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Bridging Science and Policy in Water Management

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Introduction

There is no doubt that problems with water management are becoming more complex due to rapid population growth, climate change, and the growing demands of industrial and agricultural development. The problems of water scarcity therefore become more acute, and, simultaneously, science becomes more crucial in providing the basis of sound governance and a holistic approach to enlightened policy and water management. The potential of modern science to contribute to the resolution of water scarcity is unlimited. The major challenge to sustainability is how to use science to overcome uncertainty of Agenda 21 on environment development.

Water scarcity has many causes, among them a crisis of water management, fragmented institutions, and inadequate policies, legal systems, and political will. Yet the gap between science and policymaking at the national, regional, and global levels continues to widen. Training scientists in water research will require political commitment, sustainable funding, and international outreach.

Effective water governance will require broad stakeholder participation, a transparent sharing of information between scientists and "policymakers," and a balanced sharing of authority between the government and nongovernment sectors. Effective institution-strengthening and appropriate legal frameworks to guide the public-private partnership will be needed.

Water for Life

Water is an integral part of life, the environment, and development. Yet it is not equally available to all. Currently, one-third of world's population is living in water-scarce or water-short areas. Moreover, it is estimated that 12% of the global population uses 85% of its freshwater. Water supply resources are being stretched to their limits. By 2050 an additional three billion people will be born mostly in countries already suffering from water shortage. Climate change will likely mean that as much as one-half of the global population will be living in water-scarce or water-short areas. With the advent of climate change, the water-stressed areas in the Middle East and North Africa (MENA) region will likely face extreme water scarcity as projected rainfall declines of 20% and temperatures increases of 2° to 3°C would lead to large losses of water resources, increases in the likelihood of intensifying scarcity of basic food supplies, and increases in the extent of increased poverty.

The improvement of water management techniques and technologies needed to cope with the projected increase in water scarcity will require new water science as well as extensive use of existing water science. Future water policies will have to be well informed by science if they are to be effective. Many existing water policies are not based on sound science and are aimed at goals other than ensuring that water is used efficiently, protected from qualitative degradation, and maintained for future generations. The potential of science to contribute to the resolution of current and foreseeable water problems is virtually unlimited. There are numerous examples.

At the global level the developments from nanoscience can help in a variety of ways. Development of more effective ways of cloud seeding, development of nanomembranes for cleaning polluted water, and improvements in diffusion technology, which will lower the costs of desalination, are important examples. Development of small scale solar technology can improve energy generation and thus lower the cost of desalination. The importance of such a development can be illustrated by reference to the MENA region, where solar energy falling on 1 m^2 of surface annually is the BTU equivalent to one barrel of oil. Currently, the Arab region, with 5% of world population, produces 50% of the world's desalinated water (AFED 2010). Technology can help to extend the application of desalination and other water-cleansing techniques to other areas throughout the world.

At the regional level, scientifically based management of shared water resources, whether surface or groundwater, should be placed high on the agenda of countries with shared water basins. Effective bilateral and/or multilateral agreements should lead to stronger economic and political ties among countries with shared water basins, obviating the potential for conflict. The importance of dealing effectively with shared water is almost self-evident. This is particularly true in the MENA region where "of all renewable water resources . . . two-thirds originate from sources outside the region" (AFED 2010).

At the national level science can contribute to the acquisition of knowledge about possible new water sources and about the application of techniques for using existing sources more efficiently. Thus, for example, agriculture accounts for 85% of water use in Arab region as compared with a world average of 70%. On-farm irrigation efficiency remains at 35%, so there is clearly room for improvement at the farm level (AFED 2010). Science can also contribute to the development of new crop strains that better tolerate both aridity and salinity. Rain-harvesting systems and efficiency improvements in science-based agricultural practices to achieve water savings should be emphasized. Other policy reforms leading to a new political economy of water management could focus on the acquisition of water "virtually" through imports of crops "from water-rich countries, while allocating scarce water resources to low-water-consuming, high-value crops that can generate foreign exchange" (AFED 2010). In this way, food security may be achieved through set of well-balanced trade and water management policies.

One potential new source of water is recycled wastewater. Wastewater generated by domestic and industrial sectors in the Arab region totals 10 km^3/year, of which 5.7 km^3 undergoes treatment. Of this volume of treated wastewater, only one-third is reused. However, wastewater treatment plants currently handle waste loads that exceed their capacity limits. The untapped potential of wastewater should be the focus of appropriate policy interventions, including national water management strategies for water reuse.

