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LOOKING BACKWARD TO LOOK FORWARD: WATER USE AND ECONOMIC GROWTH FROM A LONG-TERM PERSPECTIVE

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ABSTRACT

Recent research has examined the relationship between natural resources and economic growth. Considered vitally important, not only for humanity's well-being but also for ecosystem integrity, the relationship between water use and economic growth has traditionally garnered little attention by analysts. This paper studies water use trends from 1900 to 2000 throughout the world, and their main determinants. To do this, we first analyse historical water use trajectories. Second, to proceed with the determinants of water use, we reformulate the IPAT equation (Ehrlich and Holdren, 1971; Commoner et al. 1971), decomposing water use trends into changes in economic demands and in water use intensity. Finally, a simple scenario analysis is conducted, to project future water use trends under different economic, demographic and technological assumptions.

The empirical evidence shows that economic and population growth have been crucial for explaining the increase in water use over the past 100 years, with significant regional differences. Nevertheless, the decline in water use intensity has been responsible for a significant reduction in the growth of total water use.

Keywords: Water use, environmental impacts, economic growth, IPAT model, scenario analysis.

RESUMEN

Investigaciones recientes han abordado la relación entre recursos naturales y crecimiento económico. La relación entre uso de agua y crecimiento económico es de vital importancia no solo para el bienestar de la humanidad, sino para el funcionamiento del ecosistema. Sin embargo este tema, no ha generado demasiado atención entre los investigadores. En este trabajo se estudian las tendencias en el uso de agua desde 1900 hasta el año 2000 para el conjunto del mundo y sus principales determinantes. Para ello, primero se analizan las trayectorias históricas en el uso del agua. En segundo lugar para analizar los determinantes del uso de agua, se reformula la ecuación IPAT(Ehrlich and Holdren, 1971; Commoner et al. 1971), descomponiendo la evolución en el uso de agua en cambio en su demanda y en la intensidad en su uso. Finalmente, se estima un escenario simple para proyectar las tendencias futuras en el uso de agua bajo diferentes supuestos económicos, demográficos y tecnológicos.

La evidencia empírica muestra que el crecimiento económico y de la población han sido cruciales para explicar el incremento en el uso de agua en los últimos 100 años, aunque con diferencias regionales significativas. Sin embargo, el declive en la intensidad en el uso de agua ha sido responsable de una reducción significativa en el crecimiento del uso total de agua.

Palabras clave: uso de agua, impactos ambientales, crecimiento económico, modelo IPAT, análisis de escenario

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1. Introduction

Water resources play a crucial role on earth. Water is essential for human and ecosystem needs and, given its non-substitutive nature, the availability, use and management of freshwater is vital not only for human welfare, but also for environmental conservation.

It is undeniable that the limited supply of freshwater, coupled with an exponential growth in demand, seriously threatens the integrity of the natural world as well as the well-being of humanity. The global water crisis is one of the challenges to be faced in the twenty-first century, thus sustainability becomes a central issue for all regions and sectors. In this way, international agencies are increasingly coping with water stress problems, setting water-related goals, especially since 1972 (UN Water, 2009).

Looking back, water use experienced a sharp rise; according to L'Vovich and White (1990), global water withdrawal increased thirty-five-fold from 1687 to 1987. Consumption followed a similar path in the long term. McNeill (2000) shows a forty-fold increase in freshwater consumption from 1700 to 1900 and a seven-fold rise in the twentieth century.

Agriculture has walked hand in hand with water use increase through irrigation growth to achieve food security for large populations. Today, agriculture accounts for 66% of freshwater withdrawals and 85% of freshwater consumption. The remaining water uses spread at the same time as economic development advanced. From the beginning of industrialization, when industrial water use was negligible, a substantial growth has taken place. Today, industry accounts for about 20% of total freshwater withdrawals. During the twentieth century, urban populations experienced a huge rise. As a result, urbanization created a greater need for water. In spite of its steady increase, urban use currently accounts for 7% of the total (Shiklomanov, 1999).

In this general context, our work aims to study the drivers of water use from a long-term perspective. More concretely, we analyze world and regional trends in water use during the last century and their relationships with population, economic growth and technological change. On the basis of this analysis, we anticipate possible scenarios regarding water stress in the future.

In this paper, we will only consider quantity related issues; however water availability is also influenced by poor quality of hydrological resources (Tsuzuki, 2009).

Similarly, changes in water quality imply dangerous effects to human and biodiversity health, in addition to exacerbating the lack of water, making the analysis of the relationship between growth and water quality from a global perspective one of the natural extensions of the research.

To date, a number of studies have examined environmental pressures from an economic perspective, bringing the consequences of unsustainable resource use to the forefront. This literature mainly focuses on the long term (Kander and Lindmank, 2004; Gales et al., 2007) and on the recent past (Feng et al., 2009). However these investigations basically aim to assess the evolution of energy use or pollution emissions.

To our knowledge, when it comes to water withdrawal from a global and historical perspective, little research has focused on this limited resource given the lack of reliable regional and world data. Some studies, such us L'Vovich and White (1990) Shiklomanov (1999), Glokany (2002), Barbier (2004) and Gleick (2009), have made a general assessment of water resources and only a few of them have focused on the relationship between water and income (Cole, 2004; Katz, 2008), studying the cross-country evidence for recent water data. Nevertheless, the long-term perspective has often been excluded from the analysis, mainly due to the lack of reliable historical data on global water use[1]. Data from Shiklomanov (1999) could help to bridge this gap to some extent.

As far as we know, this paper is the first attempt to analyze the determinants of water use trends in the long term from a global perspective, as well as disentangling the major drivers responsible. In this regard, the IPAT model (Ehrlich and Holdren, 1971) is reformulated and adapted for the case of water withdrawal to analyze the general twentieth century trends in water use, and to identify the major components underlying water use dynamics. This analysis will be the baseline scheme to formulate scenarios on economic and demographic growth, in which we analyze water pressures under different hypotheses of population and economic growth. We strongly believe that a clear understanding of the past becomes fundamental in tackling present and future problems. That is, looking back at historical water use can offer some lessons in order to manage current and future water scarcity in the world.

