Challenges in Water Technologies to Cope with Water Scarcity

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Abstract

Water scarcity, if considered as an increasing process, is to exacerbate competition amongst water users. Problems related to the environment as well as water scarcity imply innovation in water management and engineering, including water technologies. In order to better understand the innovation challenges put forward by water technologies, it is necessary to recognize water scarcity regimes, whether they are natural of man-made. Thus, the paper focuses on water scarcity regimes and their related challenges before analysing differences in the needs for development water technologies confronting rural vs. urban areas as well as developed vs. developing regions. Related contradictions and challenges are put forward. Moreover, this paper analyses current difficulties resulting out the adoption of innovative water technologies as well as the importance of water management issues when the implementation of water technologies is considered.

Keywords: Water scarcity concepts, water use and consumption, efficient water use, water management

Introduction

The sustainable use of water involving resource conservation, respect of the environment, technologies' adequate usage, economic viability and feasibility and social acceptance of

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development issues is a priority, particularly as reference to those regions where water is scarce. Imbalances between availability and demand, surface degradation and groundwater quality, inter-sector competition, inter-regional and international conflicts, often occur in those regions where water is scarce, e.g., in the Mediterranean area. Innovation is, therefore, required particularly when applied to water technologies and related management issues, both for agriculture and non-agricultural water uses, which favour a reduced water. Demand.

Water is becoming increasingly scarce worldwide. Drought and aridity are the natural causes for scarcity. More recently, man-made desertification and water shortages are aggravating the natural scarcity while population is increasing and the demand for water faces an increased competition amongst water users, sectors as well as regions. Rainfall is not sufficient in the majority of regions and predictions relative to climate change show that problems are likely to increase in many regions. Thus, the quantity of water resources available is increasingly limited. In addition, the quality of water is often degraded as far as water resources are to become less and less available for more stringent domestic and industrial uses.

For decades, societies have been able to cope with water scarcity. Civilizations living in the Mediterranean areas, West Asia, India, China or Central and South America have developed and have flourished in conditions of water scarcity. Societies have developed skills to cope with water scarcity. However, knowledge that had been developed in old times has been questioned by modern societies because a society of abundance is desired everywhere. The modern way of life rooted in water abundant areas find it difficult to adapt to water scarce regions, nevertheless, local societies long for a more "developed" way of life. Contradictory issues have developed and adopted technologies are often not appropriate for the developing world or are able to cope with water scarcity. However, the sustainable use of water requires that societies effectively cope with water scarcity. Attention must be given to water quality assessment while considering water not as just as a good being regulated by price and market but as a good that has also an environmental, social, landscape and cultural value.

Water Scarcity Regimes

Water scarcity has various origins, natural and man-made, and corresponds to several regimes (Table 1): natural aridity and drought and man-made desertification and water-shortage (Pereira *et al.*, 2009).

Table 1. Nature and causes of water scarcity in dry environments

Water Scarcity Regime	Nature produced	Man induced
Permanent	Aridity	Desertification
Temporary	Drought	Water shortage

Aridity is a natural produced permanent imbalance in water availability and consists of low average annual precipitation with high spatial and temporal variability resulting in an overall low moisture and low carrying capacity of ecosystems. Aridity affects large regions of the world and is associated with high pressure on natural resources, strong competition for water, frequent soil salinity problems due to a poor management of water irrigation and vulnerable as well as fragile ecosystems. Great civilizations had developed in the past in regions characterised by aridity and by different development conditions from those found at present times. The sustainable use of water to cope with aridity implies an effective implementation of the integrated land as well as the planning of water resources, the improvement of water and irrigation supply systems, water allocation policies. The latter are to favour water conservation and water productivity valuing the water as an economic, social and environmental good and favouring measures able to increase water availability including wastewater and drainage water re-use, and irrigation technologies that favour efficient water use. An increased users' awareness on the implications of water scarcity should develop.