The Role of Science in the Domain of Water

Background

The focus of this section is on the importance of science in fashioning enlightened water policies to manage the intensifying global water scarcity. In the following section, the importance of water in sustaining life, the environment, and economic development is discussed. Subsequently, the decline of available water resources is characterized. The final sections focus on the importance of water science to fashioning solutions to the global water crisis, the needs to build scientific competence and capacity, and issues related to making science based water policy. An important underlying theme that runs throughout the chapter is that the existing water scarcity in the arid and semiarid Arab countries lies at the extreme edge of the global water scarcity picture. Moreover, it offers to other parts of the world, particularly those that are arid and semiarid, a picture of the future water situation likely to be visited upon them if the current situation is neglected.

Water for Life

Freshwater is tiny proportion of the water resources on earth, with salt water accounting for 97.5% of planetary waters and freshwater for only 2.5%. Currently, 70% of the freshwater is tied up in polar caps, glacial ice, and groundwater at inaccessible depths. This means that 30% of available freshwater, or only 0.75% of total water supplies, are available to humans for various uses (Shiklomanov 1997). Human water endowments, which are found in lakes, rivers, and accessible ground are but a tiny proportion of the total planetary water endowment. As documented by Vorosmarty et al. (2010) and others, that water endowment is distributed unevenly around the globe in both spatial and temporal terms. This means that there are times and places where water is especially scarce as well as times and places where it is reasonably plentiful. This is shown in figure 2-1, where it can be seen that renewable freshwater is relatively scarce in the MENA region and South Asia regions and relatively plentiful in the Americas, Australia, and New Zealand. It is also important to recognize that there is significant variability within each region, exhibited by water-sparse and water-rich locales.

The importance of water in sustaining life, the environment, and development has been acknowledged in the Dublin-Rio water principles (Assaf 2010). In addition, Article 25 of United Nations Declaration of human rights stated in 1948 that "Everyone has the right to a standard of living adequate for the health and well-being of himself and his family, including food, clothing, housing and medical care and necessary social services and the right to security."

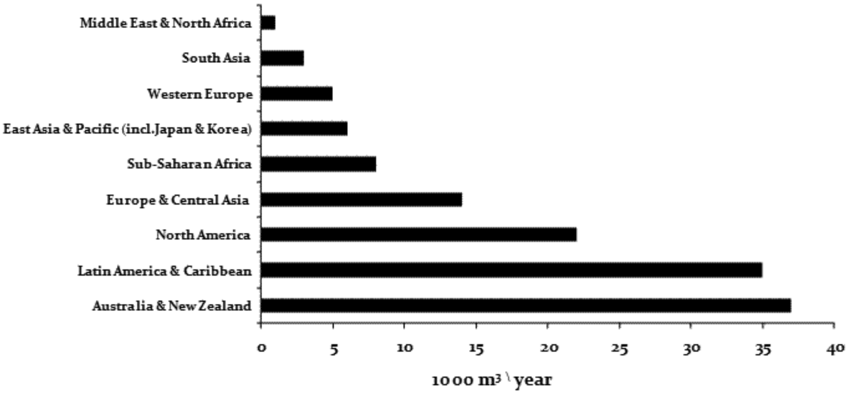

Figure 2-1. Actual renewable freshwater resources per capita, by region.
Source: World Bank 2007.

Although water is not acknowledged explicitly, it is a crucially important part of the daily human diet and sustains life. It should be recognized that some efforts to manage water sustainably have unintended side-effects that could have been predicted. A case in point is the treatment of water as a commodity, a practice which threatens the poor. Privatization of water resources has reduced the availability of fresh, sanitary water. Two in three people survive on less than $2 a day and are simply unable to pay for water for simple washing, cooking, and sanitation needs. One proposal for dealing with the problem is to create an escalating price system based on the quantities of water used. Under this system, costs to the poor are minimal since they use small amounts. This proved to be an effective social package policy related to poverty.

As resources are decreasing in quality and quantity, water policies promoted by developmental agencies with governments have concentrated on a comprehensive, integrated ecosystem of water management. Expanding demands for domestic, agricultural, and industrial water uses have made water a scarce resource in some countries in the Middle East, where total water withdrawals exceed renewable water resources. In fact, most Arab countries are already below the water scarcity level (Plan Blue UNDP Database 2005–9).

Therefore, thoughtful, science-based water policies, strategy, and management regimes are crucial if supplies, demands, and allocations among stakeholders are to be met in a balanced fashion that incorporates fairness and efficiency.

