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Editorial

Managing Water in a Changing World

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Abstract: Water, being a primary element in the diet and a necessary resource for the agriculture, can be considered a basic need for humans. In addition, also industrial practices need a growing amount of water. Since human population is continuously growing at a rate that, in the last two centuries, approximates well the exponential, water demand is increasing. However, the water resources on the Earth are finite. For this reason, even disregarding the potential threats due to the climate change, this situation appears as one of the biggest challenges of the current era. Actually, several small-scale regions already face water sustainability problems, and the scarcity of water resources is expected to spread to wider areas in the near future, if the actual trends of development and population growth do not change. The situation is exacerbated as the climate is already changing, due to the anthropogenic emissions of greenhouse gases in the atmosphere, and its rate is expected to increase by the end of this century. The effects of these changes will increase the natural variability of the climate, exacerbating the extreme climatic phenomena (drought and flood events) and increasing the difficulty of managing water resources, especially in the most vulnerable regions.

Keywords: water resources; climate change; IPCC; population growth

1. Introductory Notes

The conference organized by the IGU (International Geographical Union) Commission for Water Sustainability, entitled “Managing water in a changing world”, in July 2009 in Turin, drew together an interdisciplinary group of scientists and technologists to analyze water sustainability problems and its association with climate change. The Commission has always favored the participation of scientists and experts from many fields and a range of nations, in order to stimulate the diffusion of new ideas and merging with the local community.

The choice of Turin (Torino), a city located in the Piemonte region and surrounded by the Alps (in fact, Piemonte means “at the foot of the mountain”), also underlined the close and harmonious connection between the Alps, their rivers, their glaciers, and the region’s water supplies. Since the establishment of the first human settlements at the foot of the mountains, the presence of these rivers has favored the development of agriculture and, during the last two centuries, of industries.

It may be said that European Countries had never seriously suffered from drought problems in the past, despite the Little Ice Age. The most serious problem connected with water that affected most Europeans in the past has been floods, with their associated damage and victims.

In recent years, however, human use of water, for domestic, agricultural and industrial uses, has greatly increased, due largely to the continuous growth in population. The impact on water quality has also increased dramatically. In contrast, the warming climate is reducing the Alpine glaciers and in the near future may affect water availability even in regions that are not usually subjected to water shortage, such as the Po Valley.

These problems are most dramatic in other regions of the world where water resources are limited. Despite climatic factors which substantially affect the water resources availability provoking the most serious problems in specific regions in the world, there are also anthropogenic factors that exacerbate such problems. As a result, almost every nation deals with problems related to water sustainability.

In many countries water supply is actually very limited, and a large portion of the population lives below the minimum threshold judged permissible for a decent life. In some countries, the water supply is ensured only thanks to the extraction of fossil water, which is a limited resource that will not last indefinitely.

The continuous growth of the world population will make these problems of water availability even worse with time. In many cases, climatic global warming will increase the frequencies of drought episodes, as well as those of floods, in the same places, thus aggravating the situation. Managing the world’s resources with water sustainability in mind demands urgent attention and research.

The papers listed in this special issue of Water have been selected to be the most relevant within the frame of the following sessions from the conference: Underground resources; Water and hydrogeological risks; Planning of water resources; Infrastructures for water resources management; Hydrologic emergencies; Water resources and environmental and climatic change; and Water sustainability in the alpine environment. The selection follows the direction of trying to optimally understand all relevant systems. Water is at the heart of sustainable human development. It is thus necessary to carry out a global analysis of the problems related to water by integrating the approaches used at local scales in a comprehensive way.

2. An Historical Perspective

Since the first appearance of humanity on Earth, one of the most serious challenges faced by primitive human groups was to ensure an adequate supply and quality of water. The need increased when these societies developed agriculture. It is one of the main reasons why primitive societies settled near rivers. However, in the past, when water supplies proved inadequate to sustain them, these communities had a ready alternative: to emigrate to a place with better supplies.