Drought is naturally produced but temporary imbalance in terms of water availability consisting of a persistent lower-than-average precipitation, unpredictable rainfall frequency, duration and severity, result in a decrease in terms of water resources availability and carrying capacity of ecosystems. Droughts are both hazards and disasters, thus, coping with droughts means to own effective and efficacious measures for risk and disaster management, i.e., preparedness and mitigation measures. Prediction and observation tools and are compulsory.

Water scarcity which refers to above mentioned regimes may be aggravated when there is an insufficient infrastructure which is not able to overcome the problem of limited water availability and poor water management that would not favour equity in terms of water uses (Fig.1). In addition, natural water scarcity is exacerbated by demands placed on limited available resources and particularly by the degradation of water quality. These two aspects are central when referring to man-made water scarcity regimes as defined below.

Desertification is a man-induced permanent imbalance in the water availability resulting from land degradation in arid, semiarid and sub-humid climates. There is a combination of damaged soil by erosion and salinity, inappropriate land use, mining of groundwater, increased flash flooding, loss of riparian ecosystems and a deterioration of the carrying capacity of ecosystems. Climate change contributes to desertification and constitutes a serious threat to large areas around the world. Drought strongly aggravates the process of desertification by increasing the pressure on the limited water resources. Fighting desertification is not an environmental and technological question but an economic and social issue which may play a fundamental role (Pereira *et al.,* 2006).

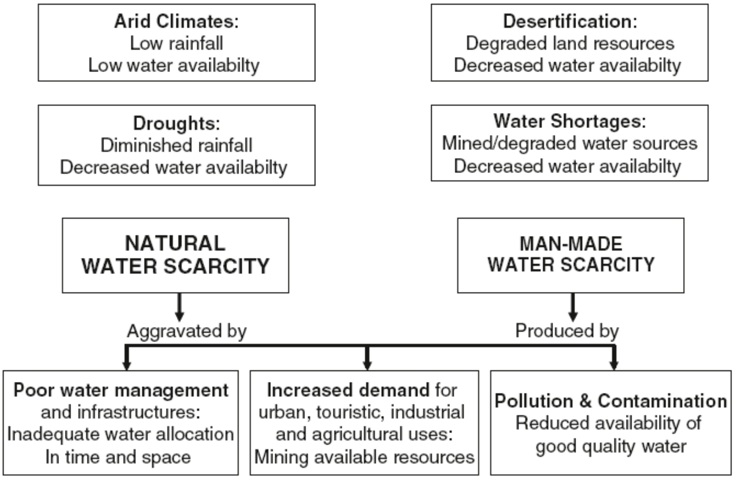

Fig. 1. Natural and man-made water scarcity: impacts of technologies and management in terms of allocation, demand and pollution/contamination

Water shortage is also man-induced but temporary water imbalance including groundwater over exploitation, reduced reservoir capacities, disturbed and reduced land use and consequent ecosystems' altered carrying capacity. Degraded water quality is often associated with water shortages and, like a drought, it aggravates related impacts.

Water management in areas which are susceptible to desertification and are affected by water shortage should focus on re-establishing the environmental balance in the use of natural resources as far as restoring the soil quality, strengthening soil and water conservation, controlling groundwater withdrawals, favouring aquifers recharge, minimising water wastes and managing the water quality as well as developing public and users' awareness.

Water use, a worldwide perspective

Data shown in Fig. 2 gives evidence of great differences in water withdrawals amongst the main regions of the world.