Freshwater Scarcity

The UN and UNESCO classify rich-water countries as those who secure 8,000 m^3 of water per capita per year. The global average is estimated to be 6,000 m^3 per capita per year. Water-scarce countries are defined as those with annual allocations below 1,000 m^3 per capita, while allocation of below 500 m^3 per capita per year constitute severe water scarcity. Annual per capita endowments of renewable water resources are shown for the 25 most populous countries in the world in figure 2-2. Global per capita renewable freshwater resources are declining at significant rates. Rayne & Forest (2013) reported "substantial reductions of global per capita stock of 54% between 1962 and 2011. There was a decrease of 75% in sub-Saharan Africa, 71% in the Middle East & North Africa (MENA), 64% in South Asia, 61% in Latin America and the Caribbean, 52% in East Asia & the Pacific, and 41% in North America". At current rates of depletion, global per capita renewable internal freshwater resources are project to decline from levels observed for 1962 by 65% by 2020. Thirteen Arab countries are among the 19 most water-scarce nations in the world. Per capita water availability of eight of those countries is below 200 m^3, less than half of the level that the UN defines as severe scarcity. Per capita annual renewable freshwater resources for the MENA region are expected to decline from 1962 values by 80% in the year 2020.

The reasons for this decline are many, and the importance of each varies by region. Population growth, which has occurred in all regions, is an obvious reason. Declines in the availability of the water resource also account for diminishing per capita availability. The world-wide trend of declining water quality means that less water is available for consumptive uses. Declining water quality reduces available supplies just as surely as drought. Lower per capita endowments also result over time when nonrenewable resources of water are persistently utilized as long-term supplies. Fossil groundwater and quantities of water that are over-drafted from renewable aquifers are the most obvious examples of nonrenewable supplies. Persistent withdrawal of such supplies depletes them to the point where demand pressures (that were previously supplied by nonrenewable sources) fall on renewable sources that are physically substitutable. A final source of explanation is climate change, which has occurred in the past and is expect to occur in the future. This means that for some regions water is less available than it was historically.

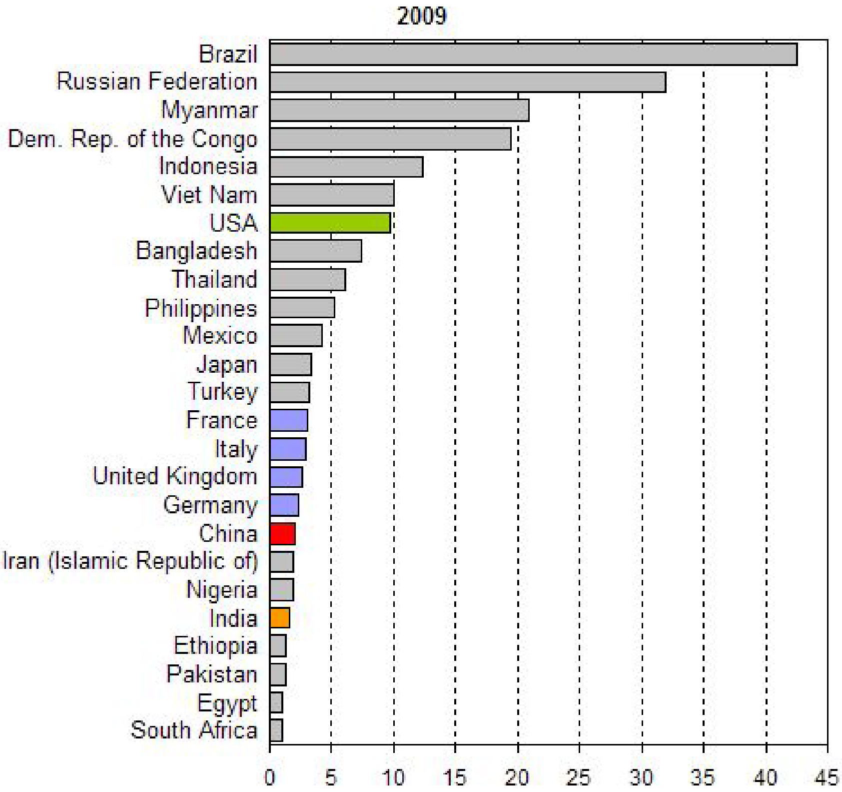

Figure 2-2. Total renewable water resources per capita for the 25 most populous countries in 2009 (in 1,000 m^3 per person per year). Among the 25 most populous countries in 2009, South Africa, Egypt, and Pakistan are the most water-limited nations. India and China, however, are not far behind, with per capita renewable water resources of only 1,592 and 2,103 m^3 per person per year. Major European countries have up to twice as much renewable water resources per capita, ranging from 2,288 (Germany) to 3,032 (France) m^3 per person per year. The United States of America, on the other hand, has far greater renewable water resources than China, India, or major European countries: 9,753 m^3 per person per year. By far the largest renewable water resources are reported from the Russian Federation and Brazil, with 31,929 and 42,496 m^3 per person per year, respectively. Without an increase in available water resources, Ethiopia, due to population growth, would become the most water-limited country in 2050, with only 633 m^3 of renewable water resources per person per year, followed by Egypt, Pakistan, South Africa, and Nigeria. Due to the projected population decline, per capita renewable water resources in some European countries would slightly increase, from 2,288 to 2,667 m^3 per person per year in Germany and from 2,954 to 3,146 m^3 per person per year in Italy. *Source:* Population: UN DESA 2008; water resources: CIA 2009.

