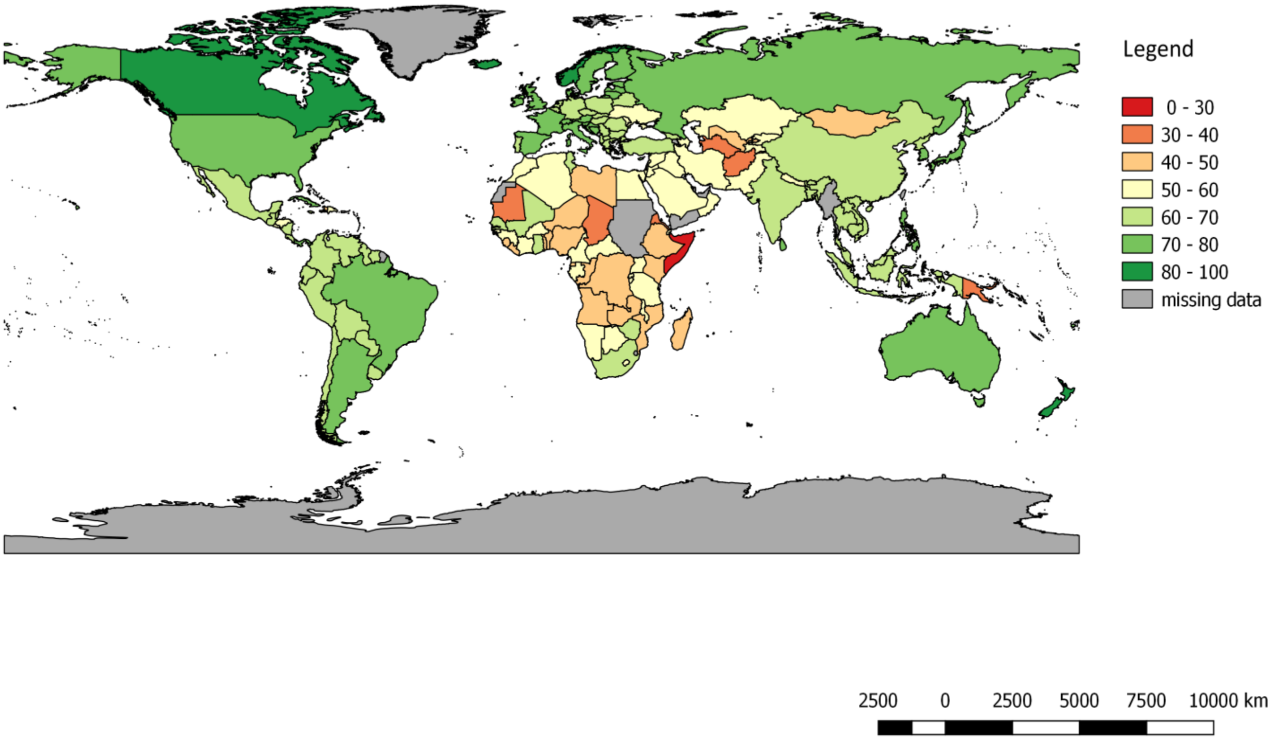


Fig. 5: Water Security Index



4.3.2. Cluster analysis of water security

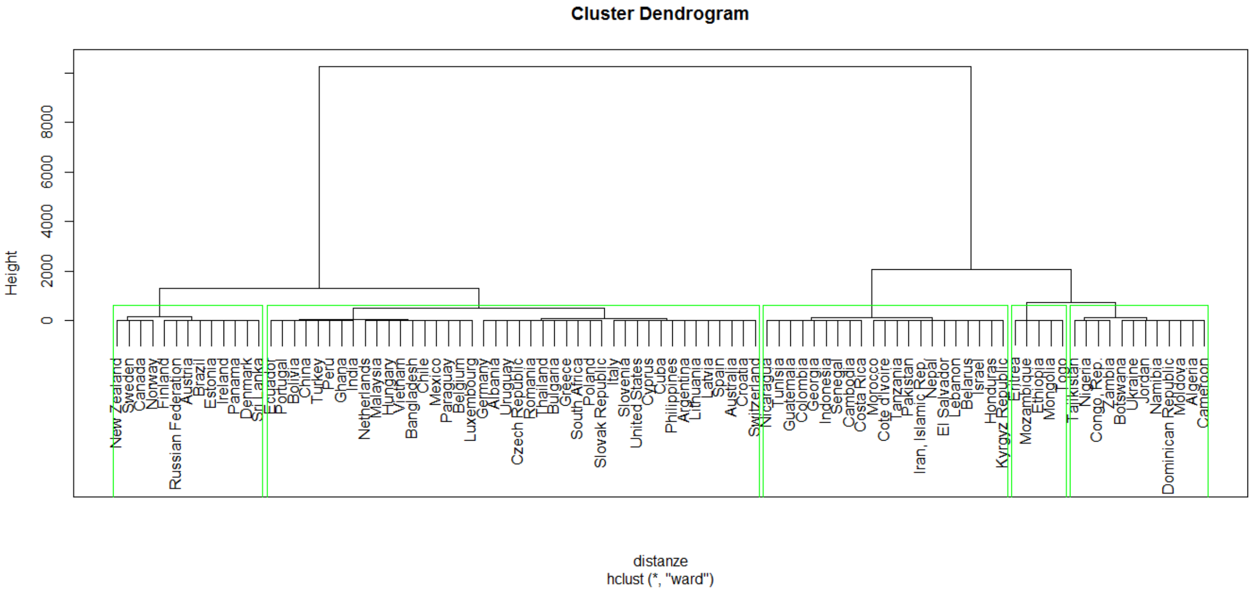
The cluster analysis is a qualitative statistical technique which allows to assemble statistical units into groups of units which are similar with respect to a certain variable or set of variables. The purpose of the cluster analysis is to minimize the dissimilarity (or distance) among units belonging to the same group and to maximize that among groups. The kind of distance chosen to aggregate units is the square of the Euclidean distance, which has the following formula:

$$d^E(U_i, U_j) = \sqrt{\sum_{k=1}^{p} (x_{ik} - x_{jk})^2}$$

With respect to the grouping algorithm, I tried several methods and the Ward method is the final choice. It is based on the variance decomposition and, step by step, aggregates the two groups the fusion of which entails the minimum variance increase.

The reason why the dendrogram was cut into five groups depends upon the fact that this number allows the most reasonable interpretation of the units division. Fig. 6 shows the five-group-cut cluster dendrogram.

Fig. 6: Cluster analysis - dendrogram



A description of the five groups obtained is given in tab. 2.

Tab. 2: Cluster analysis – group division

Groups	**Description**	**Countries**
