Challenges for Sustainable Water Management

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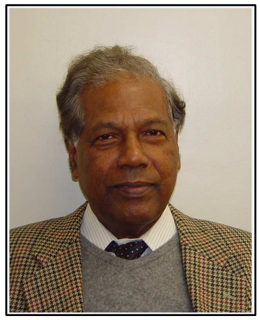

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Abstract: *Water is a precious resource essential for all forms of life. It is abundant in nature but has significant temporal and spatial variability. With increasing population, the per capita share of water on earth is decreasing, and in some regions has reached levels where communities face water stress and water scarcity. Whereas lack of safe drinking water is a major problem for close to a billion inhabitants of the earth, too much water also bring about misery, agony and destruction to many people, places and infrastructure. The former may be attributed to the physical lack of water, pollution or unaffordability whereas the latter is attributed mainly to population growth, urbanization and livelihood issues. Optimal management and use of the available water in the 21st century needs a paradigm shift to a holistic approach since all aspects of water as well as social and economic infrastructures of the world are now more interdependent than ever before. Coping with water problems in the 21st century therefore poses many challenges to water managers. Drinking water security, food security, energy security, climate change, water-related disaster management and maintaining acceptable environmental quality in a sustainable manner are among the major challenges at present and in the foreseeable future.*

Keywords: *Drinking water and food security, climate change, environmental security, disaster management, research, education.*

1. INTRODUCTION

Water is a precious commodity necessary for all forms of life. Its role and importance in societies are exemplified in the following visionary statements in history:

- "Not a drop of water that falls from the heavens shall flow into oceans without being utilized by man" – King Parakramabahu the Great (King of Sri Lanka, 1153-1186)
- "To control China one must first control water" - Guan Zhong, politician and statesman during the Spring and Autumn period of Chinese history (c 720-645 BC)
- "One who solves water problems in the world deserves two Nobel Prizes, one for Peace and one for Science" - Late President of USA, John F Kennedy (1917- 1963).

In the ancient world, civilizations began along the banks of rivers: Yellow and Yangtze in China, Nile in Egypt, Indus in India, among others. The Chinese, during the Wu, Qi and Sui Dynasties, (starting from 486 BC) built the Grand Canal which runs from Hanzhou to Beijing, - a distance of about 1900 km. It is the oldest and the longest water conveyance system in the world - longer than the Panama and Suez canals combined. Hydraulic civilization in Sri Lanka started in the 6^{th} century BC. Romans built the aqueducts in the 7^{th} century BC. In Persia (now Iran), qanats were built some 3000 years ago. Archeological findings point to the existence of aqueducts in India, Mexico, Madeira, among other places, in ancient times. More recently, the Nanzenji aqueduct in Kyoto was built in 1890 during Meiji era. The main purpose of all these engineering feats was to provide water for irrigation and drinking. The kings or the rulers had immense power over the subjects as they controlled the flow of water.

One of the main water problems around the world today is the lack of potable water. After oxygen, water is the most vital ingredient for sustaining life. Food, which requires water for growing comes next. Over one billion people in the world do not have access to safe drinking water and about twice as many do not have access to proper sanitation. The consequences of not having access to potable water are serious particularly in developing countries which suffer from various types of water-borne diseases some of which result in premature death. In terms of quantities, the requirements for domestic and municipal supplies (approximately 8% of total water resources of earth) are far less than those for growing or producing food. The two major users of water are agriculture and industry. The challenge for future is how to guarantee water and food security to all inhabitants of the world.

The second challenge comes as a result of human intervention of the environment over the years. Many of the water resources that were in pristine conditions many years ago are now heavily polluted. They are in a state where they are totally unfit for human use, or that they can only be restored to levels suitable for human consumption at a very high cost. Associated with any development activity, there is always an environmental cost. Waterbodies such as rivers, streams, and lakes also act as waste receiving bodies in many regions. When the release of wastes into such waterbodies exceed their capacities to self purify, they will become 'dead' when no living organism can survive. How the benefits arising from development activities should be balanced against environmental costs is a major issue that needs to be considered holistically in the context of the total water environment rather than as isolated systems.

A third challenge lies in the area of water-related disasters. Water, despite being essential for all forms of life can also at times be destructive. Floods, landslides, and debris flow are all triggered by excess water. Many regions in the world are vulnerable to water related disasters and the damage as well as the resulting casualties are on the increase. It is also important to note that not only the numbers of disasters are increasing but also the number of people affected too because of migration of people into areas with better economic prospects.