The picture that emerges, then, is one of intensifying scarcity. The fundamental cause of the intensifying scarcity is bound up in the fact that demands for water are growing at the same time that available supplies of water of appropriate quality are shrinking. Some of that scarcity is self-inflicted owing to the absence of effective water policies and management regimes. Some of that scarcity can be avoided by employing existing science in the making of policy and in the fashioning of improved techniques and technologies that will permit water to be used more efficiently and more extensively than it has been in the past. Commitments to programs of research and development will also be required as a basis for the public policies and innovative technologies that will be necessary to confront and manage the emerging global water crisis.

How Can Science Help?

There is little argument that science will need to be at the foundation of the policies needed to address the intensifying water scarcity. Nevertheless, while existing science and science to be developed in the future will be crucial, science by itself will not be sufficient to resolve global and regional water problems. Other needed elements will include the process of adapting scientific findings for use in managing water resources and building the necessary institutional linkages to facilitate the use of science in the making of policy.

As shown in figure 2-3, worldwide spending on research and development has grown from $522.5 million in 1996 to $1.275 trillion in 2009. Most of the growth was accounted for by OECD countries. Additionally, total spending on R&D as a percentage of gross domestic product ranged from 1.2% (Spain) to 3.37% (Sweden), as shown in figure 2-4. This figure also shows that the private sector contributes more than the the public sector for the countries listed.

These figures mask several important facts about the investment in scientific research related to water. First, water research is not a large or even constant percentage of the research budgets of any of the nation's considered. Moreover, it is not unreasonable to assert that water research budgets have not grown in parallel to the total R&D budgets over the period in question. Thus, for example, in the United States public spending on water research in real terms (adjusted for inflation) was at the same level in 2000 as it had been in the late 1970s and did not grow in parallel with the

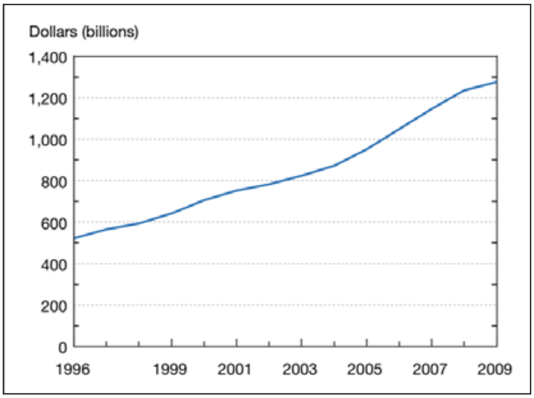

Figure 2-3. R&D expenditures worldwide, 1996–2009. *Source:* National Science Foundation 2011; UNESCO 2012.

Year	Dollars (billions)
1996	522.5
1997	564.0
1998	594.2
1999	641.4
2000	704.5
2001	752.4
2002	782.1
2003	822.2
2004	872.1
2005	951.0
2006	1,048.4
2007	1,144.5
2008	1,234.8
2009	1,275.2

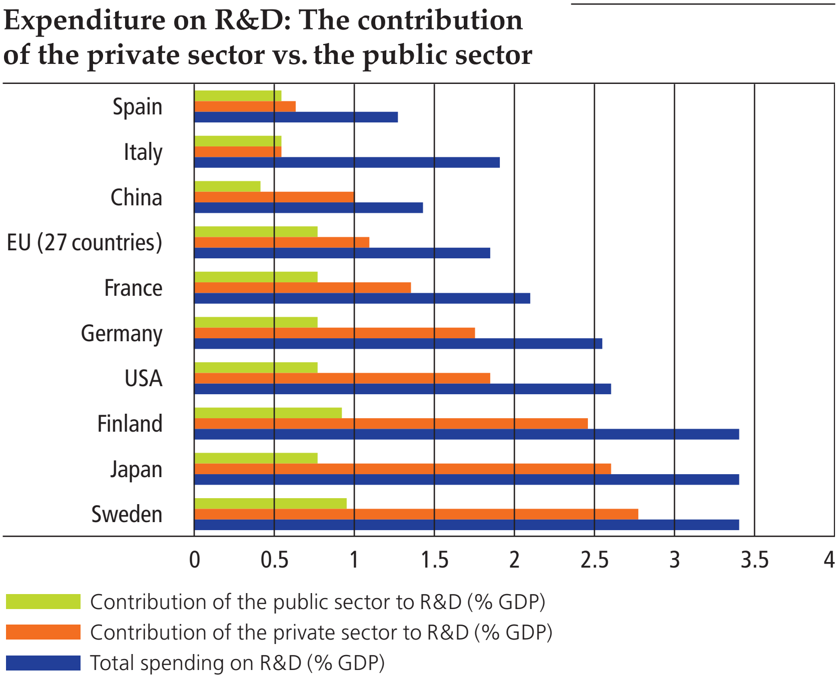

Figure 2-4. *Source:* National Science Foundation 2011; UNESCO 2012

substantial growth of general R&D over the same period (National Research Council 2004).