[1] On the contrary, there exist an abundant and interesting literature studying more specific topics such as water footprint (Hoekstra et al, 2009; Hubacek et al, 2009), virtual water (Hoekstra and Hung, 2002), water quality (Dabrowski et al., 2009) or water demand (Ruijs et al., 2008), for specific areas and recent periods.

Therefore, the contribution of this paper is two-fold. Firstly, the IPAT model together with the SDA decomposition offers understanding and quantification of the drivers of water use. Secondly, the combined study of demographic, economic and water use trends from a historical perspective offers guide for the future. That way, the experiences of developed regions which have register high economic and population growth rates, could allow developing areas to foresee and deal better with the effects of their development on water resources.

The results show that water withdrawal experienced a sharp rise until 1980, when a smooth levelling-off took place. On the whole, this growing trend could have been caused by the rapid upturn of population and GDP, together with the intensification of agriculture. Industrialization and the gradual increase in standards of living may also have boosted water use. The substantial decrease in intensity is probably one of the reasons behind the water use flattening of the past twenty years. Thus, it is reasonable to expect elements such as economics or efficiency improvements to have exerted a significant influence on water use.

The rest of the article is organized as follows. Section 2 reviews the theory behind the relationship between economic growth and the environment, as well as the methodology and data we use. In section 3, we present the main results of the analysis. Section 4 closes the paper with a discussion of the results and our conclusions.

2. Material and methods

Since the 1970s, social and physical scientists have shown concern over the impact of industrial economies on the environment. The work of Georgescu-Roegen (1971) and the seminal report "The Limits to Growth" (Meadows et al., 1972) marked the beginning of a more academic concern for environmental impacts associated with growth. In this line, economists such as Martínez Alier (1991) and Nakicenovic et al. (2000) claim that economic and population growth, as well as the improvement in standards of living, involved an ever-increasing requirement of energy and materials.

On the other hand, other economists maintain that higher levels of income reduce environmental degradation. They consider development essential for environmental quality and believe in a de-linking between natural resources and economic growth. From this perspective, the idea of dematerialization found support on the Environmental Kuznets Curve (EKC hereafter). Important papers (Grossman and

Krueger, 1992 and 1995; Selden and Song 1994) found empirical evidence regarding EKC and suggested three effects that explain the relationship: scale, composition and technology. In general terms, shifts towards the service sector, improvements in technology, trade, and societal changes in attitudes towards the environment have been given as contributors to the decrease of environmental damage when countries become richer (Gales et al., 2007; Ekins, 1997).

However, many environmental indicators do not show an EKC trajectory, and even theoretical and empirical rationales have been seriously questioned (Stern, 1998 and 2004). There exists an apparent consensus stating that environmental degradation is higher during the early stages of industrialization (Harper, 2000).

Nowadays the debate remains, focusing on the possible explanations of environmental trends. It seems that an agreement in situating different economic, technological and demographic factors behind the relationship between growth and environmental pressures exists. Thus, many studies have mainly focused on the analysis of the contribution of these factors. In this context, the Structural Decomposition Analysis (SDA) has been applied to the IPAT model (Ehrlich and Holdren, 1971; Commoner et al. 1971) to synthesize the role played by economic growth, population demands and technology, in explaining these environmental impacts. This methodology is applied to examine water use factors for the first time in this paper. The IPAT formula is suitable for macro-scale assessment of environmental impact drivers. However, it seems to have important drawbacks when making local scale assessments, since other factors such as policy or institutions may play a larger role (Turner, 1996). Therefore, as we are dealing with global trends, this tool appears to be useful to highlight the determinants of water use. It came out as a result of the discussion that in the early seventies took place between Ehrlich, Holdren and Commoner regarding the role of technology in environmental impact (Chertow, 2000). Subsequently, there was an intense debate on the different IPAT models, including those in the IPCC Special Report on Emissions Scenarios (IPCC, 2000).

The general idea underlying the IPAT equation is that an environmental impact can be observed as the interaction result between economic growth, population trends and environmental impact per unit of GDP and this relationship can be expressed in a multiplicative way.

$$Envir\,Impact = I = P * A * T = Population * \frac{GDP}{Population} * \frac{Envir\,Impact}{GDP} \quad (1)$$

Thus, in the expression above, I summarises the environmental impact, P stands for population (Nakicenovic, et al., 2000) and A (usually measured by GDP per capita) refers to affluence, being a proxy for living standards or wellbeing. Variable T generally means I/GPD, that is, environmental impact per unit of GDP, or environmental intensity. This latter factor is the most difficult to define and quantify, since other important elements, apart from technology, are also captured (economic structure, factor endowments, geography, infrastructure, cultural history and/or climate)[2]. Deitz, Rosa and York (2007), use a comparative study to demonstrate that population and affluence are the main determinants of environmental change, while "other widely postulated drivers (e.g. urbanization, economic structure, age distribution) have little effect". Methodologically, a similar expression can be derived in terms of the forces driving water use:

$$W_t = N_t * \frac{Y_t}{N_t} * \frac{W_t}{Y_t} = N_t y_t w_t \quad (2)$$

In this case, water consumption in a period t can be expressed as a result of the interaction between population (represented by N), per capita income (y) and an index of water intensity (w). Thus, trends in water use, in general terms, will be linked with the evolution of these three variables, as has been explained above.

Analytically, in order to study trends in water use and disentangle the forces contributing to this trend, SDA is applied.

In general terms, SDA tries to separate a time trend of an aggregated variable into a group of driving forces that can act as accelerators or retardants (Dietzenbacher and Los, 1998; Hoekstra and van der Berg, 2002; Lenzen et. al., 2001).

