

**FINDING SUSTAINABLE SOLUTIONS TO THE GLOBAL FRESHWATER CRISIS:
LESSONS FROM INDIA**

**A White Paper from the
International Workshop on Sustainability and Water Quality (IWSWQ 2011)
Delhi, India
January 17-20, 2011**

Introduction

Water is the most essential material for human survival, after air. Without water, life as we know it would not be possible. Yet, clean drinking water is a scarce resource in many parts of the world, including India. In January, 2011, the International Workshop on Sustainability and Water Quality (IWSWQ 2011) convened government, academic, and industry experts in Delhi, India, to exchange ideas and propose sustainable and cost-effective solutions to water quality challenges that could be implemented at the ground level and potentially replicated in other areas of the world that face similar challenges. The meeting also served as a venue for exploring prospective collaborative opportunities between the Indian and U.S. scientific communities.

The workshop was sponsored by Global Innovation Imperatives (Gii) and organized by Professor R.K. Sharma of Delhi University and Dr. Satinder (Sut) Ahuja of Ahuja Consulting, United States. Gii is a collaborative venture between the American Chemical Society (ACS) and the Society of Chemical Industry (SCI). Its mission is to create community and enable the sharing of knowledge in order to stimulate scientific innovation that addresses globally significant societal imperatives. Water was the first imperative chosen for the Gii program. IWSWQ 2011 was the first Gii workshop geared toward finding sustainable solutions to the global freshwater crisis. India is fertile ground for addressing this challenge, not only because of the widespread lack of access to safe drinking water but also because of the many innovative approaches to water quality remediation being developed, tested, and applied in laboratories and local communities nationwide. The workshop also celebrated International Year of Chemistry 2011.

A unique feature of IWSWQ 2011 was a series of on-site visits by participants to a water treatment plant on the Yamuna River that supplies drinking water to the Delhi population; a community-based fluoride treatment plant near Jaipur (the capital city of Rajasthan); and a sewage treatment plant, also near Jaipur. The on-site visits helped participants gain useful insights into the practical challenges to efficient and effective water-quality management. Much of the workshop discussion revolved around water quality issues related to the Yamuna River, Delhi, and Rajasthan. However, participants also drew on lessons learned elsewhere in India and in the United States.

This white paper describes the main outcomes of the meeting, including knowledge shared and recommendations put forth for improving water quality using sustainable approaches. The recommendations are based on input from workshop participants and insights gained during the on-site visits. A list of speakers and the titles of their presentations are provided in Appendix A; the workshop program is provided in Appendix B.

The Availability of Safe Drinking Water in India and Worldwide

Even though Earth is composed largely of water, freshwater comprises only three percent of the total water available to humans. Of that, only 0.06 percent is easily accessible -- mostly in rivers, lakes, wells, and natural springs. Even then, accessible water is not necessarily safe drinking water. The freshwater sources from which most of our drinking water is derived are exposed to a variety of contaminants, many arising from the unsafe production, utilization, and disposal of inorganic and organic compounds. Indeed, civilization has polluted most of the Earth's

accessible freshwater to a point where it is necessary to purify most water before we can drink it. Over 40 countries in the world suffer from a safe drinking water deficit, with an estimated 1.2 billion people drinking unclean water on a daily basis and five million people, mostly children, dying every year from water-related diseases. The United Nations estimates that, by 2025, 2.7 billion people will not have access to safe drinking water.

India is the wettest country in the world. However, its water resources are unevenly distributed both temporally and spatially and increasingly over-exploited by the human population. Increasing industrialization, urbanization, and population growth have contributed to a growing water pollution problem nationwide. According to statistics presented by R.B. Srivastava, Defense R&D Organization (DRDO), New Delhi, the amount of freshwater available per capita decreased from 6,008 m³ in 1947 to 2,384 m³ in 2000.

Today, an estimated 10 percent of the Indian population, including both rural and urban inhabitants, does not have access to safe drinking water. Sanjay Bajpai, Director of the Government of India's Water Technology Initiative (WTI) Programme, remarked that only 43 percent of freshwater sources in Rajasthan are potable.

India's freshwater crisis is attributed to three major factors: (1) untreated municipal and domestic sewage; (2) untreated industrial effluents; and (3) agricultural run-off. Subijoy Dutta of the Rivers of the World Foundation, Maryland, United States, described the large volume of wastewater generated in both rural and urban areas, most of which is discharged to streams and rivers without appropriate treatment because of the prohibitive cost of such treatment. Alok Adholeya, The Energy and Resources Institute (TERI), New Delhi, elaborated on the large volume of untreated waste and effluent from animal production, tannery, thermal power, oil, mining, and other industries that is being disposed into rivers and other freshwaters. Even though the Government of India has called for the establishment of Common Effluent Treatment Plants (CETP) in industrial areas nationwide, Chair R.K. Sharma said that implementation has been slow and that most industries are not connected to CETPs or only partially treat their wastewater before disposal. In addition to human activities, researchers are also finding that many water contaminants of potential concern for human health, such as arsenic and radon, can arise from natural sources.