A second important fact about investment in R&D generally and water research specifically is that there is a great deal of variation between countries and regions. In a comprehensive review on the state of science in the Arab region, Badran (2005) concluded that the region exhibited poor performance in science and technology. This was attributed to political turmoil, low-quality education, and inadequate R&D infrastructure. In short, the region has failed to deliver high-quality science and has failed to build capacity in R&D. This has resulted in low rates of innovation and a below-average evolution to a knowledge-based economy compared with the rest of the world. The results are summarized in figures 2-5 and 2-6, which indicate that the scientific research personnel per million inhabitants varies but is low in the Arab states. Only Africa has fewer scientists per million inhabitants. Figure 2-7 shows that in the Arab region only 0.2% of GDP is directed to R&D, and most of that is public.

This measure of research capacity contrasts with the general levels of water availability and the effectiveness of water management in the region. With the exception of Sudan and Iraq, all Arab countries are water poor. In agriculture, there is an effort to utilize technology for saving water in irrigation, but the effort needs expansion. Also, the International Centre for Biosaline Agriculture (ICBA) in Dubai is developing sustainable crop production by using saline water (Badran and Zou'bi, 2010), and this effort also needs to be built upon. In another area, research-based universities in the MENA region have started to give priority to research focused on the nexus of water and energy for a sustainable model of technical knowledge and a system linking technology with policy. Badran (2011) has found a strong connection between human rights, levels of R&D, and rates of innovation. Indicators have shown a strong correlation between human rights as a contributor to effective science and technology among Islamic (OIC) and Arab countries. Globally, the World Bank found effective performance of water research in various sectors such as agriculture but concluded that very little of this was being conducted in the Arab region (World Bank 2007). In another report (2005) the Bank concluded that when compared with other regions, water science was at a low level in the Arab region. Demand for water research is not yet an integral part of water policy in many countries in the region. There are, however, a few bright and promising sports, such

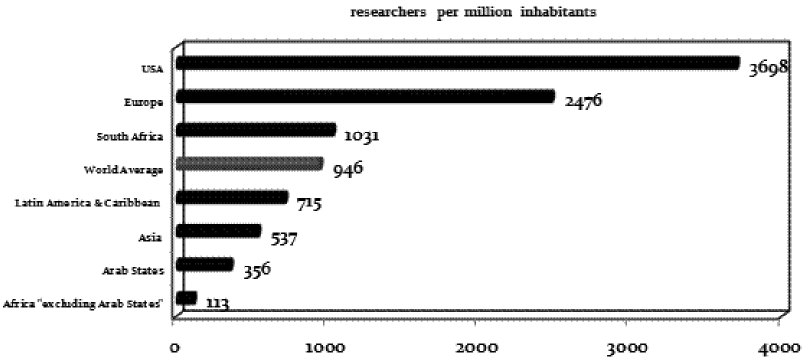

Figure 2-5. Researchers in selected regions of the world. *Source:* UNESCO 2012.

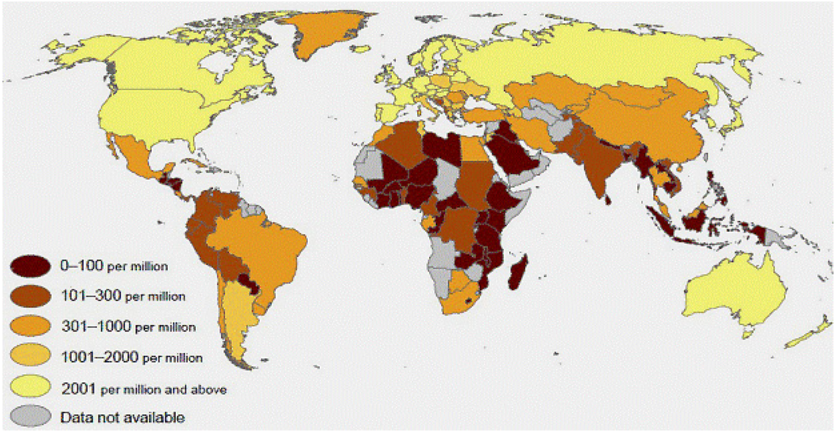

Figure 2-6. Researchers per million Inhabitants, 2010. *Source:* UNESCO 2012.