Once urban architecture become more complex, emigration became more difficult. History shows many cases of collapse of complex societies, directly or partly caused by shortages of food or water, or both. It is interesting to note that almost all civilizations followed a characteristic curve of development. At the beginning there was a phase of development, sometimes intense. Subsequently, a new steady phase was reached, during which the aggregation centers became increasingly bigger, and also *per capita* food and water needs increased. This phase normally coincided with the most brilliant phase of that civilization. During this phase, the pressure on the ecosystems surrounding the aggregation centers also became great, in some cases exceeding the capacity of the ecosystem to produce an adequate supply of food, water and other products. In other words, the human pressure on the ecosystems became non-sustainable. The concept of sustainability has several meanings. Literally, "sustainability" comes from the Latin word *sustinere*, which means to hold up or support. The actual meaning of sustainability is "having the characteristic of being able to keep up, to carry or withstand" as in bearing a weight or pressure. In the context of a closed physical system, the concept of sustainability approaches that of a conservation law: if the contents of something in a certain system are never replenished, sooner or later a continuous extraction of that material will empty the system. In other words, the system will not be able to "sustain" the pressure of having things frequently removed from it. In order for the system contents to be sustained, the amount put in must be at least as much as the amount taken out over any given period of time.

The case of the Maya is a good example for the above mentioned concept, and in particular their central and southern cities. Here we are talking about an ensemble of city-states located in Central America (mostly in modern Mexico) that, in the most brilliant phase of its splendor, counted several million inhabitants [1]. The ruins of many monuments dispersed in their territories are still visible today.

Historians and archaeologists now agree on the fact that one of the causes which contributed to the decline of these communities was a series of severe and consecutive drought events affecting Central America during the period 810–910 A.D. [2]. These climate changes exacerbated the pre-existing problems of overexploitation of the resources in their already dry territory. As a result of the shortage of water resources, *in primis*, and of food and other materials (*i.e.*, wood) as a secondary effect, Maya city-states located in the central and southern part of Mayan territories collapsed within a few decades. Most of the main dynasties fell between 800 and 830 A.D. and in the next hundred years the population of most southern areas declined by at least three-quarters. The disaster was as much cultural as demographic: the Maya continued to exist, but their central cities did not [1]. Just a few farmers dispersed in fertile niches remained as witnesses of past times. The collapse has been laid at the door of overpopulation, overuse of natural resources, and drought, as well as their political failure to find solutions to these environmental problems. In contrast, northern Maya cities, although mostly subjected to the same drought effects because that region was also arid, were able to adapt and to develop trade with other cities and nations.

A contrasting example, again relating to indigenous inhabitants of the American continent, which can well represent the relations between men and environment, is that of Amazonia. When an equatorial forest is cleared, the soil is subjected to the action of the violent equatorial rainfall, and the energy of the rain drops pounds the top few inches of earth into slurry from which nutrients are easily leached out and the soil itself easily washes away. How to cultivate these lands in order to sustain people living there? Faced with this ecological problem, the Amazon Indians fixed it: rather than adapt to nature, they created a new nature [1] by inventing the technique now known as *terra preta* (which is a Spanish expression indicating black soil thick with pottery). Their idea was to fix the terrain by using broken ceramics in order to retain the soil and to avoid erosion during violent rainfall. This technique involved replacing the original equatorial forest near their villages with new fruit trees and cultivations adapted to human use. The soil fertility was so high that it is still possible to find both fruit trees and even portions of *terra preta* along river floodplains.

These two examples prove the strict relations existing between humans and the environment, with particular regard to water resources and adaptation to ecosystem characteristics, especially in cases of changing or challenging climate. When the population of a certain area abused the ecosystem, often, during long lasting climate changes, the shortage of water resources triggered a series of events, often culminating in the collapse of the civilization itself.

After the industrial revolution, however, the increasing availability of fossil fuels made it possible for an increasing number of people to exceed the limits of the local ecosystem by progressively enlarging the portion of environment from which to draw food, water and raw materials. The growing availability of energy at a low price was also one of the factors contributing to the rapid development of quality of life and urbanization, and to the growth of the world population. These were also stimulated by the fact that the economic theories emerging during those years, most of which being still popular today, were based on the concept of almost infinite availability of goods: among them, fossil fuels and water.

