


Natural Water Treatment Systems for Safe and Sustainable Water Supply in the Indian Context *Saph Pani*

Editors: Thomas Wintgens, Anders Nättorp, Lakshmanan Elango and Shyam R. Asolekar


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Saph Pani

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and Shyam R. Asolekar

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About the Editors

Thomas Wintgens holds a PhD in Chemical Engineering from RWTH Aachen University and is Professor in Environmental Technologies at the University of Applied Sciences and Arts Northwestern Switzerland since September 2008. He is leading a research team working on water and wastewater treatment technologies in municipal and industrial applications as well as on management of scarce water resources. In the last decade he has been involved in many international research projects on water treatment and resources management. He chaired the water reuse task force of the European Water Supply and Sanitation Technology Platform. Thomas Wintgens was the coordinator of Saph Pani.

Anders Nättorp holds a PhD in Chemical Reaction Engineering from Ecole Polytechnique Fédérale de Lausanne. He worked 10 years in development and production departments in industry and joined the University of Applied Sciences and Arts Northwestern Switzerland in 2006. As a senior researcher he leads projects and work packages, complementing technical results with evaluation of cost and system analysis in the fields of water treatment technologies and resource recovery, in particular phosphorus. Anders Nättorp was the project manager of Saph Pani and responsible for the scientific quality assurance of the outputs of the project.

Lakshmanan Elango is a Professor in Geology at Anna University, Chennai, India with a PhD in Hydrogeology. He has over 28 years of experience, and gained research training from the University of Birmingham, Swiss Federal Institute of Technology, University of New Castle and Ruhr University in Europe. He has edited seven books, authored several book chapters, technical reports and research articles. He is the President of Association of Global Groundwater Scientists, Vice President of the International Association of Hydrological Sciences, Vice President of Indian National Committee of International Association of Hydrogeologists. He has organised advanced training workshops for the World Bank funded Hydrology Project and UNESCO's International Hydrology Program. Lakshmanan Elango was leader of a work package and Co-Chair of Saph Pani.

Dr. Shyam R. Asolekar is currently a Professor at the Centre for Environmental Science and Engineering at the Indian Institute of Technology Bombay (also served as the Head during 2006–2009). He is author of three books, six patents as well as several policy documents, training manuals, chapters of books and research papers. He has been a member (since, 1997) of the "Dahanu Taluka Environmental Protection Authority" constituted by the Honorable Supreme Court of India. His current research and teaching areas include: 1. reuse of treated wastewater for achieving near-zero emissions especially by combining advanced tertiary treatment technologies with low cost eco-centric natural treatment systems, 2. rejuvenation of ponds, lakes, rivers and wetlands and 3. development and application of 'Decision Support Tools' based on "life cycle" approach, minimization of carbon footprint and sustainability criteria. Dr. Shyam R. Asolekar was a work package leader of Saph Pani.

Foreword

Rossella Riggio and Dr. Panagiotis Balabanis (European Commission)

Water is a precondition for human, animal and plant life on Earth. Deforestation, pollution, over-exploitation of water resources, damage to aquatic ecosystems, climate change and security issues are challenging the sustainability of water systems. In parallel, population increase, economic development, urbanization, and land use or natural geomorphic changes also challenge the sustainability of resources by decreasing water supply or increasing demand.

Still too many people around the world do not have access to safe drinking water or basic sanitation. At the same time, three billion people will join the global consumer class over the next two decades, accelerating the degradation of natural resources and escalating competition for them.

If we continue business as usual, global demand for water will exceed viable resources by 40 percent by 2030.

In this context, access to safe drinking water and sanitation, integrated water management, including water efficiency, can clearly contribute to manage the challenges of climate change water scarcity and global equality. Water is also an indispensable resource for the economy and has a high strategic and economic importance. Water crisis have been recognized as the 1st highest risk that could undermine economic growth according to the 2015 Global Risk Report of the World Economic Forum.