Generally speaking, considering a variable y depending on n explicative factors $y=f(x_1,\ldots x_n)$, additive structural decomposition can be obtained through its total differential.

$$dy = \frac{\partial y}{\partial x_1} dx_1 + \frac{\partial y}{\partial x_2} dx_2 + \ldots + \frac{\partial y}{\partial x_n} dx_n \quad (3)$$

On the basis of a multiplicative relationship, that is $y=x_1 \ldots . x_n$, expression (4) holds:

[2] For an thorough review of this methodology, rationale, applications, extensions and criticisms, see Chertow (2000).

$$dy = (x_2 x_3 \ldots x_n) dx_1 + \ldots + (x_1 x_2 x_3 \ldots x_{n-1}) dx_n = \sum_{i=1}^{n} \left(\prod_{j \neq i} x_j dx_i \right) \quad (4)$$

In a discrete schema, when we try to measure the changes in the dependent variable between two periods, t-1 and t, there are different ways of solving this expression by way of exact decompositions, which leads the well-known problem of non-uniqueness of SDA solution. In our case, if decomposition is based on three factors, we can obtain the following 3! exact decompositions. In practice, as a "commitment solution", the average of all possible solutions is considered. Nevertheless, as Dietzenbacher and Los (1998) demonstrate, the simple average of the two polar decompositions runs as a good approximation to the average of the 3! exact forms.

Thus, based on (2), the two polar decomposition forms of ΔW_t can be written as follows:

$$\begin{aligned} \Delta W_t &= W_t - W_{t-1} = N_t y_t w_t - N_{t-1} y_{t-1} w_{t-1} = \\ &\Delta N_t y_t w_t + N_{t-1} \Delta y_t w_t + N_{t-1} y_{t-1} \Delta w_t = A_{1t} + A_{2t} + A_{3t} \end{aligned} \quad (5)$$

$$\Delta W_t = W_t - W_{t-1} = \Delta N_t y_{t-1} w_{t-1} + N_t \Delta y_t w_{t-1} + N_t y_t \Delta w_t = B_{1t} + B_{2t} + B_{3t} \quad (6)$$

and taking the average,

$$\begin{aligned} \Delta W_t &= \frac{1}{2}(A_{1t} + A_{2t} + A_{3t}) + \frac{1}{2}(B_{1t} + B_{2t} + B_{3t}) = \\ &\frac{A_{1t} + B_{1t}}{2} + \frac{A_{2t} + B_{2t}}{2} + \frac{A_{3t} + B_{3t}}{2} = PE_t + INE_t + IE_t \end{aligned} \quad (7)$$

In this way, water use evolution can be obtained as a result of the contribution of population, income and intensity effects.

$$PE_t = \frac{w_{t-1} y_{t-1} + w_t N_t}{2} \Delta N_t$$

$$INE_t = \frac{w_{t-1} N_t + w_t N_{t-1}}{2} \Delta y_t$$

$$IE_t = \frac{y_{t-1} N_{t-1} + y_t N_t}{2} \Delta w_t \quad (8)$$

This methodology is applied to a regional water withdrawal dataset from Shiklomanov (1999) over the period 1900-2000. This dataset, prepared for the Comprehensive Assessment of the Freshwater Resources of the World in the framework of the

International Hydrological Programme (IHP) of UNESCO by the Russian IHP National Committee, contains data on global freshwater resources from 1900 to 1995 as well as forecasts for 2000, 2010 and 2025 and covers all economic regions and continents in the world. Since our main goal is to examine aggregate trends from a long term perspective, we use regional and global historical data. For a more specific study on local facts, country or basin data should be used. To carry out the analysis, we need income and population data series. Income is measured by GDP (in 1990$ on a Purchasing Power Parity basis) and comes from Madisson (2010). Population information is also provided by Maddison (2010).

3. Results and Discussion

In order to organize the results and discussion, this section is divided into three subsections: the analysis of global and regional water withdrawal features (section 3.1), the quantification of the factors that entail changes in water use and the explanation of these determinants (section 3.2) and finally, the results from the scenario analysis (section 3.3).

3.1. Historical water use

Figure 1 and table 1 show the main features in water use from 1900 to 2000, both in global terms and for the seven regional areas in which the world has been divided[3].

Insert Figure 1

Insert Table 1

A first look at the data shows that water withdrawal increased approximately seven-fold, from 539 cubic kilometres per year in 1900, to 4,000 cubic kilometres in 2000. As shown in figure 1, throughout the twentieth century there was a continued growth in per capita income, and global freshwater withdrawal also experienced a continuous climb, with a weak levelling-off from the 1980s, which can be inferred from the positive but downward annual growth rates. This expansion was slightly faster in the

[3] These areas do not exactly match up with the ones presented by Shiklomanov (1999). We have deleted the former Soviet Republics from Europe and Asia to make a new region called Ex Soviet Union. Additionally, Central America and Caribbean have been removed from North America and added to South America. Thus, we are able to analyze water use trends together with regional population and per capita income data.

second half of the twentieth century and especially in the 1950s, when the highest annual growth rates were reached (3.6%). Since that time, freshwater use continued to expand, although much less rapidly than in the past. In fact, from 1990 to 2000, the average annual growth rate decreased to 0.9% (table 1).

From a *regional* perspective, a general trend can also be found; water withdrawal went up gradually in this period. That is, both developed and developing areas displayed an upturn trajectory through the twentieth century. Nonetheless, this hefty growth became weaker, mainly from the 1980s. This was particularly true in the developed areas, where water use deceleration was sharper.

North America and the ex-USSR show a growing trend that reverses from 1980. However, the reasons for this decline in water withdrawal seem to be completely different. While in the former, this change could be due to do a wide range of factors that will be examined in section 3.2., in the latter it may have a lot to do with its economic transition.

On the other hand while in the developed areas, water withdrawal growth is higher during the first half of the century, the developing regions exhibit sharper growth from 1950. As observed in the global pattern, every region but the former USSR and Oceania reached the peak of annual growth rates through the 1950s and '60s (Table1). Developed regions, i.e. North America and Europe, show the greatest annual growth rates.

In short, we have identified a long-term increase in water use that seems to have steadied somewhat. But, we should ask, what are the forces that have driven the increase in water use in the long term?

As has been stated, on the basis of the IPAT model, water use trends are decomposed into three components, showing the effects of population growth, economic growth, and other factors underlying water intensity changes. The results for different time periods and regions are presented in Tables 2 and 3[4].

If we look at water use growth rates we can perfectly distinguish three stages. The first half of the twentieth century shows moderate annual growth rates, water use accelerates from 1950 to 1980, with growth rates ranging between 2.3% and 3.6%.