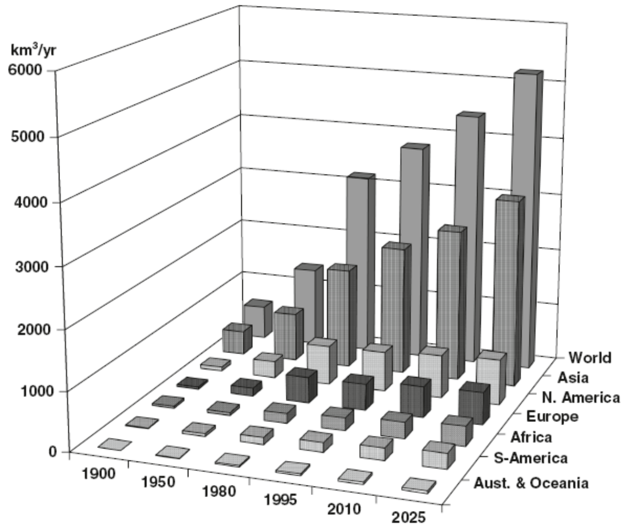

Fig. 2. Water withdrawals per continent from 1900 to 2025 (Shiklomanov and Rodda, 2003)

Fig. 2 shows that the perception of water scarcity developed only in recent times: an enormous increase in water withdrawals occurred from 1900 to 1980 and predictions have indicated that water withdrawals will increase by about 10 times from 1900 to 2025. Such an increase is larger where water is abundant and smaller where water availability is reduced as well as financial resources. In some areas like the Central Asia, an increase by 6 times would produce the well-known Aral Sea disaster while in others, like North America and Southern Europe, an increase by 11 times did not produce the same problems. This relates to the fact that highly increased water withdrawals in arid regions deeply affect ecosystems which are much more vulnerable than those of humid and sub-humid climates. These facts call for a careful attention to environmental consequences which were not yet known until a few decades ago.

Northern African countries are those with a smaller average per capita availability which is below the 1000 m^3/y/capita threshold for heavy water scarcity and many regions have <2000 m^3/y/capita, including those where irrigation plays a main role in food and fibre production. In general, the per capita water availability in Asia is close to the water scarcity threshold while many Asian regions are already facing great water scarcity problems. Data shows that water scarcity is an actual problem that tends to increase in the future mainly in those areas where irrigation is required (Fig.3).

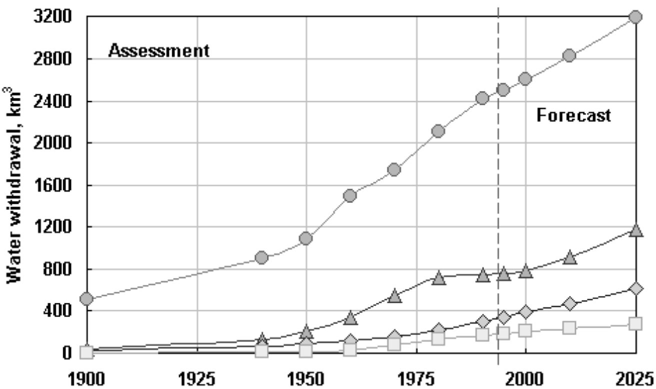

Fig. 3. Dynamics of water withdrawals for irrigation (—●—), industry (—▲—), domestic (—◇—) and reservoirs (—□—) (Shiklomanov and Rodda, 2003)

Fig. 3 shows that the main user is and will continue to be agriculture and irrigation. However, recent main increases are for industry and domestic water uses. Differently from agriculture where consumption may represent the 70% of water use, non-consumption uses in industry and domestic/urban water uses often represent more than 90%. This fact urges water treatment and reuse/recycling technologies as being particularly important in relation to non-agricultural uses both in term of coping with water scarcity and responding to environmental requirements.

Processes which influence water scarcity

The definition of water scarcity regimes, as provided above, shows that water scarcity has different causes and that the domestic water usage influences those regimes. Fig. 4 identifies the main processes causing water scarcity or contributing to it. Their knowledge is required when looking for water technologies that should help coping with or overcoming problems resulting from water scarcity.