Research and innovation plays an important role in providing solutions to major water challenges. Over the past decades, EU research funding has Framework Programme dedicated over EUR 1 billion to water research and Horizon 2020 will continue to support fundamental and applied research to address this complex and cross- cutting societal challenge. Water is also a very important area for international research cooperation with non-EU countries for promoting sustainable development in the context of the on-going Sustainable Development Goals discussion.

Within the context of the Environment (including climate change) Theme of the FP7 Cooperation Programme, a dedicated research topic on water systems and treatment technologies to cope with water shortages in urbanised areas in India was launched in 2011. SAPH PANI "Enhancement of natural water systems and treatment methods for safe and sustainable water supply in India" was selected for funding following the evaluation of that call. Since then a more strategic cooperation on water purification and wastewater reclamation, and reuse issues was built between the European Commission and the Indian Department of Science and Technology that gave rise to a joint coordinated call for proposals in 2012 and the emergence of a strong network of European and Indian researchers working together. In this context, SAPH PANI could be considered as a precursor of such cooperation.

This book summarises the key achievement of the SAPH PANI EU funded project.

On behalf of the European Commission and its Directorate General for Research, we would like to express our appreciation to the SAPH PANI partners for their efforts. We are confident that the book shall constitute a state of art knowledge experience which can find its way to contribute solving in practice the water challenge in India.

Rossella Riggio and Dr. Panagiotis Balabanis

European Commission
DG Research & Innovation
I2 Eco-Innovation

Foreword

P. Rajendra Prasad (Saph Pani Advisory Board)

Water a natural resource and essential component of human survival, contributes significantly to sustained economy and hence it is naturally in demand of multiple stakeholders. Though the principle of mass conservation indicates the quantum of water to remain the same over time, decrease in usable water resources day-by-day is witnessed globally. In recent times, the vast spread of uneven distribution of the resource in time and space supplemented by many anthropogenic interventions has induced a high degree of complexity making it more susceptible to even minor marginal changes. As a result the increasing gap between demand and supply constrained by diminished hope and scope to augment new resources has brought in a paradigm shift from development to management of the resource.

The average annual rainfall in India is quite reasonable and is around 1200 mm. However, its uneven distribution in time and space supplemented by frequent monsoon failures and ineffective management of the resource make it even scarce. So further research needs to be carried out for augmenting new sources of water and maintain its quality. Adoption of efficient renovation and recycling approaches can bring in balance in addressing the quantity and quality issues associated with the requirements.

India, being an agrarian nation, 85% of its usable water resources is spent in the farming sector leaving the rest for industrial, domestic and recreational purposes. The recent spurt in agricultural activity, industrial development and urbanization supplemented by natural disasters and liberalized policies of Government and financial institutions have been mounting stress on ground water resources in India, especially in hard rock terrain. Added to this people started realizing the importance and need of maintaining 'water quality' only in recent times.

The multi fold increase in irrigational needs associated with excess application of fertilizers and pesticides and lack of suitable technologies at affordable costs for solid and liquid waste disposal have led to unprecedented pollution of the water bodies. In addition, the impinging threat of sea water intrusion into coastal aquifer regime renders the water resources in the coastal regions more fragile and vulnerable to anthropogenic as-well-as natural hazards. Further the changing climatic conditions are yet another factor in drastically effecting the hydrological cycle. At present, in many emerging nations, water policies are driven mostly by short term economic and political concerns rather than scientific perceptions in which India is not an exception.

As per many studies done by national and international agencies, more than 50% of the deceases are found to be waterborne in India. The need to supply adequate safe drinking water with easy access has become the top national priority. The country in a bid to address the issue of meeting the growing demands for water initiated a number of programmes like rainwater harvesting, replenishing ground water from surface water resources and creating large dams and reservoirs mainly to help irrigation. Some of them do address quantity and quality aspects but incidentally they also brought in undesirable social and environmental impacts. In addition improper planning in managing sewage and irrigation waste waters has become a major issue in recent times.

The Govt. of India, in its endeavour to meet the national water needs has created huge dams and associated distribution systems. However, the ever increasing demands could not be met from available resources, forcing the system to look for alternate methods of conservation and management. This has been the guiding factor to prompt the ministries of water resources and the Department of Science and Technology (DST) to initiate major national programs like WAR for water Rajiv Gandhi drinking water mission etc., to initiate innovative research and management strategies. Many programmes supported by European Union like India- EU water projects, Indigo, FP7 etc. have been in place in support of this cause.