2. MAJOR CHALLENGES

2.1. Drinking water security

The health of a nation depends upon the level of cleanliness of the domestic water supply. It is a problem that is often ignored or sidelined by the developed countries as it is only a problem of the poor and the developing countries. Approximately one billion people, or one seventh of the world population, do not have access to clean and safe drinking water. Coupled with the accompanying sanitation problem, which affect approximately twice that number, the situation if allowed to continue can be disastrous. One of the UN Millennium Development Goals (MDG) was to halve these numbers by 2015. Now (2012), 89% of the population of the world have access to improved water supplies, up from 76% in the base year of 1990. (BBC News, March 6, 2012). However, 40% of those still without access to improved drinking water live in sub-Saharan Africa. Worldwide, almost 800 million people still drink dirty water. In the sanitation sector, the MDG has not been reached and in fact it is reported that the situation is worse than in 2000 (BBC News, November 18, 2011). Alarming facts arising from poor sanitation include a child death from diarrhoea every 20 seconds, and more diarrhoea-related child deaths every year than deaths caused by aids, malaria and measles combined (UNDP). Unlike a major flood or an earthquake which affect a small region with high population density, the effect of the lack of drinking water is spread over vast areas with relatively low population densities. From the media point of view, such widespread and prolonged suffering receives much less attention compared with that received for high impact type of disasters such as earthquakes, tsunami and major floods.

Water scarcity can be arising from physical lack of water, poor quality, or due to lack of capacity for developing and maintaining a reliable supply. Arid and desert areas suffer from physical lack of water and such areas also experience pollution problems. Traditional techniques such as rainwater harvesting, and groundwater exploitation would be better appropriate technologies than conventional water supply technology. Since such areas are sparsely populated, achieving individual household self sufficiency is more favoured and should be encouraged than traditional water distribution systems where the conveyance cost can be excessively high. It is also important to introduce low cost water filters which can be used in individual households. It is estimated that $1 invested in improving access to safe water can increase the GDP by $3-14.

2.2. Food security

The global average food intake has increased from 2250 kcal in 1961 to 2800 kcal in 2000, although, in South Asia and sub-Saharan Africa, it still remains at 2450 kcal and 2230 kcal respectively (IWMI, 2006). This increase may be attributed to a number of factors. Land and water productivity has increased with average grain production from 1.4 Tons/ha to 2.7 Ton/ha during the last 4 decades (IWMI, 2006). Global trade in food products also has increased thereby increasing the flow of virtual water. On the negative side are the facts that the population is still increasing, and that the increases are in areas where productivity is low and with inadequate human and economic capacities to upgrade their production.

It is a fact that grains have been the basic form of food for all humans. However, changing life styles have also changed the dietary habits of many societies that have attained some degree of affluence. Meat, milk and fish consumption have increased substantially thereby exerting an additional water cost to food products. For example, the water cost of 1 kg of grain varies between 500-4000 litres whereas the water cost of 1 kg of meat is about 10,000 litres. To produce the grains that are needed for meat and milk production, vast areas of land are irrigated resulting in high environmental costs. On a global scale, agriculture uses about 70% of the world's water resources, followed by industry which uses about 22%. In recent years, many countries have embarked on the production and use of biofuels in place of fossil fuels. This practice also has added a further burden of our water resources because of the additional quantities of water needed for growing the bio species from which the biofuels are extracted.

The challenge in this context is how to produce our food (and energy sources) at the least water cost. Large scale crop production necessarily depends on irrigation to ensure guaranteed successful harvest. Rainfed cultivation on the other hand is weather and climate dependent and therefore does not guarantee a successful harvest every year. The water efficiency in irrigated cultivation is always low. Flooded irrigation results in evaporation from the free water surface as well as from the bare soil. In order to increase the water productivity, it is necessary to reduce crop evapo-transpiration. Better and more efficient techniques such as drip irrigation, low pressure sprinklers are currently being used to increase the water productivity.

Food trade is another area that requires attention. It is not meaningful to attempt to grow food in water-poor regions at high costs and consequent environmental degradation. With global trade expanding, it is quite logical to grow more food in water-rich regions and make them available as food products to those in water-poor regions. However, in the present context, many countries aspire to be self sufficient in food for strategic reasons. Such aspirations will not be needed if fair and reasonable trade agreements and treaties to share trans-boundary water resources are in place. Above all, concern for the well being of other human beings should be the guiding principle for sharing the water resources on earth.

2.3. Climate change

Global warming which is an indicator of climate change is currently a hot topic. The Intergovernmental Panel on Climate Change (IPCC), has concluded that there has been significant temperature rises since the 1970's which they attribute to global green house gas emissions. The issue has also received endorsements and publicity from powerful circles and personalities. There is no doubt that discernible warming is taking place in some parts of the globe as evidenced by melting of ice caps and glaciers, sea level rises, temperature rises, among other changes. At the same time, there is another school of thought, though not as powerful as those advocating the global warming phenomena, who take the view that the issue is blown out of proportion, and that warming exists locally and that it is premature to conclude that the issue is a global phenomenon.