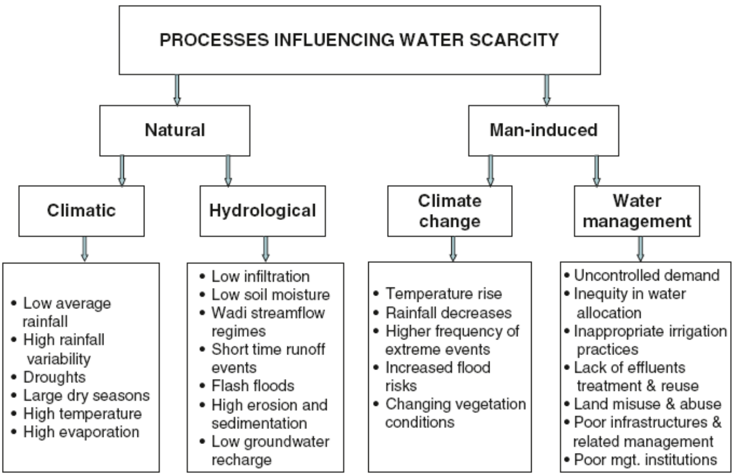

Fig.4. Natural and man-induced processes favouring water scarcity

Natural processes mainly refer to climate and hydrological processes (Fig. 4). Climate is to control precipitation regimes and, therefore, the overall available water in a given region. However, it also controls water consumption through the processes of evaporation and vegetation evaporation and transpiration. In terms of availability, variability is strictly related to seasons and, at a long-term, to droughts. Climate demand for evaporation also changes according to seasons. Differently, hydrologic processes integrate a variety of control factors that include relief and land elevation, geology and land forms, soil water features in terms of water infiltration and storage, and thus, also in terms of support to vegetation and deep percolation to aquifers. Contrariwise to climate, where man contributes to climate change or variation (Fig. 4), the hydrologic processes are notably influenced by man relative land use, soil cover, vegetation type and density, and soil sealing by cities and roads, overall influencing infiltration and soil water storage, thus, also having an impact on rainfall-runoff processes, steam-flow regimes, groundwater recharge and evaporative processes (Fig. 4).

Water management is also a main source of water scarcity when it is poorly performed and allows for uncontrolled uses, inequity in terms of water allocation of various user sectors, abuse in land and water uses, water quality degradation, contamination of groundwater and surface reservoirs, or when it does not provides for effluents' treatment. Poor water management is not only caused by technology's scarcity but by poor institutional framework that does not provide for any public participation, public awareness, and democratic governance.

Aridity and droughts

As referred before, available water in arid and sub-humid climates is limited, often insufficient and highly variable in time and space. The variability of water, thus, of its availability must be considered in terms of time, precipitation and streamflow. In arid climates only a few of rainfall events occur, they vary in space and their intensity is rather variable but often including periods of high rainfall intensity. The resulting runoff is necessarily intermittent with large peak flows and short duration. These characteristics are not that current in sub-humid regions. The seasonal variety of rainfalls is characterized by long periods or seasons without rainfall. Therefore, the streamflow regime is marked by a large variability in river discharges. In these conditions there is the quest for reservoirs and water systems to increase water availability for all users, both in time and space. This brings about the need to consider the overall impacts of reservoirs on downstream natural or man-made ecosystems.

Factors to be considered are shown in Fig. 5. They include population and its related demand, a pressure on natural resources increasingly above the sustainability's level, inter-sector competition for water, fragility of natural ecosystems, and degradation of natural resources. Measures to cope with water scarcity include technologies for increasing the water available for many purposes: water use, saving and conservation, planning and management tools, practices relative to land and water, water systems service and water allocation. Of paramount importance are the institutional frameworks for water management, which should consider water a valuable good for its economic, social, cultural and environmental importance since it provide users' participation, democratic governance, public awareness, education and training.