Group 1	Very high level of water security	Austria, Brazil, Canada, Denmark, Estonia, Finland, Ireland, New Zealand, Norway, Panama, Russia, Sri Lanka, Sweden
Group 2	High level of water security	Albania, Argentina, Australia, Bangladesh, Belgium, Bolivia, Bulgaria, Chile, China, Croatia, Cuba, Cyprus, Czech Republic, Ecuador, Germany, Ghana, Greece, Hungary, India, Italy, Latvia, Lithuania, Luxembourg, Malaysia, Mexico, Netherlands, Paraguay, Peru, Philippines, Poland, Portugal, Romania, Slovak Republic, Slovenia, South Africa, Spain, Switzerland, Thailand, Turkey, USA, Uruguay, Vietnam
Group 3	Average level of water security	Belarus, Cambodia, Colombia, Costa Rica, Cote d’Ivoire, El Salvador, Georgia, Guatemala, Honduras, Indonesia, Iran, Israel, Kyrgyz Republic, Lebanon, Morocco, Nepal, Nicaragua, Pakistan, Senegal, Tanzania, Tunisia
Group 4	Low level of water security	Algeria, Botswana, Cameroon, Congo, Dominican Republic, Jordan, Moldova, Namibia, Nigeria, Tajikistan, Ukraine, Zambia
Group 5	Very low level of water security	Eritrea, Ethiopia, Mongolia, Mozambique, Togo

From the geographical analysis conducted through the use of both maps and the cluster analysis, great disparities in the level of water security of different countries emerged. In general, the net difference between developed and developing countries is easily discernable, with the only exception of the water quality dimension, since worrying levels of water pollution can be found all over the world.