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[4] In table 3, if $\Delta W > 0$, positive signs on the different effects indicate that they contribute to the increase in water withdrawal. If $\Delta W < 0$, a negative sign on a component entails that it plays a part in the increase in water withdrawal. An effect promotes water withdrawal stabilization or decline if, and only if, it exhibits a positive sign. Furthermore, if changes in water use are insignificant, percentages will shoot up due to simple calculations.

Finally the pace of water use moderates from 1980. For that reason and to represent possible changes in long-term trajectories, we have divided the twentieth century into three periods: 1900-1950, 1950-1980 and 1980-2000.

Insert Table 2 and Table 3

To begin with, consider the world. For 100 years, global water withdrawal described a significant upward trend (Table 2). Basically, Table 3 shows how population and especially income growth, that is, demand for freshwater, boosted aggregate withdrawal. In turn, the constant drop in intensity prevented a greater increase.

It seems undeniable that the income effect stands out compared to the other components. This is particularly true until 1980, given that from this moment intensity becomes stronger. During the first half of the century, the contribution of GDP growth to the increase in water use was 60%, and it notably increased during the three following decades. Taking growth rates into account (Table 2) we can see the vast growth of income between 1950 and 1980. The ratio of water use to GDP steadily decreased throughout the twentieth century. It is in the last two decades that the intensity effect appears to be the most prominent. From 1980 to 2000, this effect fell about 1.8% every year.

Broadly speaking, every region follows a path similar to the world as a whole. Nevertheless, it is feasible to divide the world into two different groups. On the one hand, North America, Europe and Oceania, that is, developed areas, share many aspects and are included in the same cluster. On the other hand, developing regions differ significantly from the others, and are classified as a different group.

In developed areas, the income effect has been the most important determinant of water use, mainly during the second half of the twentieth century. Moreover, the intensity effect appears to have encouraged water use moderation.

North America is the only case in the world where, between 1980 and 2000, intensity outbalances the sum of population and income, involving a vague but vital fall in water withdrawal levels. The decrease in water use levels takes place during the eighties, mainly due to the great improvement in intensity that decreases annually at 3.7%, more than twice the rate of the preceding periods. Per capita levels of water use show enormous differences between regions[5]. Although developed areas display higher

[5] Data on per capita water use for all the regions available on request.

figures, there is no doubt that per capita water use reaches astonishing different values at very similar income levels mainly depending on the prevailing urban approach and other land-use related issues. These diverse land-use patterns clearly oppose European cities with the typical North American conurbations. The high per capita water use seen for North America could have led to efficiency improvements once the turning point was reached.

On the other hand, the less developed areas of the world describe a different evolution from the other regions. Nonetheless, in this case it is less viable to set a common pattern, since they are more heterogeneous.

Although, throughout the developing world, per capita GDP and population growth trigger water withdrawal, the relative importance of both has not been the same. On the whole, population has been a more important driver than income. In developing countries, the reduction in intensity has not offset the impulse of income and population on water use, but has dampened it, except for Asia between 1900 and 1950 and the ex-USSR from 1950 to 1980.

The decline in per capita GDP between 1980 and 2000 caused a reduction in water demand for economic purposes in both Africa and the ex-USSR. In the latter, contrary to what happened in Africa, this decline was so intense that it allowed the offsetting of the smooth push caused by population and intensity.

3.2. Looking behind the data

In what follows, we analyse in depth the main features that could have driven income, population and intensity effects.

3.2.1. Income effect

The increase in per capita income has been one of the most important economic facts for humanity during the two last centuries. Per capita income has affected freshwater use from different perspectives.

Growing per capita income not only increased the demand for food, but also modified consumption patterns. Improvements in standards of living have brought about dietary changes. Consumption of water-intensive goods such as fruit and vegetables has increased sharply, resulting in a significant increase in water use. However, the most serious strain on freshwater resources comes from the mounting weight of meat in the consumption package as income grows[6]. To cope with the increase in demand, agriculture has substantially increased its production throughout the past century. The expansion of irrigation has contributed significantly to this increase in production; the global irrigated area jumped from approximately 48 millions of hectares in 1900 to 235 millions of hectares in 1989 (Gleick, 1993). The development of modern irrigation systems has been also identified as a necessary condition for the efficient use of the agricultural technologies that emerged in the second half of the 20th century (Hayami and Ruttan, 1985). In the case of the Green Revolution, the new high-yield varieties worked best where irrigation infrastructure was already available and chemical fertilizers were widely used (Federico, 2005). A great investment in dams and irrigations canals became necessary and, accordingly, food supply more than doubled and water withdrawal grew by 2.81% annually. Consequently it was the intensification of agriculture that caused water withdrawal figures to soar, as agricultural water use (60% of the total) is the most important.

The economic growth is also associated with industrialization and urbanization. Water was increasingly used in production processes for purposes such as cooling, transportation, solvents and so on. Accordingly, the development of the industrial sector meant an increase in water demands. On the other hand, the growing urbanization entailed that as income rises, so does the facilities and amenities that people enjoy. Furthermore, the gradual provision of water for urban needs increased water use (Briand et al., 2009).

Geographical and temporal differences in economic growth could help us to see the different relevance of this factor as determinant of water use. The importance of per capita income improvement as driving force of water withdrawal in developed countries, like Europe during the first half of the 20th century, could be perfectly understood if we take into account its pioneer character regarding industrialization and economic growth. On the contrary, the late entrance of developing areas, such as Asia, in the process of development explains that it is not until the second half of the twentieth century when per capita income shows a higher share than population growth.

3.2.2. Population effect

[6] The production of a kilogram of wheat requires between 900 to 2,000 liters of water, and that of a kilogram of beef, between 15,000 to 70,000 liters (Gleick et al., 2009).

Undoubtedly, one of the most impressive changes of the past century has been population growth. Data from Madison give evidence of the sharp rise taking place during the last 100 years, from approximately one billion to six billion people. Annual global population growth rates were about 1.3% during the twentieth century. The demographic transition was not only a key phenomenon concerning socioeconomic changes of developed countries during the first half of the twentieth century and second half of the ninetieth century, but has spread to developing areas from 1950 (Reher, 2004). From Table 2, we can perfectly see how population exerted a considerable impact on water use throughout the century. However it was not until the period 1980-2000 that population and income gave a similar boost to worldwide water use.