3. Total Water Resources within the Earth System

The concept of water resources deserves some clarification. The total water available on the planet amounts to 1,386 million cubic kilometers [3]. However, not all these resources are potentially usable for humans. Agricultural, industrial, household, recreational and environmental activities, which constitute most of human water uses, require fresh water.

97% of water on Earth is salty, leaving only 3% as fresh water, of which slightly over two thirds (68.9%) is frozen in glaciers and polar ice caps [4]. The remaining unfrozen fresh water is mainly found as groundwater (29.9%), with only a small fraction present above ground (0.3%) or in the air. For example, rivers account for the 0.0002% of total water, or 0.006% of fresh water, *i.e.*, around 2,120 cubic kilometers.

The above figures can be considered almost constant at the global scale, though small changes can occur at time scales much longer than those of human existence, and they represent the potential reservoir of Earth's fresh water.

Humans use mainly fresh surface water (easy to extract), and partially groundwater (more difficult to extract). A recent estimate [5] shows that 69% of worldwide water use is for agriculture (mainly irrigation), 22% for industries, 1% for recreational purpose and 8% for household purposes. The latter include drinking water (also called potable water), bathing, cooking, sanitation, and gardening. Agriculture uses more water than any other activity on the planet. Currently, 65% of the water removed from all sources worldwide is used solely for irrigation, and about two-thirds of this amount is consumed by plant-life [6].

4. The Regional Distribution of Water Resources

These numbers refer to the global situation. However, two points must be taken into consideration. First, the rapid population growth and increased water consumption are rapidly depleting the availability of water *per capita*: for instance, Hinrichsen (1998) [7] evaluated that, between 1960 and 1997, the *per capita* availability of freshwater worldwide declined by about 60%.

The second point is that the water resources are unevenly distributed in the world. The World Business Council for Sustainable Development [6] estimated that the minimum amount of water required *per capita* for food is about 400,000 liters per year, but in the US the amount is about four times larger (1.7 million liters *per capita* per year [8]). At the same time, the minimum basic water requirement for human health is 50 liters *per capita* per day [3], but in the US consumption this is eight times higher (400 liters *per capita* per day [9]).

The total amount of water available globally is sufficient to provide the world population with adequate fresh water, according to minimum requirements. However, most of the total water is concentrated in specific regions, while other areas are water-deficient. In nearly 80 nations, the demands exceed the supplies [10]. In China, more than 300 cities have inadequate water supplies [11,12]. In some arid regions, such as the Middle East and parts of North Africa, yearly rainfall is low and irrigation is expensive, thus the future of agricultural production is grim. Political conflicts over water in some areas, such as the Middle East, have even strained international relations between severely water-starved nations [10]. These problems will intensify, due to the continuous population increase.

According to the Comprehensive Assessment of Water Management in Agriculture [13], the regions with water scarcity can be partitioned into three groups, as follows: (1) Physical water scarcity refers to places in which the water resources development is approaching or has exceeded sustainable limits: here, more than 75% of the river flows are withdrawn for agriculture, industry, and domestic purposes (note that, according to this correlation between water availability and water demand, dry areas are not necessarily water scarce). (2) In regions nearing physical water scarcity, more than 60% of river flows are withdrawn, and thus these basins will experience physical water scarcity in the near future. (3) The last group includes the economic water scarcity, where human, institutional, and financial capital limit access to water even though water in nature is available locally to meet human demands: in these regions, water resources are abundant relative to water use, with less than 25% of water from rivers withdrawn for human purposes, yet malnutrition still exists.

The greatest threats to maintaining fresh water supplies for the increasing needs of the rapidly growing human population are as follows. The first is the depletion of both surface water and groundwater resources, which are mismanaged and over-tapped, especially in those nations in which the natural water supply is less than the demand. Another is water pollution, which is greatest in countries where water regulations are less rigorously enforced or do not exist. Pollution can affect both surface and groundwater resources, dramatically limiting the quality of the water, especially in developing countries, where approximately 95% of their untreated urban sewage is discharged directly into surface waters [14], but also in some well-developed nations (the US Environment Protection Agency [15] shows that 37% of U.S. lakes are unfit for swimming). Human wastes, pesticides, fertilizers, soil sediments eroded by rainfall, and untreated toxic chemicals from industry are among the greatest sources of pollutants [16], and can make the water unsuitable not only for human drinking but also for application to crops [17].