4.4. Investigating water security using a regression analysis

In order to have a quantitative understanding of the relationship existing between climate change and water security, twenty different regression models were built. Indeed, the climate change-related variables (daily mean temperature, average annual precipitations, flood occurrence and drought severity) have been inserted in the econometric models in different ways. The first set of models considers the levels of the variables. The second set of models includes four out of five dummy variables, namely *D1*, *D2*, *D3*, *D4* and *D5*, which represent different climatic zones and are created on the basis of the groups obtained from a cluster analysis applied to the climatic variables. In particular, countries belonging to *D1* are characterized by very high precipitations, very low drought severity, very high flood occurrence and high temperatures. Countries in *D2* have high precipitations, low drought severity, high flood occurrence and high temperatures. The third group of countries presents medium/high precipitations, medium/low drought severity, medium/high flood occurrence and variable temperatures. Countries belonging to *D4* have low precipitations, medium/high drought severity, medium/low flood occurrence and average temperatures. Finally, the fifth group is characterized by very low precipitations, high drought severity, medium/low flood occurrence and medium/low temperatures. However, D5 is not inserted in the model, since the other dummies are interpreted with respect to it.

The third set of models deals with classes of climatic risk created on the basis of the values of the variables considered. For each of the four climatic variables the classes range between 0 (very low climatic risk) and 5 (very high climatic risk). Later, the climatic risk of a country is obtained by summing the value associated to each of the four climatic variables. Hence, the climatic risk of each country ranges between 0 and 20. Finally, the fourth set of models is given by the interaction between the classes of climatic risk and GDP per capita, which is a proxy for country's adaptive capacity to climate change. In addition, in order to give a quantitative idea of the complexity and multidimensionality of the water security concept, for each set of models the dependent variable considered is not only the Water Security Index, but also to its four dimensions.