Notwithstanding the arguments for and against global warming, it is s fact that the earth has gone through cycles of warming and cooling in the past. Changes have persisted over decades and sometimes over centuries. Although instrumental measurement of temperature started in 1850, various proxy methods (such as tree rings, ice cores, corals etc.) have been used to understand Paleoclimatology. Examples include the Holocene warm period (circa 1800-4000 BP), the Roman warm period (circa 200-500 AD), the medieval warm period (circa 1000-1100 AD) and the little ice age (circa 1200-1800 AD) (Rundt, 2008). It has also been shown that there is a 1500-year cycle of global warming (Avery, 2008). Some scientists believe that the warming has peaked and that the earth is more resilient than predicted. (Ref: http://news.bbc.co.uk/2/hi/science/nature/7329799.stm). This would mean that the temperature has not risen globally since the 1998 El Nino warm period. There are evidences of cyclical changes of climate in the recent histories of China, UK and Greenland where the warmth has been measured by the ability to grow plant species such as vine, and the ability for animal species to survive. It is also argued that the issue of climate change and global warming in particular has been used as an inhibitor to economic progress in less developed countries. Whether there is global warming or not, earth's resources should not be unnecessarily wasted, but should be shared in an equitable manner. Adaptation, rather than prevention, should be the way forward.

2.4. Environmental pollution

Environmental pollution is a by-product of economic development and goes unabated in many waterbodies as a result of indiscriminate dumping of domestic, agricultural and industrial wastes. Slow accumulation of pollutants over the years in many rivers (e.g. in China and India) has made them aesthetically unpleasant and biologically and chemically toxic. Restoration of such rivers to environmentally acceptable levels is costly and a fair and reasonable approach to recover costs is to follow the polluter pay principle. Many countries have enacted legislation to address this issue but the enforcement becomes difficult as the costs are passed back to the tax payers by the polluters as increased costs of their commercial products. Incidents of pollution caused by accidents such as the one that occurred in Songhwa River in Northeast China are also on the increase as more and more toxic industrial ingredients are conveyed too frequently and over long distances. Introduction of advanced methods of waste water treatment such as membrane technology, recycling, reclamation of waste water etc. help alleviate the pollution problem to some extent. In the long term, an integrated approach of water management in which all aspects of the water sector are considered and optimized within the framework of a single ecosystem appears to be the way forward.

2.5. Disaster reduction

Natural hazards are not preventable. In terms of the damages and the casualties, the main fresh water related hazards are floods, landslides, and debris flow. A hazard becomes a disaster when the region and the community are vulnerable and lack the coping capacity. Therefore any approach for mitigating the consequence of a disaster needs to focus on reducing the vulnerability and enhancing the coping capacity. Although there are many international and regional initiatives aimed at disaster reduction, their implementation is slow and lacks high priority due to political, cultural and economic issues particularly in developing countries. It should also be recognized that capital intensive engineered approaches of disaster reduction practiced in developed countries cannot be applied in developing countries. Rather practices which take into account the local culture, economic status, as well as the political environment would be more effective and implementable. It is only when the community attains a certain degree of affluence that people will begin to think about disasters and invest in disaster mitigation measures. For those living at or below the poverty line, day to day survival by itself is a disaster, and it is very difficult to get them involved proactively on implementing mitigative measures. Although investment in disaster mitigation is considered as a development issue in developed countries, there are other areas of higher priorities where investments need to be channeled in developing countries. More can be achieved by promoting non-engineered approaches of coping with disasters as well as assisting in upgrading the living standards of those in less developed countries.

Water has become a powerful tool that can be used to control the lives and livelihoods of millions and millions of human beings. In the not so distant future, water is likely to replace oil as an economic commodity which may be manipulated by states, enterprises and individuals to their advantage. Water though being a beneficial commodity can at times be destructive too. Floods, caused by excessive rainfalls, snowfalls, etc., can bring immense misery to humankind. This is a serious issue in Asia where about one third of the world population live. The recent floods and other water-related disasters in Sri Lanka, Thailand, Australia, China and Japan amply illustrate this. It is also an unfortunate fact that people return to the disaster-prone areas year after year because of their livelihood issues. More incentives to encourage vulnerable people to relocate to safer areas should be provided by governments to avoid recurrence of similar disasters.