The health risks of exposure to polluted water are numerous. While some pollutants, like zinc, may actually be desirable in small quantities, others are not. For example, arsenic is harmful at levels over ten parts per billion (bbp). Kshipra Misra, Defence Institute of Physiology and Allied Sciences (DIPAS), Delhi, remarked that over 70 million people in West Bengal alone are at risk of arsenic poisoning as a result of long-term exposure to arsenic-rich freshwater. Chair Sut Ajuha elaborated on the arsenic contamination problem not just in India, but also in Bangladesh and other countries. As many as 150 million people worldwide are affected by arsenic poisoning. Adholeya reminded workshop participants that water pollution is not just a public health issue; it also has a significant impact on agricultural productivity and production costs.

The Challenge of Monitoring Water Quality

Sustainable water quality management requires rigorous and regular monitoring of water resources for all potential contaminants so that appropriate actions can be taken to prevent or remediate water pollution. But rigorous and regular water quality monitoring is not a simple task.

Matthew Larsen of the U.S. Geological Survey explained how water quality monitoring in the United States has changed over the past several decades as new challenges have emerged. Most notably, monitoring efforts used to be focused almost exclusively on point source contamination. Indeed, the 1972 U.S. Clean Water Act (CWA) solely targeted specific “end of pipe” points of discharge or outfalls (e.g., factories, combined sewers). The CWA triggered engineering changes in manufacturing processes and wastewater treatment which led to significant progress toward cleaner water in U.S. rivers and lakes. Today, the overwhelming majority of water-quality problems in the United States are caused not by point source contamination, but by diffuse non-point sources from agricultural land, urban development, forest harvesting, and the atmosphere. Water quality assessments in the United States are no longer limited to “end of pipe” point-source data. However, non-point source contaminants are more difficult to effectively monitor, evaluate, and control than point source contaminants. Not only do they demand a greater understanding of the landscape and human activities associated with those non-point sources, but they also require assessment of a greater number of contaminants. Hundreds of new synthetic organic compounds, like pesticides and volatile organics in solvents and gasoline, have been introduced into the environment over the last four decades. Moreover, improved laboratory techniques have led to the discovery of a large number of microbial and viral contaminants, pharmaceuticals, and endocrine disruptors not detected or measured in the past.

In addition to the growing demand to monitor non-point source contaminants, Ahuja emphasized the importance of monitoring pollutants at ultratrace levels (i.e., below parts per million [ppm]). By way of illustration, he pointed to ultratrace methods that are available for monitoring arsenic at the level of 10 parts per billion. Plus, care should be taken to ensure that accuracy of monitoring results is not compromised by mishandling of long-distance samples, lack of proper validation, or failure to consider the impact of seasonal water flow rates. Meeting all of these criteria requires adequate financial and human resources.

Water Quality Monitoring in India

Water quality monitoring in India has shown that organic pollution in rivers is especially problematic; and that pockets of groundwater nationwide are affected by high salinity and contaminated with arsenic and fluoride. Rivers and other surface waters are also impacted by eutrophication, oxygen depletion, and generally deteriorating ecological health; ground waters by nitrate and iron pollution.

Organic Pollution in Rivers

Much of the freshwater quality monitoring in India is conducted by the National Water Quality Monitoring Programme. Founded in 1978, the programme operates under three tiers: the Global

Environmental Monitoring System (GEMS), the Monitoring of Indian National Aquatic Resources System (MINARS), and the Yamuna Action Plan (YAP). As part of the programme, the Central Pollution Control Board (CPCB) established a monitoring network of 1700 stations extending across 27 states and six union territories. The network covers 353 rivers (979 stations), 107 lakes (117 stations), nine tanks, 44 ponds, 8 creeks/seawater (15 stations), 14 canals (27 stations), 18 drains, and 491 wells. Monitoring is conducted monthly at 547 stations, quarterly at 657, semi-annually at 490, and annually at six. All water samples are analyzed for 28 physicochemical and bacteriological parameters (e.g., faecal coliform, total coliform); select samples are analyzed for an additional nine trace metals and 15 pesticides. Biomonitoring is also carried out at specific locations (e.g., measurement of diversity index). The data are reported in water quality statistics yearbooks. According to R.M. Bhardwaj, Senior Scientist at the CPCB, data to date indicate that organic pollution in rivers is especially problematic due to discharge of untreated sewage and industrial effluents. Almost all river surface water sources are contaminated with coliform bacteria. The most grossly polluted areas are certain stretches of the Sabarmati, Godavari, Satluj, Yamuna, Cauvery, Ganga, Krishna and Tapi rivers. The Brahmani, Mahi, Mahanadi, Narmada, Pennar, Brahmaputra and Beas rivers appear to be relatively cleaner.