Fig. 7: Histograms

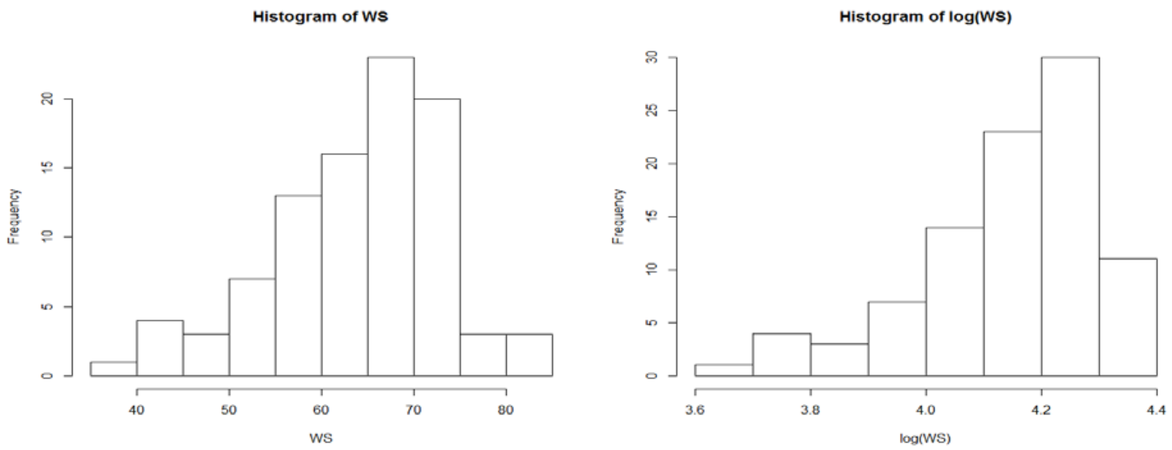


Fig. 7 compares the histograms of the Water Security Index and the one of its logarithm. As we expected, none of the two histograms presents a Normal distribution, since the dependent variables ranges between 0 and 100. However, the first histogram results better than the second one, thus there is no need to consider the dependent variable in a logarithmical form. In order to avoid eteroschedasticity and asymmetry problems, the model used is beta regression, which is conceived just for dependent variables expressed as rates and proportions. To be thorough, tables 3 to 7 present the estimation results of the regression models, considering the five dependent variables. However, detailed explanation of the model estimation results will be given only for the models having the Water Security Index as a dependent variable, as for the other models results are not consistent, as highlighted by the pseudo R^2, too. In Model 1 Climate change is measured through the four climate-change related variables (*temp, prec, drought and flood*), but only the variables *prec* and *flood* resulted to be significant. In particular, *prec* is significant for any $\alpha>0.001$ and *flood* for any $\alpha>0.01$ and the magnitude of *flood*'s coefficient shows that countries affected by recurring floods are more than ten times less water-secure compared to countries not exposed to floods. While *flood* has a negative sign, since, as expected, an increase in flood occurrence produces a greater vulnerability of freshwater resources and, thus, a lower level of water security, the sign of *prec* is positive. Its meaning is not immediately intuitive and whatever sign this variable has would not be surprising. Indeed, the discourse about the amount of precipitation is a bit controversial, as, from the water security perspective, both an abundance and a scarcity of precipitations constitute a problem. Indeed, an abundance of precipitation can easily translate into a flood, whilst a scarcity of it means a likely drought.

Among control variables, water productivity has a high significance level. It denotes the value of product obtainable with a m^3 of freshwater withdrawn. Its sign is negative because an increase in water productivity indicates an inclination to intensify water consumption for productive purposes. As a consequence, water availability per capita reduces and the quality of water can be compromised. GDP per capita is also very significant and is positively correlated with water security. Indeed, a high GDP per capita allows improving access to water, water quality and adapting to and protecting against floods and droughts.

The imports and exports of agricultural raw materials were included in the dataset because of the virtual water trade theory (Allan, 1993; 1998; 2003), which considers the water embedded in the production of any commodity, so when any commodity is traded, the water contained in it is traded too. According to this theory, dry countries may increase their water supply by producing food and commodities which require a low amount of water and importing the others. Thus, imports of agricultural raw materials are expected to increase a country's water supply, thus raising the level of water security by leveraging on the dimension of water availability, while exports of agricultural raw materials are expected to have the opposite effect. However, the exports of agricultural raw materials are not significant to explain water security, while the imports are quite significant and have a positive effect on water security. Since the signs of these two variables are the ones we expected, the virtual water theory is confirmed.

Finally, the Environmental Performance Index is a quite significant variable that has a positive relationship with water security. It reflects the set of policies and legislations a country undertakes for protecting the environment and it mainly has an effect on water quality and on vulnerability to climate change, as adaptation and mitigation strategies often coincide with environmental policies. On the whole, the model presents an acceptable goodness-of-fit, as pseudo R^2 is equal to 0.6356.

In Model 2 climate change is expressed through the dummy variables representing different climatic zones. Compared to Model 1, the climatic effect here is only significant with respect to the dummy variable *D2*, but the magnitude of its coefficient is very relevant. Indeed, countries belonging to the second group are characterized by very high precipitations, hence the positive sign of *D2* is likely explained by the increase in the dimension of water availability, in opposition to countries included in the fifth group, which have very low precipitations and high drought severity.

The control variables contributing to explaining water security are the same as in Model 1, with the exception of the variable *reg.qual,* which in the previous model was not significant. It indicates the ability of the government to formulate adequate policies and regulations and has a positive relationship with water security, meaning that the presence of good institutions is pivotal for the achievement of water security. The goodness-of-fit is higher in Model 1 than in Model 2, where pseudo R^2 is equal to 0.6029.