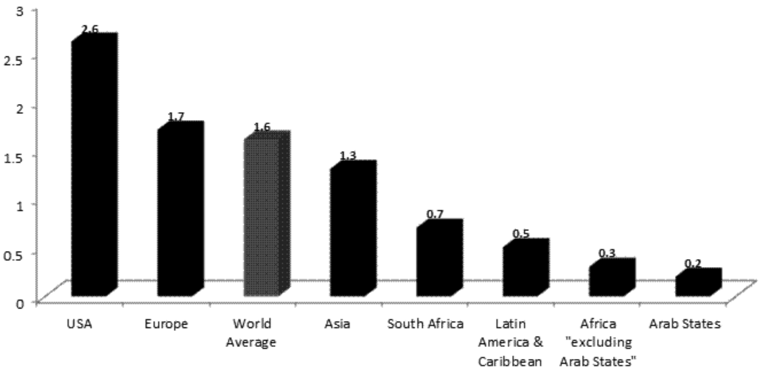

Figure 2-7. Gross expenditure on research and development (GERD) as a percentage of gross domestic product (GDP). *Source:* UNESCO 2012.

as the Masdar Institute in Abu Dhabi, King Abdullah University of Science and Technology (KAUST) in Saudi Arabia, and the Qatar Foundation (Badran and Zou'bi 2010). Taylor et al. (2008) identified constraints on the ability of science to influence policy in water management in Middle East and North Africa (MENA) region as follows.

- The unavailability of a critical mass of competent researchers in the region.
- The management and leadership of research organizations are ineffective.
- The linkages between research and policy communities are not established.
- Career opportunities in the region for researchers may not be compelling enough to retain them.
- Limited connectivity to international research communities hampers professional growth, learning, and exposure to new ideas, all of which are vital to the success of careers in research.
- Many organizations in the region lack an internal research agenda that is "owned" by the organization itself. Many research organizations feel obliged to follow donors' agendas, which are not necessarily aligned with community or national needs. Consequently, researchers may feel "sub-contracted" to pursue the agenda of others, leading to frustration and a sense of disempowerment.
- Organizations whose primary goal is to influence policy will often resort to recruiting well-connected and reputable researchers in order to increase policymakers' confidence in their research. However, reputation in the Arab region seems to be closely associated with seniority rather than performance in terms of relevant, high-quality research. The importance of seniority appears to make it difficult for young researchers to attract funding or support for their own research ideas.

Building Scientific Capacity and Infrastructure

In regions where science needs to be more fully available to support water policymaking, the scientific community needs to identify research priorities. The research itself should be conducted in an integrated and interdisciplinary fashion that will allow scientists to find solutions to complex problems arising from an increasingly dynamic environment. The international water research community should be involved in strong partnerships to the extent appropriate and feasible. Simultaneously efforts should be made to improve and expand the educational opportunities for young scientists with interests in hydrology and related water disciplines. An interdisciplinary approach should be part of the educational and training effort. It no longer suffices for water research to be done exclusively by agricultural schools or civil engineering departments, as has been the case in the past. Rather, water science needs to be viewed for both educational and research purposes as a integrated and interdisciplinary field of endeavor.

In Germany, there are 500 institutes conducting research on water and related fields. The resulting fragmentation of the research structure can be attributed to the heterogeneous funding system for universities and research institution. To combat this, a "water science alliance" was begun in 2009 with the aim of joining and strengthening existing competence in water research and creating a framework for complex research in water sciences over the foreseeable future. The alliance is a tool for bringing together and interlinking leading groups and institutions in "thematic clusters" to conduct research leading to concrete solutions to water problems. The alliance will bring synergy and added value by integrating different disciplines (Teutsch and and Krueger 2010). This model has great promise in reducing fragmentation and creating integrated programs of water research.

In Australia, South East Queensland (SEQ) has faced intensive pressures on its water resources, which may be compounded by climate change. Here an alliance for scientific research on water as established as a partnership between the Queensland provincial government, the Commonwealth Scientific and Industrial Research Organization (CSIRO), the University of Queensland, and Griffith University. The resulting partnership is to tackle problems of uncertainty and development of a strategic plan for managing the water resources of SEQ. It is supported with a $50 million appropriation over a period of 5 years (Clayden et. al, 2010). Specific elements of the task include

- ensuring the reliability and safety of recycled water.
- identifying needed infrastructure and developing needed technology for recycling waste water and storm water.
- building scientific knowledge into the procedures for planning and management of water supply systems.

- developing methods for increasing public confidence in water supplies of the future.

Integrated water management analyses have shown that coordinated development of water, land, and related resources cannot be solved by structural measures alone but require linkages of knowledge with action for sustainable development (Clark 2007). Institutional and organization structures that effectively link scientific knowledge to decision-making contribute to problem-solving and innovation for integrated urban water systems (Davis 2010).