Groundwater Contamination

Additional groundwater quality monitoring conducted by the Central Ground Water Board (CGWB), under the Ministry of Water Resources, has revealed high salinity and arsenic and fluoride contamination in pockets of groundwater across India. The occurrence of arsenic in groundwater was first reported in 1980 in West Bengal; more recently it has been reported in Bihar, Uttar Pradesh, Chattisgarh, and Assam. According to P.K. Mehrotra, Director of the Ministry of Water Resources, existing methodology, availability of instruments, and trained human resources in water-quality management are inadequate to identify their sources. Other challenges to rigorous and routine groundwater quality monitoring include lack of any agency responsible for monitoring pollution by radioactive contaminants; and lack of agriculture-related non-point source pollution monitoring.

Water Quality Remediation in India: Case Studies

Participants discussed some areas in India where water pollution is either being avoided or treated but where remediation efforts nonetheless need to be improved or considered in order to prevent future problems (i.e., Delhi and the Yamuna River; the Himalayan state of Uttarakhand, with implications for the Ganga River; and Mansagar Lake in Jaipur).

Providing Safe Drinking Water to the Delhi Population

With nearly 17 million residents, Delhi is among the most populous metropolis in India. D.R. Arya, Director of Treatment and Quality Control at the Delhi Jal (water) Board, opined that the Delhi Jal Board is doing a commendable job given the Herculean task of water treatment and quality control for such a dense metropolitan area. Safe drinking water is being provided to all residents through a 15,000 kilometer network of filtered pipes that extends across 1465 square kilometers. The Delhi Jal Board operates nine water treatment plants with plant laboratories; and six high-tech zonal laboratories, including a central laboratory covering all command areas of

Delhi. Four-hundred water samples are collected daily from the water treatment plants, the distribution network, and points of consumer use; and tested physically, chemically, and microbiologically to ascertain that water is potable and conforms to Bureau of Indian Standards maximum limits. Still, there are challenges. Delhi's water is derived from three major raw surface water sources (the Western Yamuna Canal, the Yamuna River, and the Ganga River), as well as underground water sources (i.e., the tube-wells, Ranney wells, etc.). Problems arise. Arya commended the Delhi Jal Board for quickly responding to complaints in a variety of ways, for example by attending to water supply leakages on a daily basis and by conducting a community awareness program. During his overview of the Yamuna River, Subijoy Dutta encouraged consideration of low-cost biological treatment systems for remediating highly polluted discharges flowing through the Barapullah and the Kotlah drains into the Yamuna River near Delhi.

Water Quality Management in Uttarakhand: Implications for the Ganga River

Like the rest of the country, freshwater resources in northern Indian state of Uttarakhand suffers from what Prashant Singh described as "scarcity amidst plenty." Singh, Professor of Chemistry at DAV (PG) College, Dehradun, Uttarakhand, described Uttarakhand as relatively new and as an important water-rich state that caters to India's water demand with a wide range of freshwater resources, including not just rivers but also glaciers (which serve as sources of water for the Ganga and other rivers), lakes, springs, waterfalls, and groundwater sources. However, the area's difficult hilly terrain creates a complex challenge for water resource development. For example, downstream river water is unavailable for use in the upper areas, and groundwater exploitation is not feasible; topographical limitations prohibit the laying of canals. Not only is much of the area's fresh water made unavailable by the challenging terrain, the challenge of accessing clean water for drinking and domestic needs is compounded by the inorganic and organic pollution load created by the huge number of pilgrims along the course of the Ganga River. Other human activities (e.g., industry and agriculture) and geogenic forces add to the problem. Despite these challenges, Singh observed that, overall, water quality in Uttarakhand remains good. However, maintaining that status will require regular and extensive monitoring of identified water sources; and consideration of rainwater harvesting and other sustainable means of gathering and storing water. Also, while Ganga River water is fresh and potable through much of the Himalayan range, Singh called for greater attention to water quality and corrective measures from Rishikesh and beyond.