In model 3 climate change is considered through the variable *climatic.risk*, which assigns each country a class depending upon the climatic risk it is exposed to. Also in this case climate change results to be very significant in explaining water security, as confirmed by the expected negative sign, which is statistically significant. Among control variables, income loses importance in this model, while hydropower generation and the share of land devoted to agriculture acquire significance, both with a negative sign. In particular, the negative sign of hydropower generation seems to confirm the mutual relationship existing between water management and climate change mitigation strategies, so as the trade-off between adaptation and mitigation options. Indeed, increases in hydroelectric generation may foster competition in water use, constrain access to water and reduce water quality. A similar discourse could be done for the agricultural land, which entails an increase in water use for irrigation purposes, thus reducing access to drinking water for residential needs and, through the use of pesticides and fertilizers, provoking water pollution. The goodness-of-fit of this model is higher than in Models 1 and 2, as the pseudo R^2 is equal to 0.6612.

Finally, Model 4 is part of the last set of models, in which climate change is considered according to countries' adaptive capacity, which is given by the interaction between the classes of climatic risk and GDP per capita. The adaptive capacity to climate change is represented by the variable *vuln*, which is significant for any $\alpha>0.001$, but the magnitude of its coefficient is much lower compared to the other variables concerning climate change. With respect to control variables, this models presents much similarity with Model 2, both in terms of both coefficients magnitude and significance, with the only exception of hydropower generation, which does not contribute to explaining water security when climate change is expressed as climatic zones.

Tab. 3: Models estimation results: WSI

	Water Security Index			
	Model 1: Climatic Variables	**Model 2: Climatic Zones**	**Model 3: Climatic Risk**	**Model 4: Vulnerability**
Intercept	0.04317 (0.1989)	-0.1416 (0.1884)	0.68349** (0.244446)	0.07111 (0.1771)
Temp				
Prec	0.000148*** (0.00004)			
Flood	-0.1144** (0.03579)			
Drought				
D1				
D2		0.2093* (0.09627)		
D3				
D4				
Climate.risk			-0.04739*** (0.01192)	
Vuln				-0.00002*** (0.0000005)
Water.prod	-0.001581*** (0.000413)	-0.001151** (0.00042)	-0.00077* (0.000312)	-0.001435*** (0.0004)
GDP.pcap	0.000015*** (0.000003)	0.000009** (0.000004)		0.00003*** (0.000006)
Agri.imp	0.08179** (0.02737)	0.05912* (0.02621)	0.066507** (0.025303)	0.05183* (0.02464)
EPI	0.009157** (0.003014)	0.009672** (0.003042)	0.011224*** (0.002712)	0.01042*** (0.00285)
Reg.qual		0.1125* (0.04627)	0.125817*** (0.0372)	0.08516* (0.0431)
Hydropower			-0.00268** (0.000825)	-0.001986* (0.00084)
Agri.land			-0.00333* (0.00141)	
Pseudo R^2	0.6356	0.6029	0.6612	0.6748

Notes: 1) estimates; in parentheses: standard errors. 2) *p<0.5; **p<0.01; ***p<0.0001