3.2.3. Intensity effect

Intensity is, without doubt, the most difficult component to quantify and explain. The ratio of water use to GDP includes a variety of elements such as technological or structural change, that are quite difficult to measure.

We will try to disentangle the intensity effect by examining some of the factors that, in our view, could lie behind the trajectories followed by the intensity effect through the twentieth century.

From the beginning of the twentieth century to the late 1970s, efficiency improvements were absolutely ignored. Water users paid a negligible price, supply side approaches relied on the construction of highly-subsidized hydrologic infrastructure, and wastewater discharges were rarely penalized. This involved a great disincentive for the implementation of water conservation practices in every region and economic sector. From the mid-1970s, things began to change, especially in developed countries. Water was no longer considered an unlimited and cheap resource and a broad array of technical, managerial and institutional instruments were introduced. These changes have generally affected both the efficiency with which current needs are met and the efficiency with which water is allocated among their users (Gleick, 2000).

Although agriculture received no attention during the boost of irrigation, important advances have recently been implemented. In this regard, some of the most effective methods for saving agricultural water are micro-irrigation techniques, such as drip or micro-sprinkler irrigation. According to Reinders (2006), the area under irrigation experienced a seven-fold increase during the last two decades of the twentieth century, from 436,590 ha. in 1981 to 3,201,300 ha in 2000. In spite of this extraordinary step forward in water conservation, land under drip or sprinkler irrigation, globally, today only constitutes about 1% of total irrigation. That is, developing regions seem to lag a long way behind developed areas. Nonetheless, growing use of these methods has taken place in both developed and developing countries during the 1990s. Recently micro-irrigation has become more affordable, allowing putting these innovations into practice in developing countries and for low value crops.

During the 1990s, income growth allowed some industrial processes to undergo a period of transition from inflow to circulating water supply systems. This shift was especially acute in developed countries.

As we said before, managerial and institutional changes can also involve efficiency incentives. Water metering, which began in the 1960s (Anderson, 1995), has led to important water savings in some areas like California and Israel. In the same way, water pricing enhanced water-use efficiency.

When dealing with other resources (Collard et al, 1988; Jänicke et al, 1997), some authors have suggested that the composition of an economy could be an important factor in accounting for the historical pattern followed by energy use, pollutant emissions, etc. From this historical perspective, one of the main features of modern economic growth has been structural change. It consists of a quicker growth of the industrial and service sectors than agriculture. This fact led to an increased weight of the apparently less water-intensive economic sectors; that is why the structural change implies a decline of water withdrawal figures relative to GDP, that is, of intensity.

In our case, the re-allocations of water seem to be negligible, due to the relatively greater weight that agricultural water withdrawal contributes. Industrial development and urbanization meant a substantial increase in water use. However, in general, this increase was not at the expense of agricultural use, given that agriculture was and is still the primary water user in the world.

Changes within the various economic sectors have also been able to decrease the intensity of the use of water. According to Gleick (1999), one of the reasons for industrial water use decline in the U.S. since 1970 has been the change in the mix of industries. In this case, water would shift from water-intensive to less water-intensive activities. On the contrary, as we have already said, that is not generally the case in agriculture, since production tends to move towards highly water- intensive crops over time.

Economics may also be a determining factor in water evolution. Roughly speaking, the twentieth century could be divided into two stages.

The first covers the period 1900-1980. During this time, water was believed to be abundant and inexpensive, and no efforts were devoted to its conservation. Governments and international institutions got involved in water management, giving financial support to water infrastructure. This process was exceptionally intense between 1950 and 1980, when the boom of irrigation took place. Dams, canals, and pipelines spread at an unprecedented pace. Governments and international agencies subsidized not only the construction costs of macro projects, but also the delivery and distribution of water. Moreover, the externalities of these projects were entirely ignored. As a result, water was underpriced and there was a significant degree of overspending.

However, from 1980 onwards, economics hampered the continuation of the existing approach: water was no longer cheap and plentiful, but had become a costly and scarce resource. The outstanding decrease in the intensity effect that entailed a leveling-off in water withdrawal could find a financial explanation. During this time, suitable locations for dams or irrigation canals had already been taken up. Both rehabilitation and especially construction of new ones became more and more expensive. The tremendous exploitation of groundwater entailed going deeper into aquifers and thus growing capital costs of pumping water. High financial costs, together with low crop prices, led to diminishing returns for irrigation (Postel, 1999). In sum, the costs of regulating water turned out to be greater than the value of food production.

Accordingly, new management directions appeared. Although we can still find public projects, especially in developing countries, there now seems to be a trend towards the reduction of public funding for hydraulic infrastructure. When water supply became scarce and expensive, water saving was encouraged.

Another of the possible explanations for the influence of water intensity on water use could be the increasing interest in environmental issues. During the first half of the twentieth century, economic growth was given priority in most regions at the expense of environmental deterioration. This led to a dramatic increase in hydrological projects in order to meet water demands. As a result, water use rose considerably, water quality was seriously damaged, many freshwater habitats were endangered, and many animal species came under serious threat.

From the early 1970s, environmental awareness notably grew all over the world. The emergence of new environmental values meant a significant change in the conception of water ecosystems. Until the '70s, freshwater resources were considered unlimited. From this moment, the idea of a necessary balance between economic development and freshwater resources emerged. This governing belief influenced water policies and management. As environmental ideas upgraded, opposition to large scale water constructions became stronger. Water policy gradually added ecological ideas and water management addressed many concerns of the environmental movement. Likewise, the re-allocation of water to the environment is gradually achieving one of the main environmentalist goals, water ecosystems restoration. Accordingly, a new paradigm for water planning emerged (Gleick, 2000). As a result of the implementation of these new policies, gains in efficiency have been possible. This could be the case of urban water consumption (Tello and Ostos, 2010).

3.3. Perspectives on water use in 2050. Results from a scenario analysis

Once we have look backward, let's look forward to design a simple scenario analysis on the water-use pattern that can be expected in the first half of the 21st century. The observed historical trajectories of population, economic growth and intensity help us to project the value of these three factors in 2050. To build the scenarios regarding population, and following Reher (2007), we have considered low and medium variants of UN population prospects. Under these assumptions, global population will have a yearly growth rate of 0.53% in the low variant and 0.81% in the medium. Per capita income has been projected taking into account average annual growth rates obtained for the period 1995-2005[7].