These problems can provoke water shortages and pollution threatening humans and ecosystems, and limit the option of irrigation in arid regions. When water is overused, rivers and lakes levels can become very low, even in well-developed nations (as for the Colorado River: see the old review of Sheridan [18] and some prospects for the near future [19]). Also groundwater levels may fall, due to their slow recharge rate compared with the extraction rate, making their extraction difficult or even impossible. Good examples of groundwater overdraft are the cases of Tamil Nadu in India, and Beijing and Tianjin in China [20,21]. However, the problem is not confined to developing countries, as the cases of the Ogallala aquifer in the US, or of Perth, in Australia, testify [22-24].

At the beginning of the new millennium, the United Nations World Water Development Reports (WWDR), released every three years in conjunction with the World Water Forum since 2003, constitute a comprehensive review of the state of the world's freshwater resources. Specifically, the first edition of the World Water Development Report 1 [25] included seven pilot case studies: Chao Phraya River basin (Thailand), Greater Tokyo (Japan), Lake Peipsi/Chudskoe-Pskovskoe (Estonia, Russian Federation), Lake Titicaca basin (Bolivia, Peru), Ruhuna basins (Sri Lanka), Seine-Normandy basin (France) and Senegal River basin (Guinea, Mali, Mauritania, Senegal). The above mentioned case studies (and others analyzed in the following reports) highlighted the basic issues and problems in achieving integrated approaches to water management, in order to enable the integration of the different elements on a local scale and reality into a coherent whole. Such cases, identifying the areas of greatest stress and pointing out the gaps in knowledge and understanding, were thus a kind of laboratory for testing methodologies and for evaluating lessons learned from examples of real-world practices.

5. Prospects for the Near Future

Technology is usually welcomed by many politicians and persons as a possible solution to alleviate such problems. However, even though it is clear that more efficient use and an improved environmental management of water resources can allow the same resources to serve a greater portion of the population—for instance, drip irrigation can reduce water use in agriculture by nearly 50% [26]), this is not a general solution. In fact, on the one hand, the developing countries are unable to support the high equipment and installation costs of more efficient technologies. On the other hand, science and technology also have some limitations. For instance, the desalinization of ocean water, which may appear a valid alternative for arid regions with access to the sea, is still limited by the high costs—although great advances are in being made.

At the same time, the world population is expected to continue increasing at a rate not substantially different from the present one: the United Nations Environment Programme [27] estimates a "most likely" rise of about 50% in world population by 2050. The concomitant urbanization predicted for the near future further aggravates the problem by increasing the *per capita* water demand.

A larger population automatically reflects in an increasing need for food, and thus of water resources for agriculture. One of the authors [28] showed that water consumption increased by nearly 20% in the last two decades of the 20th century, and a further 20% expansion in the area of irrigated agriculture is still regarded as environmentally feasible.

Considering that, in several nations, the local management of the water resources is actually already not sustainable; the prospects for the near future cannot be other than a matter for great concern. This consideration is even more valid for places where water resources are largely based on fossil water, extracted from deep groundwater reservoirs that are not being replenished in the current climate, as in most countries in the Middle East and North Africa. Even without considering the threat of the climate change (which is the object of the next section), it is evident that the above mentioned practices are a sort of palliative remedial act that does not solve the water resources problem at its root.

Moreover, most of the population increment will occur in the lesser-developed countries, which are generally also more prone to water shortage. The assessment of global freshwater resources [29] calculated that, whereas a third of the world's population currently lives in countries suffering moderate to high water stress, by 2025 this will have risen to two thirds of a much larger population.