Tab. 4: Models estimation results: Water availability per capita

	Water availability per capita			
	Climatic variables	**Climatic Zones**	**Climatic Risk**	**Vulnerability**
Intercept	-4.1816***	-5.108022***	-6.85565***	-6.85565***
	(0.57565)	(0.42129)	(0.44085)	(0.44085)
Prec	0.00083***			
	(0.000096)			
Temp	-0.0494***			
	(0.00876)			
Flood				
Drought				
D1		1.119364***		
		(0.169019)		
D2		0.730248***		
		(0.204223)		
D3		0.6944237***		
		(0.14294)		
D4				
Climate.risk				
Vuln				
Water.prod	-0.002108*		0.016773***	
	(0.00084)		(0.002153)	0.016773***
Pop.dens	-0.003498***	-0.00226*		(0.002153)
	(0.00074)	(0.000918)		
Rur.pop	-0.025316***	-0.003233***	-0.023266***	
	(0.004158)	(0.000778)	(0.004775)	-0.023266***
Agri.imp	0.2714**	-0.018157***		(0.004775)
	(0.083)	(0.004313)		
Agri.exp	-0.03968**	0.282698**	0.07059***	
	(0.01455)	(0.08999)	(0.017889)	0.07059***
EPI	-0.02078**	-0.0707***		(0.017889)
	(0.00683)	(0.01629)		
Reg.qual	0.222243**		0.356578***	
	(0.08366)		(0.093698)	0.356578***
Hydropower	0.01099***	0.294388***	0.016773***	(0.093698)
	(0.00178)	(0.08325)	(0.002153)	0.016773***
Agri.land	-0.01038***	0.008251***	-0.012229**	(0.002153)
	(0.003097)	(0.002013)	(0.003971)	-0.012229**
Industry	0.031004***	-0.01433***	0.046609***	(0.003971)
	(0.005548)	(0.00336)	(0.00754)	0.046609***
		0.023528***		(0.00754)
		(0.00654)		
Pseudo R^2	0.6236	0.5755	0.4931	0.4931

Notes: 1) estimates; in parentheses: standard errors. 2) *p<0.5; **p<0.01; ***p<0.0001

Tab. 5: Models estimation results: Access to improved water source

	Access to improved water source			
	Climatic variables	**Climatic Zones**	**Climatic Risk**	**Vulnerability**
Intercept	1.11 . (0.5762)	1.13057 . (0.58815)	1.125 . (0.578)	1.726** (0.6241)
Prec				
Temp				
Flood				
Drought				
D1		-0.595514* (0.23657)		
D2				
D3				
D4				
Climate.risk				
Vuln				0.0000042*** (0.000001)
Water.prod			-0.00276* (0.001405)	
Rur.pop	-0.01122* (0.004965)	-0.015172** (0.00488)	-0.01048* (0.00497)	
Agri.imp	0.19223* (0.07749)	0.22027** (0.07832)	0.1748* (0.07617)	
Agri.exp	-0.04873** (0.01578)	-0.04155** (0.01557)	-0.04966** (0.01569)	-0.05621*** (0.01485)
EPI	0.03092*** (0.00819)	0.04267*** (0.00803)	0.02879*** (0.008288)	0.0336*** (0.008292)
Reg.qual	0.4208** (0.1362)	0.58742*** (0.11392)	0.3829** (0.1401)	0.3907** (0.1352)
Hydropower		-0.00516* (0.00222)		-0.00581* (0.00232)
GDP.pcap	0.0000336** (0.0000105)			
Pseudo R^2	0.6993	0.7053	0.7038	0.7038

Notes: 1) estimates; in parentheses: standard errors. 2) .p<0.1; *p<0.5; **p<0.01; ***p<0.0001

Tab. 6: Models estimation results: Water Quality Index

	Water Quality Index			
	Climatic variables	**Climatic Zones**	**Climatic Risk**	**Vulnerability**
Intercept	-0.5815 (0.3633)	-0.2504 (0.3102)	0.1048 (0.702)	-0.5719 (0.5612)
Prec	0.0004137*** (0.000113)			
Temp				
Flood	-0.1974* (0.1005)			
Drought				
D1				
D2				
D3				
D4				
Climate.risk			-0.1281*** (0.03509)	
Vuln				-0.000008*** (0.0000016)
Water.prod	-0.004434*** (0.00121)	-0.003357** (0.001216)	-0.003424** (0.001182)	-0.003641** (0.001148)
Rur.pop	-0.01663** (0.005158)	-0.01344** (0.00503)	-0.01837*** (0.005185)	-0.01626*** (0.004938)
EPI			0.01776* (0.008624)	0.01769* (0.008074)
Pol.stab		0.3088** (0.0000102)		
Hydropower			-0.005886* (0.002561)	-0.00656** (0.002386)
GDP.pcap	0.000057*** (0.000009)	0.000039*** (0.00001)	0.000034*** (0.000009)	0.0001028*** (0.000016)
Pseudo R^2	0.3903	0.3569	0.4366	0.5111