We contemplate four possible scenarios for water use intensity. The degree of optimism with which we look at the reduction in the use of water per unit of GDP is the difference between them. In the most pessimistic case, let's assume a 10% improvement in global water intensity. The most optimistic would be one in which, as proposed by Harper (2000), developed areas achieve a factor 7 improvement in intensity and developing regions intensity is twice the European levels of 2000. Subsequently we suppose two intermediate situations. In the first, the ratio of water use to GDP notably decreases in developing regions. However it is still twice the intensity of the developed

[7] This yearly growth rate can be considered unrealistic, given that years of economic crisis are not included in projections. At this moment, it is difficult to elucidate a realistic growth rate for the next 40 years. In any case, we consider that these values (a maintained per capita growth rate equal to that corresponding to the 1995-2005 period for each region) can be interpreted as an upper limit to economic growth for the next 40 years.

world, where it converges to European levels. In the second, water use intensity reaches European standards all over the world.

Insert Table 4

On these assumptions, we obtain the results in Table 4, which displays different future situations given the year 2000 as a baseline. Worldwide water use will continue to grow under most hypotheses. Only the most optimistic scenario shows a flattening in global water withdrawal from 2000 to 2050. That is, assuming low population growth, together with the highest reduction in intensity.

In all other scenarios with low population growth, the use of water would globally increase from a minimum of 14 percent to a maximum of 177%.

If we now suppose a medium population growth, and an economic growth that projects 1995-2005 annual rates, the results are even worse. Under these circumstances, the best global result leads to a 14% global rise of water use. The most pessimistic case entails a more than three-fold expansion in overall water use.

It is undeniable that these results are strongly determined by the former assumptions. However, it is probably reasonable to argue that water use is expected to follow an important growing trend during the period 2000-2050. Population and affluence seem to keep expanding into the future, especially in developing regions. This growing demand can only be offset by a great improvement of the ratio of water use to GDP. In our analysis, we have presented several scenarios concerning intensity. Only in the most optimistic of these, scenario 4, would water use remain steady.

Furthermore, these conclusions fit with the predictions made by Shiklomanov (1999) and Gleick (2009), who respectively forecast a 31% increase in global water use by 2025, and an approximate 40% rise by 2020.

Could these increase forecasts on water demand be sustained? Under a cautionary way we follow the "thirds" hypothesis proposed by Margalef (1996). He suggested that at least two thirds of total freshwater must be left to surface runoff and resource endowment, if natural systems are going to be kept in a healthy state able to provide environmental services to us. Therefore, those scenarios that forecast a withdrawal above 33% of freshwater resources seem rather unlikely. That way, the most pessimistic scenarios regarding intensity seem to be unreal, specially in those regions where a great population growth is expected.

In sum, if the current demographic and economic trends persist, an institutional, technological, or structural change that allows a reversion of water use patterns seems to be unlikely.

4. Conclusions

In this paper, we have analysed the evolution of water use throughout the twentieth century, and assessed the extent to which certain demographic, social and economic factors have contributed to the water withdrawal pattern, and will affect future trajectories.

Both global and regional evidence clearly illustrate a great expansion of water use. Population growth, economic development and the intensification of agriculture have been identified as some of the main drivers for this growing trend. Rather, efficiency improvements, structural change, environmental concerns, and the increasing costs of supplying water, have made population and income growth compatible with a slight levelling off in water use from 1980.

In regional terms, water withdrawal has followed a similar path, i.e., a quick climb that stabilized during the last two decades of the century. Nevertheless, the three effects behave distinctly, depending on the region considered. Chiefly, the income effect is more closely related to water use in developed areas since 1900. Likewise, the intensity impact on freshwater use was more abrupt in the developed regions. However, the population effect was comparatively more important in developing areas. We find that North America stands out from the other areas because of the decline in water withdrawal during the period 1980-2000, this drop being largely driven by the intensity effect, since it offset the boost given by income and population growth.

On the whole, as seen in our analysis of various scenarios, water use will describe a growing trend during the first half of the twenty-first century. Only in one of the eight future pictures would global water withdrawal remain stable. Even if important improvements in efficiency took place, water use would grow, mainly in developing regions, where significant increases in population and affluence are expected.

In sum, although from 1900 to 2000, we have managed to increase production with gradually less freshwater needed per unit produced, water withdrawal appears destined to grow.

This study offers great scope for further research. As we commented previously, intensity comprises a wide variety of interdependent factors that are difficult to measure. One of the natural extensions of this research would involve opening the "black box" of long term water intensity. Moreover, it would also be really interesting to separate aggregate water uses. That way, we would be able to study water withdrawal form a local and sectorial perspective.

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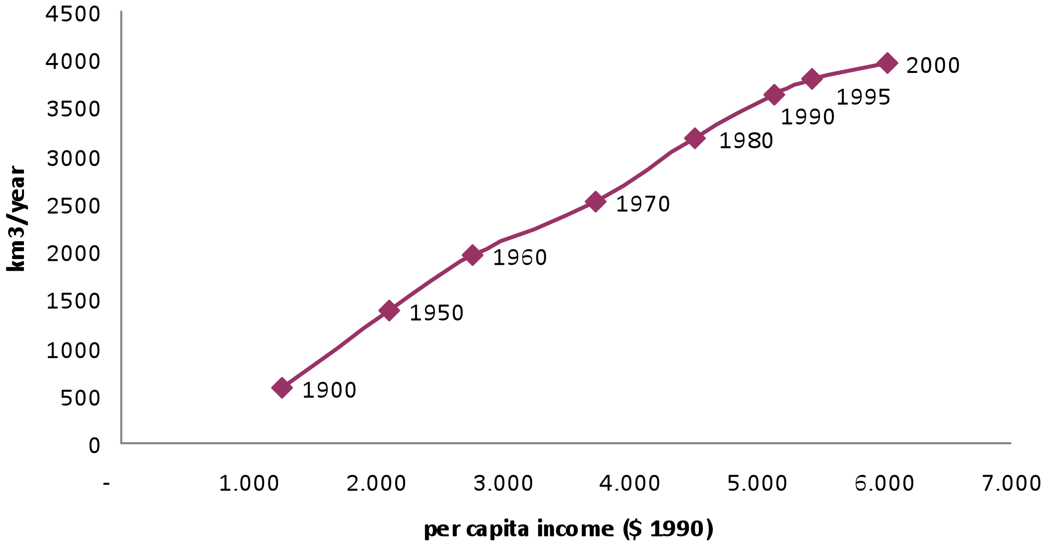
Figure 1: Worldwide water withdrawal, 1900-2000



Source: Own elaboration from Shiklomanov 1999.