Also needed are business-based models for technology transfer. These can be established by research managers in the form of incubators and science parks. Funding mechanism that are mostly governmental tend to be inadequate and not sustainable. Although external funding has contributed importantly to meet water research challenges, the emerging research agendas were not based on national needs but on the donors' agenda. High-quality research requires a national science and research agenda, political endorsement, outstanding research managers, and sustainable funding and linkage between research and policy (Laarmani Salih 2010). Ultimately, water decision makers must employ the results of carefully targeted research and development in establishing water policy or the most important water challenges are unlikely to be addressed.

Bridging Science and Policy

Interactive knowledge sharing in the development of policy for the sustainable management of water resources is sometimes hampered by stakeholders who oppose certain policies on political or ideological grounds. Solid scientific knowledge can provide the basis for a credible common ground among stakeholders that leads to effective science-based water policies. The key element in linking science to policy is a governmental requirement that research be used in the formulation of policy (Carden 2009). Taylor et al. (2008) found in a survey that building institutional relationships between independent or private research organizations and policy-making bodies is difficult to sustain.

A UNESCO conference held in 1977 on the multiple uses of water and integrated water management is seen by many as the genesis of integrated water management. Many countries, including the United States, South Africa, Australia, and the United Kingdom, have adopted integrated watershed management as the fundamental approach to water policy. Powerful environmental movements in North America and Europe in the 1980's confronted existing governmental policies that concentrated exclusively on economic growth. In their place were substituted additional objectives that were equity and sustainability.

Global efforts that resulted in the development of the Dublin-Rio water principles for a holistic approach for integrated water management (Assaf 2010) gave further voice to the notion of integrated watershed management.

- First principle: Freshwater is both of finite quantity and essential to sustain life, development, and environment. Freshwater is needed to maintain all forms of life and for human socioeconomic development.
- Second principle: Management should include participation of stakeholders, users, and policymakers.
- Third principle: Women should be purposefully involved in the making of water policy and in water management. Women in rural areas can spend most of their time looking for water and carrying it over long distances.
- Fourth principle: Water has an economic value and should be structured as a commodity.

The last principle, which leads to pricing of water, is not popular unless the poor are secured and consumers understand the value of water, so as not to pollute or waste it. Still, in many countries, water is perceived as a public good. Withal, research for water policy should be conceived of within the framework provided by the notion of integrated watershed management.

The concepts of green water, blue water, and virtual water also need to inform the research-policy interface. Green water is the soil moisture within 2 m of depth that is made available for absorption by the root systems of plants. Additionally, it contributes to water vapor in the atmosphere through direct evaporation or transpiration from plants. To conserve green water, soil ploughing, particularly for rainfed summer crops, and fallowing is practiced. Also, the use of plasticulture to conserve soil moisture has been found effective as a water-management technique. Engineered crops that use less water and sometimes are subject to moisture stress is another way to conserve green water. The management and manipulation of green water is a highly promising area for water research and development.

Blue water is found in rivers, lakes, aquifers. It includes transboundary waters, whether surface waters or aquifer waters. Globally, blue water is becoming fully appropriated. This means that research should be directed at means of economizing on blue water but also at economical ways of using green water. Protecting blue water from pollution and from diversions that are not renewable are other ways to conserve blue water.

Virtual water is water embodied in foodstuffs and other commodities that can be imported. It permits water-short countries to acquire water from water-rich countries and use internal supplies to grow high-value crops that will generate foreign exchange.

Scientists and Policy-Making

Scientists in the labs and the field largely believe that their mandate is to create knowledge and disseminate it through publication in peer-reviewed journals, and that other professionals should take the task of bridging scientists with policy and decision makers. The missing link in politics is to bridge science output with policy. Carden (2009) suggested the creation of knowledge brokers, whether IGOs or NGOs. The National Water Research Center of Egypt is an ideal mechanism. The Royal Water Commission in Jordan, or the higher council for water and climate in Morocco are other examples.

Policy-science interaction (PSI) in the water sector aims to bridge the science–policy gap with different types of knowledge brokering instruments (KBI) at national and regional levels. KBI aims to increase the quality of science–policy interactions by positioning the public to learn about the complexity of the issue and by understanding the impact of driving forces affecting their future.

The major challenge to sustainability is how to use science to overcome uncertainty in basic issues of Agenda 21 related to environment and development (Grubb and Grubb 1992). These are complex issues that cannot be addressed except through alliances and interdisciplinary, holistic approaches of physical, life sciences (e.g., hydrology, ecology, agriculture, human food and health) and social sciences (e.g., policy, social sciences, economics, human development). An approach of this type will lead to physical and social agenda for the use of natural resources linked with managerial skills responsive to stakeholders.

