Groundwater assessment and management: implications and opportunities of globalization

Karen G. Villholth

Abstract The present and predicted increase in groundwater's share of human freshwater withdrawals, its unprecedented importance for human activities globally, and the emerging threats from escalated and unplanned use and degradation, especially in the developing countries, point to the need for intensified efforts to cope with the imbalances. Despite these facts, there is little intervention by governments in developing countries. Sufficient knowledge, awareness and understanding of the groundwater resources and their proper management are missing in these countries, as well as in the international community. Links and trends are described, which highlight problem areas, such as water contamination, urbanization, and socio-economic factors related to groundwater management practices. Globalization provides novel opportunities for facilitating the process of acquiring and applying the necessary knowledge and can, and should, be further explored and developed. The likely benefits of this are: increase in convergence of understanding and approaches; the sharing of knowledge; and potentially wide-reaching, lasting, and scale-crossing networks. The international development and research community is in a particularly fortunate position to promote and facilitate such a process, which should go hand in hand with well focused and coordinated "on the ground" tasks, such as local networking, field investigations, capacity building, and advocacy activities.

Résumé La croissance actuelle et future de l'exploitation des eaux souterraines pour le prélèvement d'eau douce, l'émergence de menaces provenant d'usages et de dégradations en escalade et non planifiés, spécialement dans les régions en voie de développement, montrent du doigt lles efforts nécessaires et intensifs pour affronter ces déséquilibres.

Malgré ces faits, les gouvernements des pays en développement réagissent faiblement. Les connaissances suffisantes, les consciences et les compréhensions des ressources en eaux souterraines et de leur bonne gestion, manquent dans ces pays et dans la communauté internationale.

Les liens et les tendances des régions à problémes sont décrits, tels que les problèmes relatifs à la contamination, à l'urbanisation, aux facteurs socio-économiques au regard de la gestion des eaux souterraines. La globalisation apporte de nouvelles opportunités, facilitant le processus d'acquisition et de sollicitation des connaissances nécessaires, et peut, et devrait, être mieux explorée et développée. Les bénéfices seraient vraisemblablement : une augmentation de la convergence des compréhensions et des approches; le partage des connaissances; et potentiellement un réseau largement étendu, permanent et croisé. La communauté internationale de recherche et développement est en position de promouvoir et faciliter de tels processus, qui devraient passer de main en main jusqu'au terrain, via les réseaux locaux, les investigations de terrain, la formation (/capacity building/), et les activités de promotion des intérêts.

Resumen El incremento presente y predicho en la participación del agua subterránea en los aprovechamientos humanos de agua dulce, su importancia sin precedentes para las actividades humanas en general, y las amenazas que surgen a partir del uso y degradación crecientes y sin planeación, especialmente en los países en vías de desarrollo, llevan a la necesidad de intensificar los esfuerzos para afrontar los desbalances. A pesar de estos hechos hay una escasa intervención por parte de los gobiernos en los países en desarrollo. El conocimiento, la atención y la comprensión suficientes de los recursos de agua subterránea y de su manejo apropiado están ausentes en esos países, así como en la comunidad internacional. Se describen relaciones y tendencias, que resaltan las áreas con problemas, tales como contaminación del agua, urbanización y factores socio-económicos relacionados a las prácticas de gestión del agua subterránea. La globalización da oportunidades novedosas para facilitar el proceso de adquirir y aplicar el conocimiento necesario, y esto podría y debería ser aún mas explorado y desarrollado. Los beneficios probables son: El incremento en la convergencia del entendimiento y de los avances, el intercambio de conocimiento y la conformación

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K. G. Villholth (✉)
International Water Management Institute (IWMI),
P. O. Box 2075, Colombo, Sri Lanka
e-mail: k.villholth@cgiar.org
Tel.: +94-11-278-7404
Fax: +94-11-278-6854

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de redes potencialmente ilimitadas, de amplio alcance y duración. El desarrollo internacional y la comunidad científica están en una posición privilegiada para promover y facilitar ese proceso, el cual debería ir de la mano con las tareas presentes bien enfocadas y coordinadas, tales como la conformación de redes locales, investigaciones de campo, fortalecimiento de la capacidad, y actividades de promoción.

Keywords Groundwater resources · Groundwater management · Globalization · Knowledge generation and application · Developing countries

Introduction

Groundwater occurs with varying prevalence, extent and natural quality over the globe, and hence its importance for humans and nature varies from region to region. However, looking at the globe as a whole, across various climatic zones, and various countries and regions with various levels of economic development, groundwater plays a very significant role in the supply of water for human activities (Shah 2004).