Table 1: Cumulative annual average growth rates in water withdrawal (%)

	1900-1950	1950-2000	1900-2000	1950-1960	1960-1970	1970-1980	1980-1990	1990-2000
Africa	0.6	2.9	1.8	4.8	3.3	3.0	2.0	1.5
Latin-America	2.0	2.9	2.5	3.9	2.9	3.9	2.0	2.0
North America	3.1	1.6	2.3	3.4	3.1	1.6	-0.6	0.5
Oceania	3.8	2.3	3.1	3.4	3.2	1.7	1.9	1.3
Europe	2.7	2.3	2.5	5.1	2.8	2.2	0.8	1.0
Asia	1.4	2.1	1.8	3.3	1.9	1.8	2.1	1.3
Ex-USSR	1.7	2.3	2.0	3.1	5.0	5.5	0.9	-2.7
World	1.8	2.1	1.9	3.6	2.5	2.3	1.4	0.9

Source: Own elaboration from Shiklomanov (1999)

Table 2: Yearly growth rates in water use, population, per capita GDP, water use intensity (1900–2000)(%).

		W	N	y	w
Africa	1900-1950	0.63	1.47	0.79	-1.6
	1950-1980	3.7	2.5	1.79	-0.61
	1980-2000	1.75	2.68	-0.23	-0.68
Latin America	1900-1950	1.99	1.9	1.64	-1.52
	1950-1980	3.57	2.53	2.71	-1.65
	1980-2000	1.97	2	0.26	-0.28
North America	1900-1950	3.1	1.43	1.71	-0.06
	1950-1980	2.69	1.4	2.26	-0.97
	1980-2000	-0.08	1.09	2.11	-3.2
Oceania	1900-1950	3.81	1.62	1.26	0.88
	1950-1980	2.75	1.88	2.06	-1.18
	1980-2000	1.63	1.26	1.99	-1.59
Europe	1900-1950	2.71	0.51	0.91	1.26
	1950-1980	3.34	0.7	3.53	-0.88
	1980-2000	0.85	0.28	1.74	-1.15
Asia	1900-1950	1.42	0.93	0.23	0.26
	1950-1980	2.35	2.09	3.54	-3.18
	1980-2000	1.69	1.69	3.17	-3.07
Ex-USSR	1900-1950	1.68	0.74	1.68	-0.73
	1950-1980	4.52	1.32	2.76	0.39
	1980-2000	-0.91	0.41	-1.81	0.51
World	1900-1950	1.76	0.97	1.03	-0.25
	1950-1980	2.81	1.89	2.57	-1.62
	1980-2000	1.13	1.59	1.45	-1.88

Source: Own elaboration from Shiklomanov and Maddison dataset.

Table 3: Contribution of any factor to water use changes (1900–2000) (%).

		ΔW(abs)*	N	y	w
Africa	1900-1950	15.1	240.1	162.5	-302.6
	1950-1980	110.2	67.2	52.2	-19.4
	1980-2000	69	153.7	-13.8	-39.9
Latin America	1900-1950	46.9	95.1	112.9	-108
	1950-1980	139.7	70.4	89.6	-60.1
	1980-2000	102.5	101.4	13.5	-14.9
North America	1900-1950	204.4	46.8	55.7	-2.5
	1950-1980	318.2	52.3	89	-41.3
	1980-2000	-9	-1393.8	-2949	4442.8
Oceania	1900-1950	8.8	43.9	30	26
	1950-1980	13.1	68.1	82.2	-50.3
	1980-2000	9	77.3	126.7	-103.9
Europe	1900-1950	85	20.5	32.4	47.1
	1950-1980	194	22.1	108.9	-31
	1980-2000	57.4	33.3	205.7	-139.1
Asia	1900-1950	395.5	65.2	16	18.8
	1950-1980	785.4	89	204.9	-193.9
	1980-2000	623.8	100	210.5	-210.5
Ex-USSR	1900-1950	47.4	44.2	106.7	-50.8
	1950-1980	232.3	30.8	59.4	9.8
	1980-2000	-52.7	-45.4	201.3	-55.9
World	1900-1950	803	55.2	60.5	-15.6
	1950-1980	1793	67	104.1	-71.2
	1980-2000	798	141.6	136.6	-178.2

* ΔW(abs) shows water use absolute variation in km^3/year.

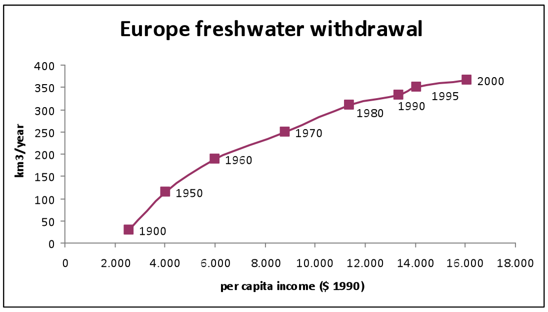
Source: Own elaboration from Shiklomanov and Maddison dataset.