Remediation of a Freshwater Lake: Methods and Challenges

Mansagar Lake restoration efforts exemplify the demand, opportunities, and challenges of water remediation. K.P. Sharma, Department of Botany, University of Rajasthan, described how. Located in the city of Jaipur, Mansagar Lake covers 130 hectares, with a catchment area of 23.5 square kilometers. Its maximum depth is seven metres. The lake has greatly reduced in size over time as a result of road construction on three sides. The main source of water into the lake is storm water during the rainy season. The lake was unpolluted until 1962. The main sources of pollution since then have been sewage (both raw and partially treated) from the walled city of Jaipur; and wastewaters from the tie-and-dye and carpet industries. An ongoing restoration program involves diversion of wastewater drains; lake bed de-silting; raising wetlands along the

lake bed; and several bioremediation technologies, including lake bed aeration (bio-stimulation), inoculation of microbial consortium (bio-augmentation), and tertiary treatment of municipal sewage in the dry weather. Major drawbacks of the program include poor implementation of the bioremediation program and lack of treatment for the catchment area.

Innovative Approaches to Water Quality Remediation

IWSWQ 2011 participants considered a wide range of innovative water quality remediation technologies that are being developed, tested, or used in laboratories or communities across the country and which could potentially be used on a more widespread basis. Some of these technologies are being developed as part of the Government of India's Department of Science & Technology (DST) Water Technology Initiative (WTI) Programme. Sanjay Bajpai, Director of the WTI Programme, described various desalination and arsenic, iron, and fluoridation removal technologies being developed by research institutes in collaboration with local communities.

Additionally:

- It was proposed that a low-cost biological wastewater treatment and reuse system that has been tested in Hyderabad, India, could be used in other areas. Subijoy Dutta, Rivers of the World Foundation, discussed the advantages and disadvantages of the system and presented preliminary results.
- Domestic ultra filtration (UF) systems with iron and arsenic removal capability have been developed by the Bhabha Atomic Research Centre and are being used in homes and schools in rural Maharashtra, as described by Pradip Lalla.
- Kshipra Misra described a cost-effective, environmentally "friendly" filter technology for removing arsenic from drinking water that was developed by the Defence Research and Development Organisation (DRDO) and has been installed in many villages in West Bengal and elsewhere.
- Several innovative water reuse technologies are being developed at the University of Massachusetts, Dartmouth, in the United States, by Sukalyan Sengupta and colleagues. These include ion exchange technologies for heavy metal and phosphorus removal and recovery from industrial, agricultural, or municipal wastewater; and biological processes for nitrogen removal from wastewater and agricultural or storm water.
- Rainwater harvesting was proposed as one solution to the water crisis in Rajasthan by R.K. Sharma, Professor of Chemistry at the Institute of Engineering and Technology, MIA, Alwar (Rajasthan). Sharma described rainwater harvesting as a self-sufficient technology that is neither energy-intensive nor labour-intensive.
- After describing the salinity, fluoride, nitrate and other contamination problems affecting groundwater in Rajasthan, as well as other areas of India, R.V. Singh, Professor of Chemistry at the University of Rajasthan, described some desalination, defluoridation, and nitrate removal technologies that should be considered.

- R.B. Srivastava described various technologies being developed by the Defence R&D Organization (DRDO), India, to provide safe drinking water to Indian armed forces personnel. These include simple field kits for arsenic testing, poison detection, etc.; and other innovative (e.g., solar-powered, portable) systems for water purification, flood water treatment, etc.
- P.K. Tewari, Bhabha Atomic Research Center, Mumbai, discussed membrane-based water purification and desalination technologies and emerging trends in membrane technology (e.g., the use of nano-structured materials).

In sum, Chair Sut Ahuja emphasized the importance of finding not just effective but also economic solutions, with green chemistry solutions being the preferred options. Chair R.K. Sharma described the educational and networking efforts of the University of Delhi's Green Chemistry Network Center to create greater awareness about available remedial measures.

Recommendations

The speaker presentations, discussions, and on-site visits to the Yamuna River and water and sewage treatment facilities near Jaipur led workshop participants to make four general types of recommendations for addressing water quality challenges in India in ways that could also be applied in other parts of the world: (1) ways to improve water monitoring, which was generally viewed as a necessary first step toward improving water quality; (2) ways to improve water quality (beyond the necessary first step of monitoring); (3) ways to engage local communities in these efforts; and (4) specific remedial actions to improve the quality and quantity of groundwater in particular.