Escalating pressure on less than 1% of the world's total supply of water is made more difficult to manage by population increases that are exacerbated by climate change and degradation of water quality. In addition, research activity is fragmented and poorly linked to policy and management needs. UNESCO and WMO set up HELP (Hydrology for the Environment, Life and Policy) initiative to deliver social, economic, and environmental benefits through sustainable use of water by deploying hydrological science to achieve and integrated catchment area. The objective is to form a global network to bring together hydrologists, water resource managers, and policy and legal experts to address water issues defined by local stakeholders (see www.unesco.org\water\ihp\help). Twenty-five basins were established from different climatic, social, and economic regions around the world. These basins will serve as "outdoor labs." The main outcome is to integrate hydrological, socio-economic, and legal research responsive to water policy. HELP has created a platform for dialogue among physical and social scientists, water resource managers, and policymakers.

Jordan's Water Situation: A Snapshot

In Jordan, there is a strict policy on national (as opposed to transboundary) water aquifers. Hydrological studies and geological surveys have provided the basic data needed to manage groundwater. In 1993, the Jordan Ministry of Water and Irrigation established a bylaw prohibiting the drilling of new wells in most parts of the country, and since no new licenses have been offered for drilling water wells, with few exceptions for university campuses and hospitals (El-Naqa and Al-Sayeb 2008). All wells are controlled and supervised by the water national authority, and meters have been installed and are monitored very closely. The amount of water pumped from underground is measured and actions are taken accordingly.

The landscape of water resources in Jordan is as follows:

Rainfall distribution of water in Jordan

- 8,200 million m^3 annual rainfall, 80% loss to evaporation
- 1,640 million m^3 annually left: (Haddadin 2011)
- 510 million m^3 blue water–surface
- 200 million m^3 groundwater blue water–aquifers
- 860 million m^3 soil moisture green water–soil moisture
- 70 million m^3 reclaimed water recycled water

- Jordan's share of transboundary annually (blue water):
  80 million m^3–Yarmouk transboundary basin (original 296 million m^3) according to Johnston plan of distracting between Syria, Israel, and Jordan
  60 million m^3–Tiberias
  68 million68 million m^3–Syrian–Jordan underground basins
  100 million m^3–Saudi–Jordan basin underground (the Disi aquifer)

Total: 1948 million m^3 annually (314 m^3/capita/yr), which puts Jordan, according to UN classification, as a severely water scarce country. Virtual water is hard to calculate since there are imports of meat, grains, fruits, and vegetables as well as exports of fresh produce.

Jordan has been facing the problem of demand that has exceeded the limits of supply. Many of the wells that were licensed before 1993 are overdrafted, and some wells are turning brackish. Recycling waste water is one solution for increasing the efficiency of water-reuse. Another is using ROs in desalinating brackish water for irrigated crops and utilizing tolerant genomic biosaline plants.

Research aimed at developing technologies and techniques for exploiting green water, conserving blue water, and identifying economical opportunities to acquire virtual water is needed.

Finally, demand management policies that emphasize rationing or economizing on water have not been fully utilized, though many of them have a strong basis in science. Any research that can increase the public acceptability of demand management policies will be helpful.

Conclusion

Analyses of links between science and policy in water management in the MENA region show that water research is not part of water policymaking. There is an absence of cutting-edge scientific research, and linkage of knowledge to policy is not well-developed. There is a lack of national science and technology policy and coordination. Agendas may be dictated by donor agencies, and water policy is influenced by the politics of interest groups more than by science-based discourse. Capacity building in training scientists to excel in water research is needed. This requires a national agenda that includes water research priorities, political commitment, sound research management, sustainable funding, and a manpower plan to attract outstanding scientists and to send outstanding graduates abroad on scholarships for PhD and postgraduate studies to develop a critical mass in water research nationally.

Conferences and other interactions between scientists, planners, communicators, managers, and public officers should bring water science to policy making process for water management. Stakeholders should be engaged in water policymaking and should use knowledge in overcoming differences. Universities and research centers should develop water science research groups to tackle the priorities of the water sector. This will develop an interdisciplinary approach, pool resources, and develop a critical mass of the know-how to attract funding for joint proposals related to the priority of the water national agenda.

National water agendas should not be subjected to the whims of outsiders, but international scientific cooperation with world-class research institutions should be encouraged and maintained. Scholars should produce tangible scientific results that are perceived by government as credible. Research must be placed at the center of water policy, and governments should implement sustainable water policies to rationalize demand to ensure efficient use. Government's role should be shifted from being exclusively a provider to being an effective regulator and planner.

A report from the Economist Intelligence Unit (2012) on challenges to meet water supply in 2030 emphasized that shortage and stress will yield scientific innovations. The report cited a few promising technologies:

- Lower-cost water desalination: from carbon nanotubes with membranes to radial deionization for removing salts from water.
- Better wastewater reuse: research and development is reducing energy by 30 to 45%.
- Managing aquifers recharge; storing surplus water.
- With the political will and consumer backing, water stress will force technology development and innovation in all phases of the water cycle.

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