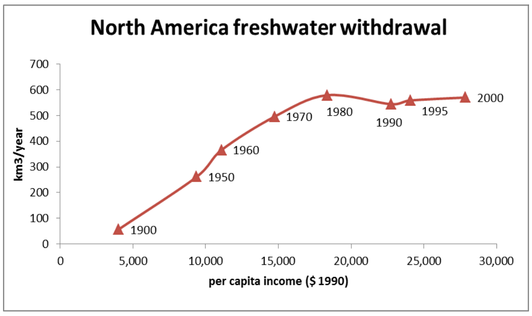
Table 4: Scenario analysis results. Water use in 2050 (2000=1)*

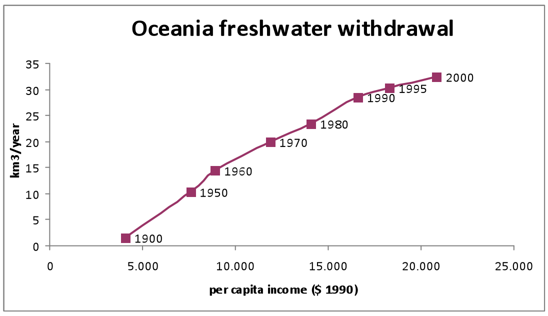
		Africa	Latin America	North America	Oceania	Europe	Asia	World
N: low variant								
y: 1995-2005								
w:10%	Scenario1	5.37	2.17	3.16	3.59	2.25	3.41	2.77
w: int.	Scenario2	2.39	1.86	2.14	2.35	2.25	1.90	1.57
w:Eu	Scenario3	1.19	0.94	2.14	2.35	2.25	0.95	1.14
w:factor7_int.	Scenario4	2.39	1.86	0.49	0.56	0.35	1.90	0.99
N:medium variant								
y: 1995-2005								
w:10%	Scenario5	6.15	2.53	3.57	4.08	2.55	2.54	3.20
w: int.	Scenario6	2.73	2.17	2.42	2.68	2.55	1.41	1.81
w:Eu	Scenario7	1.37	1.10	2.42	2.68	2.55	0.71	1.32
w:factor7_int.	Scenario8	2.73	2.17	0.55	0.64	0.40	1.41	1.14

*Values displayed in the table are W_{2050}/WI_{2000} considering W_{2000}=1 and under the corresponding assumptions on N, y and w. We consider low and medium variants of UN population (N) prospects. Per capita income (A) has been projected taking into account average annual growth rates of 1995-2005. There are four scenarios for intensity. a) w:10%, 10% improvement in global intensity. b) w: int, the developing world's intensity doubles that of the developed world, where it converges to European levels. c) w:Eu, water use intensity reaches European standards all over the world. d) w:factor7_int, developed areas achieve a factor 7 improvement in intensity, and the developing world's intensity is twice European levels in 2000.

Appendix 1


Europe freshwater withdrawal
km3/year
0
50
100
150
200
250
300
350
400
0
2.000
4.000
6.000
8.000
10.000
12.000
14.000
16.000
18.000
per capita income ($ 1990)
1900
1950
1960
1970
1980
1990
1995
2000


North America freshwater withdrawal
km3/year
0
100
200
300
400
500
600
700
0
5,000
10,000
15,000
20,000
25,000
30,000
per capita income ($ 1990)
1900
1950
1960
1970
1980
1990
1995
2000


Oceania freshwater withdrawal
km3/year
0
5
10
15
20
25
30
35
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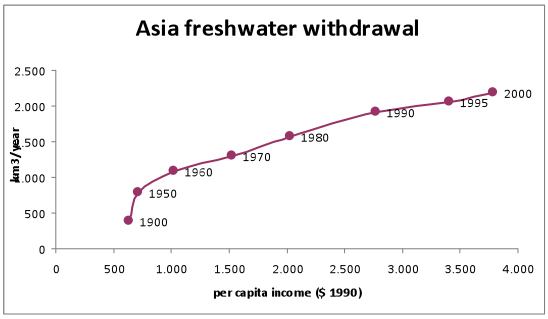
25.000
per capita income ($ 1990)
1900
1950
1960
1970
1980
1990
1995
2000


Asia freshwater withdrawal
km3/year
0
500
1.000
1.500
2.000
2.500
0
500
1.000
1.500
2.000
2.500
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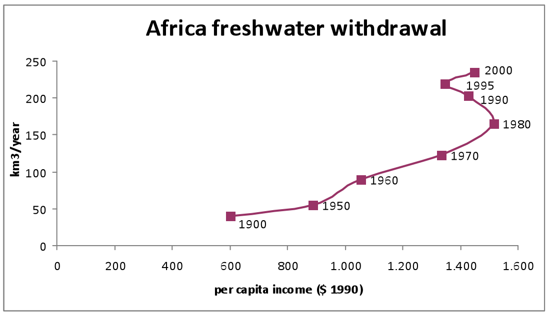
4.000
per capita income ($ 1990)
1900
1950
1960
1970
1980
1990
1995
2000


Africa freshwater withdrawal
km3/year
0
50
100
150
200
250
0
200
400
600
800
1.000
1.200
1.400
1.600
per capita income ($ 1990)
1900
1950
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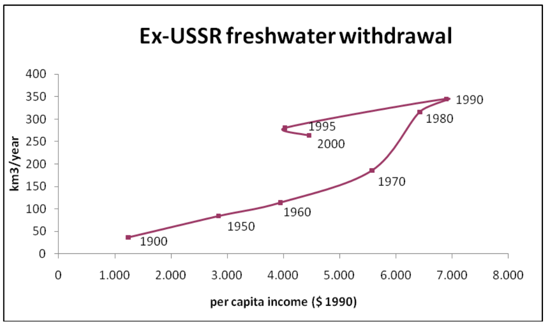
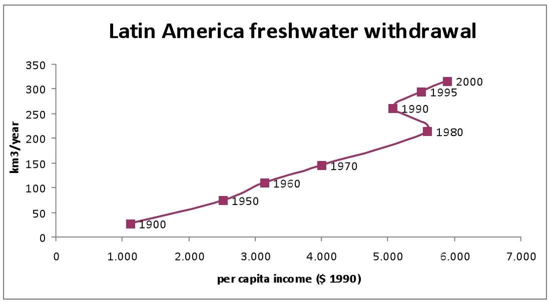
1970
1980
1990
1995
2000


Ex-USSR freshwater withdrawal
km3/year
0
50
100
150
200
250
300
350
400
0
1.000
2.000
3.000
4.000
5.000
6.000
7.000
8.000
per capita income ($ 1990)
1900
1950
1960
1970
1980
1990
1995
2000


Latin America freshwater withdrawal
km3/year
0
50
100
150
200
250
300
350
0
1.000
2.000
3.000
4.000
5.000
6.000
7.000
per capita income ($ 1990)
1900
1950
1960
1970
1980
1990
1995
2000