2.6. Research and development

Understanding a problem is a prerequisite to solve it. This applies to the water sector too. Technical issues in the water sector are all contained within the confines of the hydrological cycle in which meteorology plays the upstream role and oceanology the downstream role. In between there are several processes taking place. They can be quantified using the basic concepts of fluid mechanics, hydraulics, hydrology and environmental engineering. Quantification is done using the basic laws of physics such as conservation of mass, conservation of momentum and conservation of energy. Governing equations are obtained using the Lagrangian approach which follows the motion of the same mass of fluid in space and time, or the Eulerian approach which follows the fluid passing through a given fixed position in space. The latter approach uses the control volume concept and leads to the differential form of mathematical representation whereas the former leads to the integral form. The catchment can be considered as the basic unit of domain within which all such processes are considered.

Catchment is a topographically demarcated region which is influenced by the atmosphere from above, the geosphere from below, and the biosphere and the hydrosphere from within. The main challenges of catchment hydrology arise as a result of the interactions of influences from these various components, influences brought about by human activities and the need to ensure that the catchment processes are sustainable. In the past such influences may have existed but to a lesser degree with no conspicuous adverse effects. In the recent times, human influences have accelerated, and the cry for a sustainable future has become louder. A better understanding of the dynamics of the catchment is the key to face such challenges.

Understanding the dynamics of the catchment can be achieved in many ways. For example, collection of better and more comprehensive data could be a starting point. Without data no theory or technique can be validated. Almost all practical tools of hydrology in the past have been empirical. Over the years, techniques of data collection have also changed – from on-site measurements to remotely-sensed. Space based remotely sensed data have become accessible to almost anyone, anywhere, but not without problems. They are grid-based and one data point may represent several hundreds of square kilometres. They then have to be down-scaled to the catchment scale and the methods of downscaling are not perfected yet. Another challenge is that the governing equations of the catchment processes may not be the same at different scales. This is another challenge.

Understanding can also be achieved by modelling the catchment dynamics using conceptual, data driven, and/or physics-based approaches. Nowadays, there is no shortage of models. However, there is no hydrological model that has universal applicability and as a result, more and more models seem to originate at a rate faster than many hydrologists can digest. In fact there are simple models, not-so-simple models, complex models and more complex models with each type having its own pros and cons. There has been a proliferation of models and modeling techniques in the past few decades, and as a result, it is confusing even to an experienced hydrologist. Establishing guidelines on the choice of models under different constraints is another challenge. Simple models have fewer parameters and are relatively easier to calibrate. However, such models do not represent the catchment processes adequately and therefore would in many instances be over-simplified. On the other hand, complex models can potentially describe the catchment processes to any degree of sophistication, but with a price. With increasing complexity of the model, the number of parameters also increases and the principle of parsimony is often violated. The interaction of the multi-parameters give rise to the problem of “equifinality” implying that there is no unique set of parameter values that will give a set of output results but rather a “Pareto” set of feasible parameter space.

There are also emerging techniques of modelling such as for example artificial neural networks that emulate the brain, genetic algorithms and genetic programming that emulate genetic evolution of biological species, phase space re-construction methods that uses the theory of chaos, fuzzy logic that takes into consideration partial truths for dealing with imprecise information, and their various hybrid forms. These methods can be considered as belonging to 'data mining' which attempts to uncover hidden information contained in the data. Such techniques have been mainly developed in the mathematics, statistics control engineering domains and are gradually finding their way into Civil Engineering applications. Embarking on research in these areas would be challenging and rewarding.

2.7. Education

Education plays an important role in the sustainable management of the water environment. Earth's water resources belong to all living things but are controlled by humans only. For its fair and equitable use (and misuse), all human beings should have at least a basic understanding of the water cycle including its relationship to the environment. This is best achieved by introducing related subjects in the school curricula very early in life. Advanced and specialized knowledge should be provided at university level for the professionals who would be managing the resource including their impacts on the environment. A more important aspect is continuing education. Learning is a life-long experience. Knowledge is never at steady state. Many engineering professional bodies promote, and in some cases require, engineers to update their knowledge by attending continuing professional development (CPD) courses to retain their memberships. It is also important to have such CPD courses accredited by reputed and relevant learned societies.

3. CONCLUDING REMARKS

Sustainable management of earths water resources needs the attention, commitment and dedication of all stakeholders. The quantities are dwindling and the qualities are deteriorating. Many issues including societal and cultural matters are interconnected. The problem of water management therefore needs to be addressed in a holistic way. Responding to different challenges sometimes need addressing conflicting interests. If any of the above challenges are taken in isolation, other challenges may have to be overlooked or ignored. An approach in which a balance is sought between development and conservation, and where modern technology and traditional practices go hand in hand would be ideal but the implementation of such an approach requires the will and commitment of all stake holders. A guiding principle would be to share the resources of the planet earth in an equitable manner. Failure to do so will result in a situation whereby the water-rich countries can starve the water-poor countries when conflicts reach critical stages. In the not so distant future, water will take the place of fossil fuel as a political and economic tool that can be used to manipulate communities and governments.

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