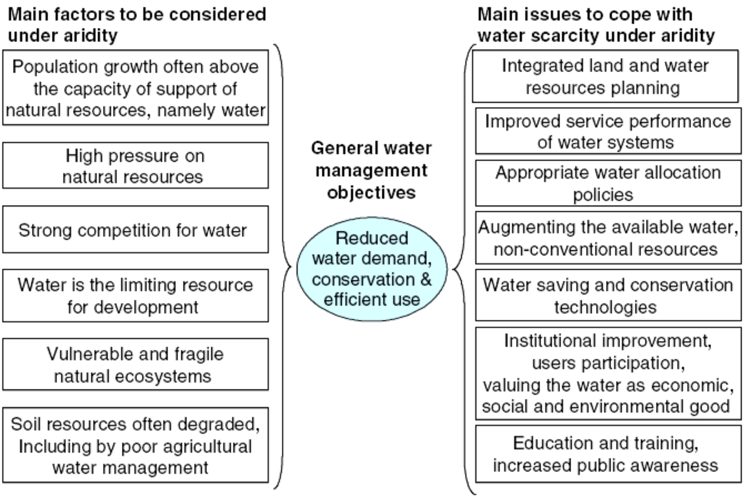

Fig. 5. Coping with water scarcity under aridity conditions

Impacts of droughts in arid and sub-humid climates may be very important (Fig. 6). Impacts refer to economic activities, (with agriculture becoming more vulnerable), to environment and society, both urban and rural as well as to society lifestyles and health. Recognized impacts call for management and technologies that would minimize them. Water technologies have then a main role.

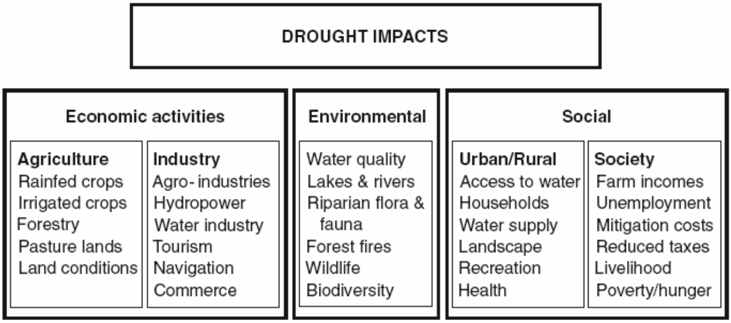

Fig. 6. Activities on which drought can have significant impacts

Droughts are both hazards and disasters, therefore, coping with droughts requires the adoption of risk and disaster management, i.e., preparedness and mitigation measures as well as adequate prediction and observation tools. (Fig. 7). Droughts have a slow initiation and they are usually only recognized when the drought is already established. Forecasting a drought either when it is likely to begin or to come to an end is extremely difficult. Therefore, an adequate lead-time – that period between the release of the prediction and the actual onset of the predicted drought hazard - is often more important than the accuracy of the prediction. The lead-time makes it possible for decision and policy makers to implement policies and measures to mitigate the drought effects in a timely manner. Developing prediction and early warning tools that would be appropriate to climatic and agricultural conditions prevailing in different drought affected areas is a current challenge in research.

Creating a lead-time prediction, even by a short time scale, improves the usefulness of the drought monitoring and its related information. Then, changes in water allocation and the implementation of reduced demand practices are timely controlled.