As an indicator, the World Water Development Report by the World Water Assessment Programme (WWAP) states: "Rapid expansion in groundwater exploitation occurred between 1950 and 1975 in many industrialized nations, and between 1970 and 1990 in most parts of the developing world. Systematic statistics on abstraction and use are not available, but globally groundwater is estimated to provide about 50% of current potable water supplies, 40% of the demand of self-supplied industry and 20% of water use in irrigation. Moreover, the value of groundwater to society should not be gauged solely in terms of relative volumetric abstraction. Compared to surface water, groundwater use often brings large economic benefits per unit volume, because of ready local availability, drought reliability and good quality requiring minimal treatment" (UN/WWAP 2003). Groundwater is estimated to contribute to a quarter of total global water withdrawals (Shah 2004).

India serves as a special case amongst developing countries, in the sense that it has 15% of the world's population, which has to be sustained with only 6% of the world's water resources and 2.5% of the world's land (Zektser and Everett 2004). Groundwater supplies about 80% of domestic water supply in rural areas. Further, some 244 km^3/year (equivalent to an estimated quarter of the world's total annual withdrawal of groundwater) are currently estimated to be pumped for irrigation from about 19–26 million motorized dug wells and tubewells (Burke and Moench 2000; Foster et al. 2000). Shah et al. (2003) estimated that 55–60% of the Indian population (about 620 million) is dependent, directly or indirectly, on groundwater for its livelihood. Groundwater investments by farmers over the last 50 years are estimated to be in the order of 12 billion USD compared to 20 billion USD for public sector investment for mostly surface water irrigation. However, the economic benefits from the former are considered to be many times greater (Shah et al. 2003).

Concurrent with this reality, and as a direct consequence, increasing problems associated with excessive groundwater exploitation and degradation have been reported. These include declining water tables, wells running (seasonally) dry, increasing pumping costs, competitive deepening of wells, ground subsidence, loss of wetlands and flowing springs and rivers, salt water intrusion and other salinity problems, groundwater degradation from natural toxins (e.g. fluoride, arsenic), and from spreading or leaching of anthropogenically-used substances from point and non-point sources (Moench and Dixit 2004; Richardson et al. 2004; FAO 2003; Llamas and Custodio 2003; Moench et al. 2003; Morris et al. 2003; Burke and Moench 2000; Shah et al. 2000).

Despite increased knowledge and recognition of these facts, it is also very clear that there remains a huge gap in our comprehension of the larger picture of groundwater resources and their use, significance and management on a global scale (Moench et al. 2003).

Finally, and with crude generalization, it is evident that the developing part of the world is facing relatively greater problems than industrialized nations due to the higher rate of groundwater development combined with limited economic, technical and institutional capacity to control and confront them and above all, lack of political and wider social support for standard regulatory or related interventions.

The objective of this paper is to summarize some general trends and pertinent issues of groundwater use and management, with special focus on the developing countries. The paper attempts to identify the impediments and associated requirements for, and a path towards, long-term sustainable global groundwater use and management. The discussion presents the perspective of an international water research organization, and the emphasis is on the role of globalization and how the international community can facilitate and accelerate a more regular and concerted effort towards sustainable groundwater utilization.

Global trends and pertinent issues of groundwater use

The terms "sustainable yield" and "overexploitation"

The total groundwater reserves of the world are enormous, with an estimated 98% of total liquid freshwater of the earth being held in underground reservoirs/aquifers (UN/WWAP 2003). Having said this, very little is known, on a global, or even local, scale of the extent of the available reserves and even less of the exploitable amounts. This becomes increasingly evident as the water resources become committed and cause increasing frustration to natural resources managers who would like to define and plan according to some levels of "sustainable yield" and avoid "overexploitation".

The reality is that due to the intricacy and the concealed and heterogeneous nature of groundwater systems, it may never be feasible to map the total global groundwater resources with great accuracy. In any case, it will never be feasible to extract and utilize the whole reserve, as

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irreversible consequences would follow, in terms of: massive seawater intrusion; dewatering of freshwater lakes, rivers, and springs; large scale contamination and/or major geological consolidation and land subsidence. An estimated 8.2% of annually renewable groundwater is being extracted for human use (Shah 2004), which appears to be a small fraction, but this number covers a large global variability of groundwater recharge, basically reflecting differences in rainfall and geological formations. It says little about the potential for further groundwater exploitation on a local, or even, global scale.