Ways to improve the monitoring of water quality in India

- Improve the existing methodology, availability of instruments, and trained human resources necessary for identifying various sources of water pollution.
- Strengthen water-quality monitoring network and surveillance systems in India.
- Develop and integrate a national database on water quality.
- Increase the number of water monitoring stations.
- Monitor radioactive pollutants, including naturally occurring contaminants such as radon, fluoride and arsenic.

Ways to improve water quality in India

- Improve research and development in the field of water quality by collaborating with international scientists.
- Identify freshwater aquifers that can provide safe drinking water in arsenic- or fluoride-affected areas.
- Use low-cost treatment methods when possible.
- Improve water quality by recharging groundwater.

- Protect the quality of surface and groundwater through an improved regulatory framework.
- Initiate measures that would minimize pollution of rivers and other water sources.
- Encourage pollution boards to cover non-point source pollution from agriculture.

Encourage community-based approaches to dealing with water-related problems

- Increase the role of local leader groups (*panchayat*) in assuring water quality.
- Organize public-private partnerships to address water quality problems.
- Educate people to discourage immersion of people in holy rivers during religious pilgrimage.
- Show language-friendly media clips on popular T.V. channels about the ill effects of water pollutants.

Remedial actions to improve the quality and quantity of groundwater

- Base allowable water withdrawal on sustaining the aquifers for irrigation, domestic and industrial water supplies, as well as for ecological needs.
- Integrate groundwater quantity and quality in decision making.
- Focus attention on overexploited/critical areas (i.e., urban- and rural-stressed areas).
- Practice rainwater harvesting and aquifer recharging.
- Adopt conjunctive use management of both surface water and groundwater.
- Deepen and rejuvenate wells and protect water bodies.
- Provide arsenic-free and fluoride-free water to affected populations.
- Explore the application of simple, low-cost water treatment technologies.

Future Interactions Among Indian and International Scientists

This first-ever Gii workshop served as a venue for consumers, policymakers, researchers, and industry representatives to share their experiences and ideas about water quality management and propose sustainable and cost-effective solutions that could be implemented not only in India but also in other areas of the world that face similar situations. Observations made during tours of the water and sewage treatment plants, knowledge shared during the speaker and open discussion sessions, and the recommendations put forth at the end of the workshop together underscore the need for continued interaction among scientists with different backgrounds, experiences, and knowledge bases as a promising path toward solving the global challenges of water availability, quality, and remediation. Follow-up workshops should be convened in other parts of the world to foster the international dialogue that was initiated in Delhi and to explore ways that proposed chemistry-based solutions for dealing with water-related problems in India could be replicated elsewhere.

Appendix A

List of Speakers

Speaker	Affiliation	Title of Presentation
Alok Adholeya	Director, Biotechnology and Bioresources Division, The Energy and Resources Institute, New Delhi, India	Impact of Industrial Waste on Water Quality for Agriculture and Human Consumption
Dr. Satinder Ahuja	Ahuja Consulting, Calabash, NC, 28467, USA	How we can Improve Water Quality
D.R. Arya	Director, Treatment and Quality Control, Delhi Jal Board, Government of National Capital Territory (N.C.T.) of Delhi, India	Organised Drinking Water Supply in N.C.T. of Delhi
Sanjay Bajpai	Director, Water Technology Initiative (WTI) Programme, Department of Science and Technology, Government of India	Water Challenges and R&D Scenario in Water Technologies
R.M. Bhardwaj	Senior Scientist, Central Pollution Control Board, Ministry of Environment & Forests, Delhi, India	Water Quality Management in India: Achievements and Constraints
Subijoy Dutta, P.E.	Rivers of the World Foundation, Maryland, United States	A Locally Compatible Wastewater Treatment and Reuse System for Treating the Polluted Discharges to the Yamuna River
Pradip Lalla	Sonadka Industries	Domestic Ultra Filtration (UF) System for Rural Use with Arsenic and Iron Removal Capability
Dr. Matthew C. Larsen	Associate Director for Climate and Land Use Change, U.S. Geological Survey, United States	Water Quality Status and Trends
Dr. Sanjay Malhotra	National Institute of Health, USA	Water Reservoirs and Public Health
Dr. P.K. Mehrotra	Director, Ministry of Water Resources, India	Ground Water Pollution
Dr. Kshipra Misra	Defence Institute of Physiology and Allied Sciences (DIPAS), Delhi, India	A Sustainable Solution for Arsenic Poisoning of Ground Water
Prof. Sukalyan Sengupta	Professor and Chairperson, Environmental Engineering Department, University of Massachusetts, Dartmouth, United States	Onsite Treatment Methods for Removal and Recovery of Macronutrients (N/P) from Wastewater
Prof. K.P. Sharma	Department of Botany, University of Rajasthan, Jaipur, India	Mansagar Lake: Restoration