Notes: 1) estimates; in parentheses: standard errors. 2) .p<0.1; *p<0.5; **p<0.01; ***p<0.0001

Tab. 7: Models estimation results: Water Score (Vulnerability of freshwater resources)

	Water Score (Vulnerability of freshwater resources)			
	Climatic variables	**Climatic Zones**	**Climatic Risk**	**Vulnerability**
Intercept	-0.9549***	0.2293	-1.051***	-1.051***
	(0.2482)	(0.1407)	(0.282)	(0.282)
Prec	0.0243***			
	(0.00642)			
Temp	-0.0003458***			
	(0.000079)			
Flood	0.2159***			
	(0.05725)			
Drought	0.2507***			
	(0.0741)			
D1		-0.5008**		
		(0.1639)		
D2				
D3				
D4				
Climate.risk			0.07683***	0.07683***
			(0.02008)	(0.02008)
Vuln				
Water.prod	0.0023***	0.001836**	0.001836**	0.001836**
	(0.000597)	(0.0007)	(0.00068)	(0.00068)
Pop.dens	0.000639*	0.000787*		
	(0.000293)	(0.000319)		
Agri.land			0.006429*	0.006429*
			(0.002502)	(0.002502)
Prot.areas		-0.009716*	-0.00873*	-0.00873*
		(0.004241)	(0.00412)	(0.00412)
Pol.stab	-0.1653*			
	(0.06558)			
Hydropower		-0.0039**		
		(0.001498)		
GDP.pcap	-0.000019***	-0.000026***	-0.0000017***	-0.0000017***
	(0.0000046)	(0.0000044)	(0.0000043)	(0.0000043)
Pseudo R^2	0.595	0.4147	0.4398	0.4398

Notes: 1) estimates; in parentheses: standard errors. 2) .p<0.1; *p<0.5; **p<0.01; ***p<0.0001

5. Conclusions

Water security has always been a social priority, the absence of which puts at risk not only whole economies, but human livelihoods, too. As discussed before, water security is a complex issue, since it is influenced by many factors and the effects of a lack of it involve manifold sectors and actors. As a consequence, governments should deal with it from a comprehensive perspective, considering all the interrelated challenges it poses, assigning priorities to different objectives and promoting the participation of the several stakeholders involved.

As emerged by the qualitative analysis, much has to do to improve countries' security in relation to water resources all over the world, since water pollution is a major challenge threatening even the most advanced societies. Besides, in developing countries lack of access to water and sanitation is an urgent problem, as it affects, both directly and indirectly, well-being and quality of life: individuals and communities who do not have access to clean drinking water are often forced to depend on water sources of inferior quality, becoming even more vulnerable to several diseases and triggering a dangerous vicious cycle.

In this context, climate change further worsens the situation, by making water supply no longer predictable and deteriorating water quality. As revealed by the econometric results, in the first three models climate change has a predominant (negative) effect on water security, while when considering the adaptive capacity dimension, some control variables result to be more decisive. In all four models where the WSI is the dependent variable results are consistent, as the coefficients of both climatic and control variables are always correctly sloped and their magnitude varies little.

In contrast, it is not true for all of the four dimensions of water security: for instance, the dependent variable water availability per capita is not influenced by the climatic risk and the vulnerability to climate change, while water quality is only affected by those two aspects of climate change. However, the goodness-of-fit of the models analyzed is quite high in the models in which the dependent variable is the WSI, while it is rather low in the other models.

Because of the great interconnection between climate change and water security, an important implication of these results is the need to address water and climate change policies together, in order to be sure to generate real benefits.

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