The question is then: How much can feasibly and sustainably be abstracted on a long term basis (say one or two generations) in specific regions? The major recognition required here is that an abstraction of groundwater always has an associated impact on the water balance and hence on the availability of water resources in other parts of the water cycle, and that abstraction will lower the groundwater level and hence the available resource to a level where inflow in a semi-steady state situation, and on a longer time scale, balances outflow.

The question cannot be answered solely based on a quantitative assessment of the available resource and its replenishment rate, but necessitates a wider analysis of demands of various users, and the trade-offs between positive and negative consequences (technical, socio-economic and environmental) of specific planned abstraction. Hence, the terms "sustainable yield" and "overexploitation" are unfortunate as they convey the false cognition of a definite, clear-cut threshold limit beyond which groundwater utilization is not sustainable (Custodio 2002). Proper groundwater management, of necessity, is an inter-disciplinary exercise, adding to the complexity of the issue.

However, the terms sustainable yield and groundwater overexploitation should not be dismissed altogether, despite lack of precession because they convey a clear message to the public and the politicians and may bring about the dialogue necessary to define the acceptable negative costs to society associated with intensive use of groundwater.

Typology and trends of groundwater development

It is highly likely that the future expansion of groundwater use will continue to take place in the developing countries. This is primarily due to the relatively high population growth rates in these countries, combined with the gradual rise in industrialization and welfare, which tends to increase the average per capita water use. The largest single consumer of water is, and will continue to be, agriculture with urban and industrial uses on the rise.

The generalization made here may not be totally justified, as differences exist across developing countries and regions. A significant distinction seems to be necessary between the general case in Asia and Africa, with Asia (especially India and the North China Plains in the northeastern part of China) following an accelerated pace of development, whereas Africa, and especially Sub-Saharan Africa, offers a case of slower development due to resource, population or economic constraints. However, the analysis of the latter is flawed by uncertainty, due to lack of comprehensive data and information (Giordano, in press).

Current groundwater use in many developing countries is characterized by uncoordinated development and uncoordinated supply to all sectors: rural and urban users, small and large scale users, industrial and agricultural users. This, in part, is attributable to the intrinsic properties of the resource. The general prevalence and stability in time and space of groundwater makes it a reliable and widely-accessible resource, easily amenable to private, local, and on-demand exploitation. However, this "common pool" property of groundwater also complicates a more formalized and coordinated control (Custodio 2002).

The spectacular increase in groundwater use has mainly been market driven, with the cost of development and extraction being relatively modest and the necessary technology available in most countries. Another remarkable aspect of the groundwater development process in developing countries is that while the resource helps to secure the livelihood of a large fraction of the lower income population, primarily through small scale irrigated farming, the consequences of groundwater degradation and lack of control measures affect the poor population groups disproportionately more (Mukherji and Shah 2002). The reason for this is that while wealthier groundwater users normally have some alternative economic options for substituting depleted and contaminated wells, the poor do not have the same options available to them.

Missing links in groundwater management and debate

Four important links that may not have been very conspicuous when the level of groundwater development was modest, have become increasingly clear with more intense use and dependency on groundwater, to the point that they cannot be separated in practical cases of analysis and management. The first is the link between *groundwate*r and *surface water*. In most parts of the world, the pre-development groundwater levels and occurrence were in close enough proximity to the land surface to cause significant interaction between water above ground and below ground, e.g. through wetlands, springs, rivers, lakes, etc. As major impacts of intensive use of groundwater are often manifested in the reduced interconnection between the two accompanied by negative impacts on valuable ecosystems, this link has been quickly recognized. However, this understanding has yet to be translated into management strategies in developing countries (Sophocleous 2003; Llamas 1988). Many developed countries legally protect in-stream flows—sometimes called environmental flows—which has the effect of limiting groundwater development and forcing conjunctive groundwater/surface water management.

The second link is that between groundwater *quantity* and groundwater *quality*. Not withstanding the fact that the main cause of groundwater pollution is related to poor land use, intensive agriculture and insufficient industrial and domestic waste treatment and disposal, there is a growing recognition that changes in groundwater flow and

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groundwater level, per se, can significantly change the chemical composition of the groundwater with detrimental effects on the serviceability of the water for particular uses. Examples include sea water intrusion as a consequence of intensive pumping of coastal-near aquifers, the release of certain inherent adverse or toxic constituents (manganese, iron, selenium, sulfide) as a consequence of lowering groundwater levels and subsequent entry of oxygen into the previously anaerobic environments (Morris et al. 2003).