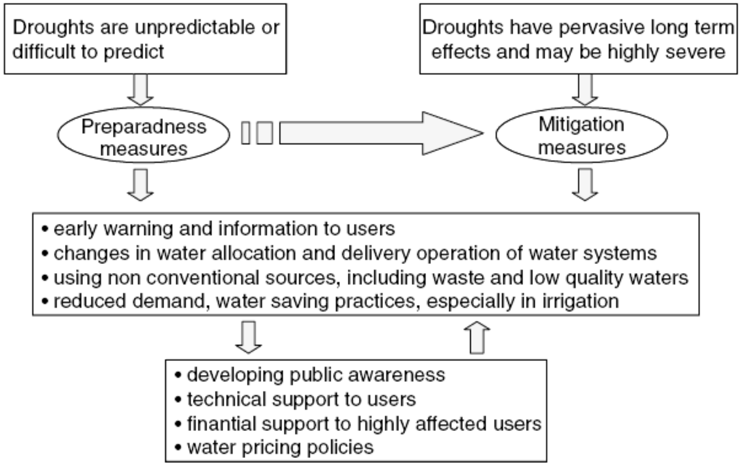

Fig. 7. General measures to cope with droughts

A successful use of water technologies to cope with droughts also depends on the framework created for drought risk management. On the one hand are technologies for water treatment, reuse and recycling since when water is scarce during a drought in as much as when there is a growing demand for unconventional water uses. On the other hand, there are water technologies that help reducing the demand for water and to preserve the available resource. However, the success on using such water technologies depends on the public awareness, training of users and professionals, technical and financial support to users, and the adoption of incentives in addition to an appropriate water pricing policy.

Efficient water use

New concepts to clearly distinguish between consumptive and non-consumptive uses, beneficial and non-beneficial uses are being developed. Similarly, the differences between reusable and non-reusable fractions of non-consumed water diverted into a given water system or subsystem are being clarified. When water is diverted for any use there happens that only a fraction is used for consumption. The non-consumed fraction returns after use while its quality is preserved or degraded. Quality is preserved when the primary use does not degrade its quality to a level that does not allow further reuse, or when water is treated after that primary use, or when water is not added to poor quality, saline water bodies. Otherwise, water quality is considered degraded and water is not reusable (Fig. 8)

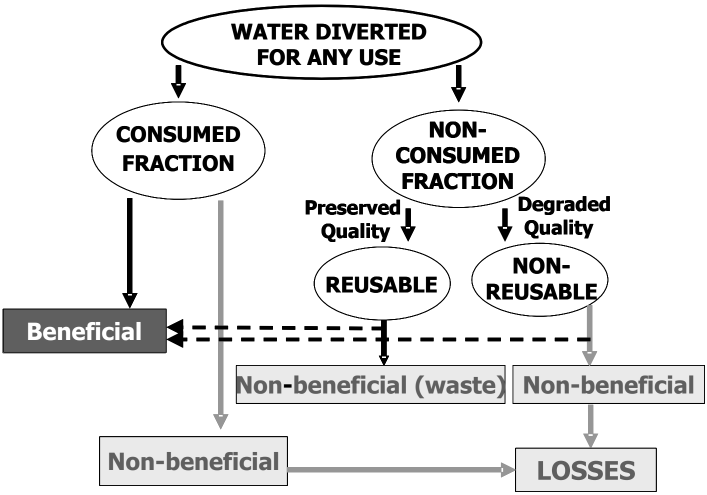

Fig. 8. Water use, consumptive and non-consumptive use, beneficial and non-beneficial uses, water wastes and losses

Both consumed and non-consumed fractions concern beneficial and non-beneficial water uses. These are beneficial when they are fully oriented to achieve a desirable yield, product, or service. Alternatively, when that use is inappropriate or unnecessary, it is called as non-beneficial. Reusable water fractions are not lost because they return to the water cycle and may be reused later by the same or by other users. They are not losses but wastes since they correspond to water unnecessarily mobilized. Contrarily, non-beneficial water that is consumed or returned of a poor quality, saline water bodies, or which contribute to degradation of any water body are effectively considered as water losses (Fig.

8). These concepts recognize a great importance to water treatment technologies that transform poor quality used water into an acceptable quality reusable water, certainly when the treatment matches the reuse requirements.