6. Water Resources and Climate Change: Challenges for the 21st Century

Unfortunately for humanity, climate change is not a distant possibility, but is already occurring. The IPCC (Intergovernmental Panel on Climate Change) Report [30] represents the most comprehensive international scientific assessment ever conducted. The Report concludes: "*Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level.*" The evidence of global warming over the last two centuries is now overwhelming. There is also broad agreement amongst all the major Global Climate Models that the warming is likely to continue over the coming century so long as the concentration of greenhouse gases in the atmosphere continues to rise. Global water resources are highly sensitive to temperatures, not only through the obvious effects of evaporation, but also because of the effects on wind patterns, convection and rainfall distribution [31].

The warming is expected to be highest in winter and at high elevations and latitudes. The predictions relative to the precipitation are subject to the highest degree of imprecision, due to the intrinsic local variability of this variable. However, the results of the simulations recently carried out using regional climate models show that Mediterranean Europe is expected to experience drier summers than at present, while the northern and central Europe will experience an increase in severe rainfall events [32,33].

However, the climate system is not linear. Thus an increase in precipitation does not directly cause an increment in the water availability. In the case of a temperature increase, for instance, evaporation will increase too, limiting, and in some cases actually reducing, the water availability. Moreover, strong and irregular precipitation events may damage the vegetation and wash fertile soil into rivers.

Many recent publications have attempted to predict the impact of an enhanced greenhouse effect upon regional water resources in the twenty-first century (e.g., [34-37]). If the first generation climate models had a spatial resolution which was too low to reproduce the regional characteristics of the hydrological budget, the most recent models combine atmosphere, ocean and land surface interactions, in order to evaluate the water resources components. The studies of Arnell and King [38] and Jones *et al.* [39] compare the impact on water resources with a calculated increase in demand, based on recent estimates of national population growth rates [29].

The results of those studies show that, in addition to the increase in number and intensity of extreme events (such as droughts and floods), the bigger climate variability will likely have direct and indirect impacts on the economic and social development. In fact, climate change, differently from other drivers, determines how much water there is in the Earth system, while other drivers, being demand-side drivers, influence how much water is required. In other words, climate change directly affects the hydrologic cycle by altering the quantity (and quality) of water resources, both for ecosystem and human activities.

In history, humans have learnt how to manage water resources, by practically finding solutions to the naturally occurring variability. Now, the threat of climate change concurs to increase the natural variability, introducing greater uncertainties in the quantity and quality of long term water supplies and posing problems for their sustainability.

In summary, the emerging key messages are as follows. First: there is evidence that the global climate is changing, and the main impacts of climate change on humans and the environment occur through water. Second: climate change is a fundamental driver of change in water resources and an additional stressor through its effects on other external drivers. Third: policies and practices for mitigating climate change or adapting to it can have impacts on water resources, and the way we manage water can affect the climate.

7. Conclusions

One of the most urgent challenges facing the world today is ensuring an adequate supply and quality of water in light of both burgeoning human and ecosystem needs and climate variability and change. Variations in evaporation and precipitation patterns due to climate and land use changes, as well as increasing water usage to meet human needs, are fundamentally changing the availability, quality, and timing of water across the globe. Despite its importance to life on Earth, there are major gaps in our basic scientific knowledge of the water cycle, including the impact of a changing climate and human activity on water availability and quality.

How can we protect ecosystems and better manage and predict water availability for future generations given alterations to the water cycle caused by climate variability and change and human activities?

In order to address this question, a holistic approach is needed, involving the predictive understanding of the complex water cycle and water resource processes, the feedbacks associated with the water system, and the vulnerability and resilience of water systems to climate and anthropogenic change. There have been few attempts to study an entire water system with an integrative, systems science approach or even study similar aspects of different water systems in a comparative sense that will develop such a framework.

The scope of the conference organized by the IGU Commission for Water Sustainability, entitled "Managing water in a changing world", in July 2009 in Turin, has been to draw together an interdisciplinary group of scientists and technologists to analyze water sustainability problems and relations with climate change, in order to try and answer the above mentioned questions.

The papers contained in this special issue of Water represent the most relevant subjects discussed during the conference. They have been chosen with the aim to show the different aspects of the problems covered by the expression "water sustainability" in several areas of the world, and suggest different possible solutions.

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