Further, it is becoming clear that many significant contamination problems in groundwater systems are not direct, but rather secondary effects of groundwater pollution. For example, when aquifers are loaded with organic contaminants (from landfills or from land surface sewage disposal or waste water irrigation), a plume with zones of varying redox conditions develops giving rise to various processes that may release soluble toxic or adverse chemicals, e.g. arsenic, iron and manganese (Morris et al. 2003). Certain chemicals intentionally or unintentionally released to groundwater environments, like pesticides and petrol products, may undergo transformation and degradation processes in the sub surface rendering them more harmful to the environment and health than their original counterparts (Morris et al. 2003). These interrelated factors and processes are complex and though some general mechanisms and cause-effect relationships are known and documented, site-specific and chemical-specific knowledge and data are necessary. This is an area that deserves greater focus in research, as much is still not known sufficiently to be able to predict and prevent impacts on groundwater quality based on knowledge of aquifer properties, changing flow and groundwater level conditions and sources of pollution, which even in a developing country context encompass a multitude of chemicals. Equally essential is the need to convey research results, and to disseminate experience in training and capacity building from the developed part of the world to the less developed, as there is a great disparity between the two when it comes to knowledge on groundwater contamination processes and prevention.

The third link is that between *rural* and *urban* areas. With urban populations increasing relatively faster than rural1, the interaction and interdependency, which also entails conflicts, between the two become increasingly evident. As an example, the larger cities in China are now pressing for, and are given, precedence in terms of fulfilling water demands for domestic and industrial purposes, which occurs at the detriment of water access for agricultural purposes in adjacent and upstream rural and peri-urban areas.

Urban water use is characterized by relatively higher water demands per unit area, due to the concentration of population, but also by relatively little overall consumptive use, meaning that a large fraction of water used is returned, in one way or another, to the system, but in most urban areas in developing countries that is as untreated wastewater with reduced value for other uses. The growth of larger cities tends to involve the increased capture of water, from either surface water or groundwater, involving transfer from adjacent groundwater or distant surface water sources that previously served the rural population. In return, the peri-urban areas or rural areas downstream now receive the wastewater in an ambiguous cost/benefit situation, as the rural population is then required to cope with this generally lower quality, but in many cases increased and more stable supply of water. Irrigated farming at various scales supported by this kind of resource (either directly from the surface water source, or indirectly through pumpage of excess water that infiltrates to groundwater), is an increasing world-wide trend that cannot be ignored and needs proper attention to understand the whole intricacy of *rural/urban* areas, *surface/groundwater* and water *quantity* as well as *quality* (Foster and Chilton 2004; Morris et al. 2003).

In general, groundwater issues in urban areas are highly complex and variable from case to case, dependent on the stage of development, available water resources, and underground conditions. This is illustrated by the fact that the overall groundwater level under large cities may be declining, with its associated contamination and land subsidence risks due to excess pumping, whereas in other cities the trend may be the opposite or may have been reversed as a result of a shift from local groundwater use to imported surface water with associated large conveyance losses to the groundwater (Morris et al. 2003; Foster et al. 1998).

The fourth link to be further recognized and integrated in groundwater research, debate and management is the inter-relationship between the *physical characteristics and processes* of the groundwater resources and the *socio-economic factors* governing the human decisions on how to develop and benefit from these resources and ultimately adapt to potential negative consequences of overexploited and degraded resources. A far more coherent understanding is needed of the relationship between human/institutional and physical factors in actual and potential driving forces that direct human interactions with groundwater. Physical scientists and the socio-economic community need to develop common language, integrated tools and methodologies, and specific interdisciplinary projects and databases.

Globalization and its implications for groundwater management

The main presumption of this paper is that the present globalization has major impacts on the way that groundwater problems are, and especially will be, solved in the future. Globalization is here defined as: the expansion of global linkages, communication and information, integration of markets, technology and social life on a global scale, and growth of global consciousness, hence consolidation of world society.

As groundwater in general has been developed later in history (at a significantly accelerated rate within the last half century in the developing world, mainly due to the advance and availability of pumping technology) in comparison to surface water, the way that groundwater will be managed and associated problem-solving, will be much different from the way surface water utilization and management has developed over history. Some likely consequences of this, compared to surface water, include:

– Groundwater problems will be solved in a more consistent, but not necessarily similar, way across the globe
– Groundwater problems will receive more global attention and decision makers will be under increasing pressure to find solutions
– As a result, groundwater problems will be addressed with increasing promptness and urgency
– The international community (defined here as international organizations, like the United Nations (UN), international research and consultancy institutions, and international development banks and agencies) in collaboration will play a greater role in devising adaptable and collaborative solutions.