Sharma, RK	University of Delhi, Delhi, India	Green Chemistry
Prof. Sanjay K. Sharma	Professor of Chemistry, Green Chemistry Research Laboratory, Institute of Engineering and Technology, MIA, Alwar (Rajasthan), India	Rain Water Harvesting: Solution of Water Crisis in Rajasthan
Prof. Prashant Singh	DAV (PG) College, Dehradun, India	Water Quality and Sustainability Management of Uttarakhand with Special Reference to Ganga River
Prof. R.V. Singh	Department of Chemistry, University of Rajasthan, Jaipur, India	Status of Water Quality of Rajasthan
Dr. R.B. Srivastava	Director, Defence Institute of High Altitude Research, Defense R&D Organization (DRDO), New Delhi, India	Water Quality Management: DRDO Contributions
Prof. P.K. Tewari	President, Indian Desalination Association; Professor, Homi Bhabha National Institute; Head, Desalination Division, Bhabha Atomic Research Center, Mumbai, India	Recent Trends in Membrane Technology for Water Quality Management

Appendix B**Program**

Date	Activity
January 17, 2011	Presentations on water availability, water quality, and remediation of water quality.
	Visit to Yamuna River and a state-of-the-art water treatment plant that supplies drinking water to the Delhi population
January 18-19, 2011	Tours of a community-based fluoride treatment plant and a sewage treatment plant near Jaipur
January 20, 2011	Presentations on low-cost, sustainable water monitoring and remediation technologies
	Open discussion on suggestions and recommendations for moving forward, based on information that was shared during the meeting and on-site visits and tours.

References

Ahmed M.F., S. Ahuja, M. Alauddin, S.J. Hug, J.R. Lloyd, A. Pfaff, et al. Ensuring safe drinking water in Bangladesh. *Science* 314(5806):1687-1688. 2006.

Ahuja, S., Ed. *Arsenic Contamination of Groundwater: Mechanism, Analysis, and Remediation*. United States:Wiley. 2008.

Ahuja, S., Ed. *Handbook of Water Purity and Quality*. Great Britain: Elsevier. 2009.

Ahuja S. and J. Malin. Analysis and remediation of arsenic contamination in groundwater. *Chemistry International* 28(3):14; 2006. Available online (accessed 23 August 2012): http://www.iupac.org/publications/ci/2006/2803/pp2_2003-050-1-021.html .

Ahuja, S. and J. Malin. A search for solution to the problem of arsenic contamination of water in Bangladesh. Presentation at CHEMRAWN XV conference, Chemistry for Water, Paris, France, June 21-23, 2004. Available online (accessed 23 August 2012): <http://old.iupac.org/reports/2006/CHEMRAWN-XV-July2006.pdf> .

Alexander R.B., R.A. Smith, G.E. Schwarz, E.W. Boyer, J.V. Nolan, J.W. Brakebill. Differences in phosphorous and nitrogen delivery to the Gulf of Mexico from the Mississippi River basin. *Environmental Science and Technology* 42(3):822-830.

Behera B., V.R. Reddy. Environment and accountability: impact of industrial pollution on rural communities. *Economic and Political Weekly* 37(3):257-265. 2002.

Bhardwaj R.M., et al. Status of water quality in Yamuna River. A presentation at the *Seminar on Water for National Capital Territory, Delhi*, April 30, 2003, organized by Indian Association of Hydrologists and sponsored by Ministry of Water Resources.

Callender E., P.C. Van Metre. Environmental policy analysis, peer reviewed: reservoir sediment cores show U.S. lead declines. *Environmental Science and Technology* 31(9):424a-428a. 1997.

Central Board for the Prevention and Control of Water Pollution, New Delhi. *Scheme for Zoning and Classification of Indian Rivers, Estuaries and Coastal Waters*. Central Board report No. ADSORBs/3/1978-79.

Central Pollution Control Board. Status of Water Quality in India – 2007. Monitoring of Indian Aquatic Resources Series: MINARS/29/2008-2009. Available online (accessed 24 August 2012): http://www.cpcb.nic.in/upload/NewItems/NewItem_129_NWMP-2007.pdf.

Central Pollution Control Board. *Water Quality in India: Status and Trend (1990-2001)*. Monitoring of Indian National Aquatic Resources Series: MINARS/17/2001-2002. Available online (accessed 23 August 2012): <http://www.cpcb.nic.in/newitems/10.pdf> .