In the water economy perspective, it is important to recognize both the beneficial and non-beneficial water uses. In crop and landscape irrigation, the beneficial uses are those directly contributing to an agricultural product or an agreeable garden, lawn or golf course. Non beneficial are those uses resulting from excess irrigation, poor management of a supply system, or from water misuse. In industrial, urban or energy uses, those beneficial uses refer to water applied in processes leading to the achievement of some benefiting production or service such as washing, heating, cooling, or generating energy. These uses turn to be not as beneficial when water is used in non-necessary processes, when it is misused or is used over the usual requirements.

Taking into account the concepts above, it is important to recognize what is the meaning of "efficient water use". To support this concept, a few main ideas are developed in Fig. 9.

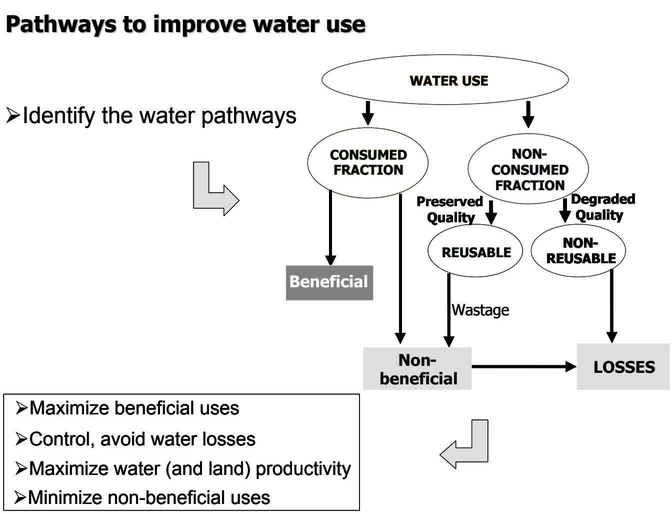

Fig. 9. Pathways to improve the efficient use of water

Firstly, it is required to identify water pathways in any water use, to distinguish what is a consumptive and a non-consumptive water use, what is a beneficial or a non-beneficial water use and which fractions are considered to be as real losses or only as wastes. This requires that productive and non-productive processes, i.e., oriented to achieve the purpose of water use, are to be recognized. Then, a water use is more efficient when beneficial water uses are maximized and water losses as well as wastes are minimized, and the water productivity (ratio between the product or service value generated by one cubic meter of water used) is increased. By this standpoint it is possible to define water use indicators which can adapt to any water use or system, for irrigation or non-irrigation users, and to adopt them to make the use of water more efficient i.e., aiming at improved performances from water resources conservation's perspective. These indicators may be useful for water resources planning and management in a condition of scarcity. They may be combined with process indicators, including those which relate to the quality of service of water systems.

Conclusive remarks

As referred above, developing and implementing the use of appropriate water technologies responds to challenges of coping with water scarcity. However, these challenges are different in rural and urban societies. In rural societies access to safe water is proportionally much less than in urban societies. The same happens with wastewater treatment and disposals. However, the poor segment of urban societies may face higher health problems than in rural societies when safe drinking water and urban drainage systems are not properly available (WHO, 2004, 2006a, b). Health problems related to water may affect this segment of urban population much longer. Differently, difficulties found in having access to safe water in the rural world may have an impact on how long family take to get their water ration, even when the water quality is poor. Health problems also occur because drinking water is often contaminated but health

risk associated with wastewater drainage is much less. Contrariwise, rural people often face health problems related with the reuse of untreated wastewater (WHO, 2004, 2006a, b).
These facts create two types of challenges. One refers to the need of prioritizing water supply and sanitation in those less developed regions where there is not access or reliable access to drinking water and safe sanitation (WHO, 2006b). A second challenge is to develop appropriate water treatment in under developed or developing regions where there is a high demand for wastewater, particularly where untreated or poorly treated wastewater is already being reused (WHO, 2006c, d, e, and f). These challenges are more evident in arid and drought affected areas. Therein, when a drought occurs a demand for water is not properly satisfied and the health risk for populations is increased. Innovative approaches are definitely required in terms of technology and management as well as in terms of funding schemes and institutional issues.

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