Globalization has some general features that tend to increase the amount and speed of communication and information flow, provide consensus on the world's problems and focal areas to address (poverty, hunger, malnutrition, climate change, inequity in world trade, lack of security of basic water supplies), and facilitate the networking and collaboration across different regions and scales.

The issue of groundwater use and associated problems has been subjected to this globalization process. The effects are seen in the increase in global initiatives to document conditions, and facilitate solutions to the world's groundwater problems. Initiatives include: GW-MATE (Groundwater Management Advisory Team) under the World Bank and Global Water Partnership, established in 2000; IGRAC (International Groundwater Resources Assessment Centre) under the auspices of UNESCO and WMO (United Nations Educational, Scientific and Cultural Organization and World Meteorological Organization respectively), established early 2003; and various working groups/consortia involving UNESCO and IAH (International Association of Hydrogeologists, established in 1956).

The objectives of these initiatives are primarily that of collecting and disseminating data and information on a global scale on hydrogeology and the properties of aquifers, the status and development of groundwater resources, various tools and methodologies for groundwater assessment and management, and constraints and potentials for proper groundwater use and management. In addition, they function as a networking nucleus between researchers, practitioners, stakeholders and other interested parties across the globe. Not surprisingly, these initiatives work heavily through the ultimate globalization media, the Internet.

IGRAC, whose stated mission is to "facilitate and promote world-wide exchange of groundwater knowledge to improve assessment, development and management of groundwater resources," has established a number of working groups of international experts to develop guidelines to assess the exploitable groundwater resources and for groundwater monitoring. IGRAC is also developing a Global Groundwater Information System (GGIS) for various categories of stakeholders. The system is envisaged as an interactive and transparent portal to groundwater-related information and knowledge on the Internet (IGRAC 2005).

The objectives of GW-MATE are to: a) support and strengthen the groundwater components of World Bank and GWP (Global Water Partnership) projects, at country or regional level; b) advise on management and protection issues in project identification (including the definition of key government functions and policy options); c) facilitate (at least at pilot level) the emplacement of management systems, including the mobilization of stakeholders to address groundwater resource management and protection needs; and d) harvest and evaluate global experience, taking account of hydrogeologic and socio-economic diversity. GW-MATE is involved in awareness training and capacity building activities, has produced a series of easily comprehensible briefing notes on various topics related to groundwater (World Bank 2004). GW-MATE was also instrumental in the development of a theme issue on groundwater development and management in Hydrogeology Journal (Kemper 2004).

UNESCO is part of a consortium involved in a project to develop a global groundwater map, WHYMAP (The World-wide Hydrogeological Mapping and Assessment Programme) (BGR 2004). UNESCO has also established a working group on groundwater indicators, which is developing nine indicators to be included in the second edition of the World Water Development Report (WWDR), scheduled for publication in 2006 (UNESCO 2003).

Other interim initiatives include the Comprehensive Assessment of Water Management in Agriculture, an international research, capacity-building and knowledge-sharing program running from 2000 to 2005, under the auspices of the Consultative Group on International Agricultural Research (CGIAR) and hosted by the International Water Management Institute (IWMI). As agriculture, and especially irrigated agriculture, is the major consumer of the world's water resources, with an estimated 69% of global human water withdrawal going to agriculture (FAO 2002), and the groundwater share of this increasing, the final analysis and results provided by the Comprehensive Assessment are highly relevant and anticipated. One volume of a series of books emanating from this exercise is dedicated to the topic of groundwater in agriculture: its use, its economic and societal importance, and the constraints and possibilities for management, focusing on the developing part of the world with high dependency on groundwater (Villholth 2005).

One manifestation of globalization is the advent and development of remote sensing, which encompasses a wide range of primarily satellite-based techniques for acquiring spatially resolved, but large scale coverage, data and information on the properties of the Earth and its atmospheric surroundings. It has been estimated that by 2010, the constellation of forty-five major planned satellite systems will provide 52 billion remotely sensed observations per day of the continental land mass, oceans, and atmosphere, an increase of four orders of magnitude from year 2000 (UN/WWAP 2003). Remote sensing has considerable potential for diverse applications, from detecting and planning of landuse to investigating climate change, especially in developing countries where the availability and accessibility of data are relatively limited. Within the last couple of decades, great efforts have been put into releasing the

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great promise of remote sensing within environmental and water resources research and management (Bastiaanssen 1998), including groundwater (Schultz and Engman 2000). The UN agencies have convened an expert panel to assess the relevancy of all such potentially useful data sets (UN/WWAP 2003).