Chauhan A., S. Singh. Evaluation of Ganga water for drinking purpose by water quality index at Rishikesh, Uttarakhand, India. *Report and Opinion* 2(9):53-61. 2010.

Dasgupta K., Soumitra Kar, Ramani Venugopal, R.C. Bindal, S. Prabhakar, P.K. Tewari. Self-standing geometry of aligned carbon nano-tubes with high surface area. *Materials Letters* 62:1989-1992. 2008.

DeSimone L.A., P.A. Hamilton, R.J. Gilliom. Quality of water from domestic wells in principal aquifers of the United States, 1991-2004: overview of major findings. U.S. Geological Survey Circular 1332. 2009. Available online (accessed 27 August 2012): <http://pubs.usgs.gov/circ/circ1332/>.

Domagalski J.L., D.L. Knifong, P.D. Dileanis, L.R. Brown, J.T. May, V. Connor, C.N. Alpers. Water quality in the Sacramento River basin, California, 1994-98. U.S. Geological Survey Circular 1215. 2000. Available online (accessed 27 August 2012): <http://pubs.usgs.gov/circ/circ1215/#pdf> .

Dutta S. *Environmental Treatment Technologies for Hazardous and Medical Wastes: Remedial Scope and Efficacy*. India: McGraw-Hill. 2002.

Earman S. and M. D. Dettinger. Potential impacts of climate change on groundwater resources -- a global review. *Journal of Water and Climate Change* 2(4):213-229. 2011.

Escobar I.C. and A. Schäfer, Eds. *Sustainable Water for the Future: Water Recycling versus Desalination (Sustainability Science and Engineering, Volume 2)*. The Netherlands: Elsevier. 2010.

Farooquee N.A., T.K. Budal, R.K. Maikhuri. Environmental and socio-cultural impacts of river rafting and camping on Ganga in Uttarakhand Himalaya. *Current Science* 94(5):587-594.

Gilliom R.J., J. E. Barbash, C. G. Crawford, P. A. Hamilton, J. D. Martin, N. Nakagaki, et al. *Pesticides in the Nation's Streams and Ground Water, 1992-2001*. U.S. Geological Survey Circular 1291. 2006 (Revised 2007). Available online (accessed 23 August 2012): <http://pubs.usgs.gov/circ/2005/1291/> .

Graham J.L., K.A. Loftin, M.T. Meyer, and A.C. Ziegler. Cyanotoxin mixtures and taste-and-odor compounds in cyanobacterial blooms from the midwestern United States. *Environmental Science and Technology* 44(19):7361-7368. 2010.

Green, C.T., L. H.Fisher, and B.A. Bekins. Nitrogen fluxes through unsaturated zones in five agricultural settings across the United States. *Journal of Environmental Quality* 37:1073-1085. 2008.

Gurdak, J.J., P. B.McMahon, K.F. Dennehy, and S. L.Qi. *Water Quality in the High Plains Aquifer, Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and*

Wyoming, 1999–2004. U.S. Geological Survey Circular 1337. 2009. Available online (accessed 23 August 2012): <http://pubs.usgs.gov/circ/1337/> .

Handa B.K. Water quality and water pollution problems on the Indian sub-continent. Pp. 313-322 in Eriksson E., ed., *Hydrochemical Balances of Freshwater Systems: Proceedings of the Uppsala Symposium, September 1984*. International Association of Hydrological Sciences Publication No. 150. Available online (accessed 27 August 2012): <http://iahs.info/redbooks/a150/150029.pdf> .

Helmer R., I. Hespanhol. *Water Pollution Control – A Guide to the Use of Water Quality Management Principles*. A report published on behalf of United Nations Environment Programme, Water Supply and Sanitation Collaborative Council, and World Health Organization. London: F & FN Spon. 1997.

Hinds B.J., N. Chopra, T. Rantell, R. Andrews, V. Gavalas, L.G. Bachas. Aligned multiwalled carbon nanotube membranes. *Science* 303(5654):62-5. 2004.

Imandoust S.B., S.N. Gadam. Are people willing to pay for river water quality, contingent valuation. *International Journal of Environmental Science and Technology* 4(3):401-408. 2007.

Jagucki M., M.K. Landon, B.R. Clark, S.M. Eberts. Assessing the vulnerability of public-supply wells to contamination: high plains aquifer near York, Nebraska. U.S. Geological Survey Fact Sheet 2008-3025. Available online (accessed 27 August 2012): <http://pubs.usgs.gov/fs/2008/3025/>.

Jangwan J.S., N. Semwal. Ionic composition of high altitude Himalayan rivers with respect to their source of origin. *Research Journal of Pharmaceutical, Biological and Chemical Sciences* 1(3):198-1997. 2010.