Impediments for proper groundwater management

Defining the issues

When comparing countries or regions across the globe in terms of groundwater dependence and degree of control of the exploitation of the resource, it becomes evident that there is no direct relationship between the level of dependence on groundwater and the problems related to its use. The determining factors are rather associated with the institutional, human and economic capacity and resources with which a country can face the problems and the underlying focus and priority vested in groundwater issues. Hence, in general the developing countries face much greater challenges when it comes to groundwater management. Groundwater management is lagging behind the pace of development, and often, very little control is exercised in the exploitation of groundwater resources.

Relevant questions present themselves: What is the real extent of the problems?; why are the present efforts so limited?; and what can be done to change the situation, to start on a path to more sustainable and equitable development and management of groundwater resources?

To be able to address these questions and devise intelligent answers, an analysis of the present impediments deserves attention. Only by clarifying the constraints and addressing these, will any significant changes be possible, let alone occur.

Current strategies and policies discourage groundwater protection

A major, and perhaps fundamental, impediment to sensible groundwater management in developing countries is their ingrained and complimentary strategies and commitment towards poverty eradication, on one side, and the sustaining of the agricultural sector as a basis for national food self-sufficiency, on the other. As long as groundwater remains a major factor in sustaining livelihoods of a large fraction of the population, as well as supporting stable crop production on which they depend, it is highly unlikely that major direct brakes will be imposed on its development, especially when alternative water sources are equally depleted or increasingly expensive and controversial to develop, like gigantic inter-regional river-linking or water transfer schemes.

All other major obstacles for sound groundwater management, such as absence of or ineffective legal and regulatory framework, poor technical and institutional capacity, the overall lack of data and information on the resource base seem to partly be derived from these overriding strategies.

However, it is clear that it is necessary to break the vicious circle of groundwater dependence that leads to its own degradation. Some authors think (Morris et al. 2003), and this argument presumably also underlies current strategies, that groundwater protection cannot be afforded at the present economic status of societies, and only through economic development, partly sacrificing the environment in the process, will these states be able to raise themselves out of poverty and concurrently face externalities in the form of environmental degradation, here exemplified by groundwater-related degradation. This argument is fueled by the easy comparison to a parallel historic development in the present day industrialized countries (Hervani and Tweeten 2002).

Requirements for sustainable groundwater utilization and management

The outcome of the analysis of the present constraints for sustainable groundwater utilization and management can be inverted to summarize four essential prerequisites for reversing the despondent situation:

1. *Significant national economic surplus* is needed to enable a general increase in standard of living and, in terms of groundwater, the financing of initiatives, institutions, and systems needed to upgrade the capacity to take a concerted unilateral responsibility of the governance of national groundwater resources
2. *Knowledge and information* concerning groundwater resources, and of options and tools for proper management
3. *Political will*, commitment, and tenacity at national level to confront the problems
4. *A significant, detrimental groundwater-related event* with large-scale effects (hitting across sectors and various user groups) to fuel a consensus and more unified goal of groundwater protection and balanced groundwater development.

China provides an example of the first point. The significant increase in national income over the last few decades has been associated with the establishment of regulations and licensing systems of groundwater abstraction (Shah et al. 2004). Time will tell whether these systems in fact will be adhered to and enforced.

An example of the fourth point is the continuing groundwater declines and associated seawater intrusion and land subsidence problems in the Bangkok metropolitan area in the mid-1980s, which prompted and enabled a public authority to establish effective controls on domestic and industrial supplies. Another example is Israel, which managed to shift, albeit temporarily and despite lobby from powerful farmers, water allocation from the agricultural to the industrial sector, impelled by a severe drought in 1986 and 1991–1992 (Morris et al. 2003).

Despite the last factor not being desired and planned for, it may incidentally act as a direct incentive and catalyst for more prompt response. The first three factors

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in unison, potentially accentuated by the fourth, are expected to forge awareness, incentive, capacity and ultimately a commitment for a process of more sustainable groundwater management.

Globalization revisited: How to benefit from the inevitable?

Possibilities of globalization

The last part of this paper is devoted to an analysis and synopsis of possibilities of globalization in promoting sustainable groundwater management, particularly in developing countries with high dependency on groundwater.

Revising the prerequisites listed in the previous section, and taking the perspective of an international water research institute, it becomes clear that the major role that can be played by the international research community is primarily associated with the second factor, related to knowledge and information generation, dissemination, application and sharing.

The first and third factors, which may be overriding, however, should not be overlooked. They entail the analysis of global market mechanisms, global politics and access to natural resources in a broader sense and internal national wealth distribution ethics, which is outside the scope of this paper. As an example, issues of ethics in water development and management is increasingly emphasized as an impediment to sustainable and equitable resource allocation (Llamas 2004; FCIHS 2002).

The requirements for information intensification on groundwater issues at global as well as local scales is highly compatible with the characteristics of the present functioning of globalization and, in fact, the current trends are a reflection of this compatibility. Having said this, and realizing that this is an on-going process, it is stressed here that there is ample room for further opportunities to take advantage of globalization when it comes to groundwater management.

Some of the tasks that may combine to contribute to the further development and sharing of a global knowledge and understanding of groundwater issues, and which all benefit from the facilitating power of globalization, include:

1. To document, pool and disseminate knowledge on the present groundwater conditions and trends at a global scale
2. To compare, analyze and synthesize approaches, methodologies and experiences in groundwater management across the globe, from developing to developed countries
3. To promote awareness, advocacy, capacity building, commitment and ethics on groundwater issues across various users, institutions and scales
4. To facilitate dialogue, networking, partnerships and coordination across stakeholders, researchers, specialists, decision makers and donors
5. To promote development of global and national monitoring systems, databases, indicator systems, and guidelines for groundwater assessment and management
6. To promote interdisciplinary/multidisciplinary scientific collaboration, terminology, approaches and tools on groundwater
7. To develop and apply integrated remote sensing and dynamic modeling tools at various congruent scales and at various complexity with various interlinked purposes
8. To complement and support global initiatives to assess and document the freshwater situation in the world, with respect to groundwater
9. To promote the development of large-scale to global-scale future development scenarios and impact assessments (for example, on food security and environment) related to groundwater use and over-exploitation, incorporating less traditional parameters like virtual water, shift in irrigation and cropping patterns due to groundwater depletion, world trade policies etc.

On point 3 above, the CGIAR Challenge Program on Water and Food is launching a large-scale project under the title “Groundwater Governance in Asia: Capacity Building through Action Research in Indo-Gangetic and Yellow River Basins”. The project, which is headed by IWMI, focuses on capacity building and networking within existing institutions in two large, highly populated and groundwater-dependent areas of Asia and the approach is based on an innovative, interactive and self-disseminating methodology. By directly involving practicing managers/decision makers in training and research, it is envisaged that the uptake and dissemination of research results and knowledge will become more efficient.

It is the premise of this project that by applying such an approach: [a] scientific research is more context-specific, relevant and responsive to the managerial requirements of groundwater governance; [b] “learning by doing” promotes better internalization of new ideas and frameworks than lecturing by others; [c] groundwater managers themselves would be far more effective in propagating a broader governance perspective amongst their professional colleagues than professional external researchers; [d] capacity building and research emerge as joint, mutually enforcing processes and products.

Courses and research work is designed to address multidisciplinary facets of groundwater governance (physical/technical, socio-economic and policy/institutional) and to address groundwater governance issues in different regions in Asia.

It is anticipated that this multi-disciplinary and cross-regional approach will: [a] promote cross-disciplinary and cross-regional fertilization of learning, with opportunities for comparative policy research; [b] produce future leaders with a broad vision; [c] create cross-regional and interdisciplinary networks and partnerships on groundwater governance beyond the lifetime of the project. The project also targets the media, in recognition that the dissemination of general awareness on groundwater is a major requirement for proper utilization of the resource.

In general, capacity building and development assistance within groundwater, promoted by the international research and development community, is still relatively new and

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traditionally it has focused on the more technical aspects, like data base development, resource exploration and development. There is a great need to expand the efforts of capacity building and assistance, and to ensure more integrated, multi-disciplinary approaches. At the same time, there is a great need to document and publish the results and experiences resulting from such activities, to disseminate knowledge of best practice. Institutions that could benefit from collaboration on capacity building within groundwater involve, but may not be limited to, IWMI, GW-MATE, TNO (the Dutch geological survey), NGWA (National Groundwater Association, in the USA), Cap-Net (Capacity Building for Integrated Water Resources Management, under the GWP), UNESCO-IHE Institute for Water Education, and TWAS (Third World Academy of Sciences) and associated national academies of sciences. A suggested means of bringing this together could be to develop and issue a newsletter specifically dedicated to international capacity building within groundwater.

Some of the purposes that dynamic modeling tools, mentioned in point 7, may serve are: to incorporate, integrate and analyze remotely-sensed data; to demonstrate, visualize and animate groundwater behavior, problems and management options; to analyze trends in groundwater use; and to predict the consequences of various management scenarios, including "business as usual" and less controllable scenarios of climate change.