Jeong B-H., E.M.V. Hoek, Y. Yan, A. Subramani, X. Huang, G. Hurwitz, A.K. Ghosh, A. Jawor. Interfacial polymerization of thin film nanocomposites: a new concept for reverse osmosis membranes. *Journal of Membrane Science* 294:1-7. 2007.

Joshi D.M., A. Kumar, N. Agrawal. Assessment of the irrigation water quality of River Ganga in Haridwar District. *Rasayan Journal of Chemistry* 2(2):285-292. 2009.

Joshi D.M., A. Kumar, N. Agrawal. Studies on physiochemical parameters to assess the water quality of River Ganga for drinking purpose in Haridwar District. *Rasayan Journal of Chemistry* 2(1):195-203. 2009.

Khosla A. The Ganga water machine. *Science* 188:611-616. 1975.

Kolpin D.W., E.T. Furlong, M.T. Meyer, E.M. Thurman, S.D. Zaugg, L.B. Barber, H.T. Buxton. Pharmaceuticals, hormones, and other organic wastewater contaminants in U.S. streams, 1999-2000: a national reconnaissance. *Environmental Science and Technology* 36(6):1202-11. 2002.

Larsen, M.C., 2012, Global Change and Water Sources, Where Are We Headed? Water Resources Impact, American Water Resources Association, vol. 14, no. 5, p. 3-7.

Maria A. The costs of water pollution in India. Paper presented at the conference on Market Development of Water and Waste Technologies through Environmental Economics, 30th-31st October 2003, Delhi, India. Available online (accessed 27 August 2012): <http://www.cccindia.net/maria-delhi.pdf> .

Ministry of Environment and Forests, Government of India. Conservation of water bodies. Chapter 5 in *Annual Report 2004-2005*. Available online (accessed 27 August 2012): <http://envfor.nic.in/report/0405/Chap-05.pdf> .

National River Conservation Directorate, Ministry of Environment and Forests, Government of India. *Status Paper on River Ganga: State of Environment and Water Quality*. 2009. Available online (accessed 27 August 2012): <http://moef.nic.in/downloads/public-information/Status%20Paper%20-Ganga.pdf> .

Nolan B.T., K.J. Hitt. Vulnerability of shallow groundwater and drinking-water wells to nitrate in the United States. *Environmental Science and Technology* 40(24):7834-7840. 2006.

Robinson K.W., S.M. Flanagan, J.D. Ayotte, K.W. Campo, A. Chalmers, J.F. Coles, T.F. Cuffney. Water quality in the New England coastal basins: Maine, New Hampshire, Massachusetts, and Rhode Island, 1999-2001. U.S. Geological Survey Circular 1226. Available online (accessed 27 August 2012): <http://pubs.usgs.gov/circ/2004/1226/>.

Scudder B.C., L.C. Chasar, D.A. Wentz, N.J. Bauch, M.E. Brigham, P.W. Moran, D.P. Krabbenhoft. Mercury in fish, bed sediment, and water from streams across the United States, 1998-2005. U.S. Geological Survey Scientific Investigation Report 2009-5109. 2009. Available online (accessed 27 August 2012): <http://pubs.usgs.gov/sir/2009/5109/> .

Sen H.S. The drying up of River Ganga: an issue of common concern to both India and Bangladesh. *Current Science* 99(6):725-727. 2010.

Shannon M.A., P.W. Bohn, M. Elimelech, J.G. Georgiadis, B.J. Mariñas, A.M. Mayes. Science and technology for water purification in the coming decades. *Nature* 452(7185):301-10.

Sood A., P. Pandey, S. Bisht, S. Sharma, M.P. Gusain, O.P. Gusain. Assessment of bacterial diversity in the Gangetic river system of Uttarakhand, India. *Current Science* 99(12):1660-1663. 2010.

Soumitra Kar, R.C. Bindal, S. Prabhakar, P.K. Tewari. Potential of carbon nano-tubes in water purification: an approach towards development of an integrated membrane system. *International Journal of Nuclear Desalination* 3(2):143-150. 2008.

Srikanth R. Challenges of sustainable water quality management in rural India. *Current Science* 97(3):317-325. 2009.

Van Metre P.C., E. Callender, C.C. Fuller. Historical trends in organochlorine compounds in river basins identified using sediment cores from reservoirs. *Environmental Science and Technology* 31(8):2339-2344. 1997.

Van Metre P.C., B. Mahler, E.T. Furlong. Urban sprawl leaves its PAH signature. *Environmental Science and Technology* 34(19):4064-4070. 2000.