Initiatives emphasizing the broader aspects of freshwater, such as the GWP, and the WWAP could benefit from more input and focus on the aspects and knowledge of groundwater (point 8 above). Both seem to have largely ignored, or understated, the 'Silent revolution of intensive groundwater use' (Fornés et al. 2005).

Keys to success

The success of the proposed, and on-going, activities depends not only on what is being done, but very much on the way that these activities are being implemented and essentially on the degree to which the globalization potential is being realized. Despite the generally increasing awareness of groundwater at the international level, fundamental challenges persist.

One issue is *coordination*. It is essential that international efforts are seen in a larger perspective and that the various international partners succeed in coordinating their activities through networking and efficient communication links. Traditionally, this has been a weak and overlooked side of international development support. However, a critical review and change in mindsets among international organizations are needed to address the coordination/communication aspect of support to groundwater management.

Equally important is that the initiatives are sustained in the *longer term*, to build up a momentum with significant impact and credibility, and to avoid repetition and duplication of efforts. As groundwater flow processes are relatively slow (compared to surface water flow), the response time of the aquifer systems to external impacts is generally long. Hence, it is essential that data collection, monitoring and any dynamic modeling takes place continuously and on a longer time scale to be able to detect and document effects of groundwater degradation and conversely show the effect of remedial activities, despite the superimposition on natural climatic variability. However, the international efforts also need to be temporary and eventually phased out, in order to avoid a strong and continuous, detrimental dependence on external support on behalf of the developing countries.

New knowledge should build on old knowledge in an efficient, linear process. Under this, the documentation, storage and dissemination of the knowledge are important. It is essential to keep global databases and literature bases, integrated as "*knowledge tanks*" that can be easily accessed and updated. For the dissemination, it becomes increasingly important to use *effective communication*, as knowledge can only be transferred and disseminated through channels that are properly chosen and targeted.

A future, and until now neglected, form of media in the process of sharing, raising awareness and training, is *visual techniques*, e.g. video, multimedia techniques, interactive computer tools, pilot/demonstration projects. Some new capacities and skills, not necessarily associated with groundwater, such as communication skills, media techniques and computer visualization, need to be incorporated into the new integrated approaches. There is a great challenge in making groundwater 'visible', popular, and relevant, whether to school children, individuals, villages, watershed communities, nations or the global society.

Finally, it is important to continuously maintain the *link 'on the ground'*, i.e. to actual activities, initiatives, developments and institutions at the local scale. Only by maintaining this and directing the larger scale activities based on the analysis of in-situ observations, the local perceptions, demands, experiences and feedback and by building partnerships across the various scales and supporting and facilitating local stakeholder involvement will the globalization approach to groundwater management reach its full potential.

It has to be recognized that the international community cannot, and should not, be the only or the main driver for proper groundwater management, but rather that it has a role to play as a facilitator and catalyst, in as much as the process needs to be demand-driven and sustained by a continued local and national commitment.

Through the development of awareness, knowledge and capacity at the global as well as at the national and local level, it is envisioned that the overall knowledge gap on groundwater, as well as the knowledge gap between developed and less developed countries, and hence the dependence of developing on developed countries, will diminish.

Conclusions

It can be concluded, from the analysis done in this paper, that there is an increasing recognition of the importance that groundwater plays in the world today in terms of

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sustaining millions of people's livelihoods, besides serving as a major input factor for significant economic activities. This is reflected in the various recent reports and global initiatives that are trying to come to grips with this complex, yet pressing, issue.

It is equally apparent that despite the current recognition and initiatives, the knowledge of the groundwater situation in the world, the potentials and threats to development and the options and strategies for management are still not sufficient to be able to cope efficiently and effectively with the major challenges presenting themselves around the globe.

Knowledge is not the only factor necessary for improving our custodianship of groundwater, but it is a major prerequisite, and it is perhaps the factor that the international society, and particularly international research institutions, can most significantly and effectively contribute towards.

It is suggested in the present paper that globalization and the tools and opportunities it provides (in terms of facilitating communication, the sharing of information, and the linking of people) should play a pivotal role in the shaping of future initiatives and activities. It will go a long way towards filling the knowledge gap, devising ways forward and ultimately attaining a more sustainable groundwater utilization around the globe.[1]

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[1] In 1990, urban dwellers comprised 43% of the world's total population, while in least developed countries 35% of the population lived in cities. By 2020, the proportion of urban population in least developed countries is predicted to surpass 50% and it is expected that 57% of the world's total population will live in cities (UN [United Nations] Report 1997).

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