The Saph Pani initiative supported by the FP7 programme of European Union is not only timely but also evolved as a model in Natural Treatment Systems in water resources treatment and management in India. Among many EU supported programmes Saph Pani initiative has the unique distinction on more than one count. It is a unique programme that dealt with treatment of fresh water, waste water and treatment of natural systems. It dealt with treatment of natural systems in different geographic, geomorphic and climatic environments. It addressed issues related to normal and extreme events. It also dealt with three major components of water cycle viz., atmospheric, surface and groundwater with a balanced approach. In addition it could also create awareness among stakeholders.

The Saph Pani Programme is focussed around natural treatment systems for safe and sustainable water supply in India. The Programme is built around three major components dealing with bank filtration (BF), management of aquifer recharge and soil aquifer treatment (SAT) including constructed wetlands. The project aims at adopting a comprehensive approach synergizing the European experts and the Indian resources with application to Indian field conditions. The project demonstrates its potential in the Indian context in developing and implementing cost effective innovative scientific technologies and also contributes to capacity building to replicate in other parts of the country. The different technologies were implemented in different geographic hydro climatic and hydro geological settings with different field conditions and varying uses.

Bank Filtration was adopted as a natural field treatment technology for treating the surface water from lakes and rivers to make them potable. As a part of the programme, a number of bank filtration wells and systems have been developed and monitored. Apart from keeping their turbidity, the systems have demonstrated its efficacy in the removal of pathogens, colour, dissolving organic carbon and reduced coliform count. The studies also briefed to be effective even under high abstraction rates both during monsoon and non-monsoon periods. The studies have led to the design and construction of flood-proved wells and prevention of bank erosion. A standard protocol has also been developed for adoption in different hydro climatic and hydro geological conditions.

Managed Aquifer Recharge (MAR) has been implemented not only to inject treated storm water and surface water into the aquifer regime but also to improve the water quality including sea water intrusion. Techniques were developed to adopt and manage highly varying flows to recharge the aquifer regime. The project mainly dealt with the design and development of various wetland systems for treatment of waste water. Different types of wetlands constructed worldwide have been modified and engineered to suit the local waste water characteristics and the environmental conditions.

The project could achieve low operational maintenance costs. The results have demonstrated many reuse options acceptable at community level. It also demonstrated that systems can be operated with the skills of rural folks with suitable training and it can contribute to supplement the shortfall between the water supply and sewage treatment.

The project was able to produce state of the art technology that can easily be adopted to suit the local conditions in improving the quality of water and contribute to augment additional resources. The quality research publications resulted out of the project is a testimony to the high degree of professionalism, industry and academia interaction and its societal application.

P. Rajendra Prasad
Saph Pani Advisory Board

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Partners of the Saph Pani project:

FACHHOCHSCHULE NORDWESTSCHWEIZ FHNW Switzerland, Thomas Wintgens, Anders Nättorp, Julia Plattner, Liang Yu, Linda Stamm, Jeremias Brand.

UTTARAKHAND JAL SANSTHAN UJS India, P. C. Kimothi, S. K. Sharma, Ramesh Chandra, R. K. Rauhela, Manish Semwal, P. K. Saini, Pooran Singh Patwal.

NATIONAL INSTITUTE OF HYDROLOGY NIH India, R. D. Singh; N. C. Gosh, V. C. Goyal, C. K. Jain, Sudheer Kumar, A. K. Lohani, Surjeet Singh, Anupama Sharma, Sumant Kumar, Shashi Indwar, Biswajit Chakravorty, Y. R. S. Rao, B. Venkatesh, T. Thomas, B. K. Puarendra, Sanjay Mittal, Rakesh Goyal, Biswajiit Das, Saroj Khatania.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE IITR India, Pradeep Kumar, Indu Mehrotra, Ankush Gupta, Medalson Ronghang, Soma Kumari, Himashu Singh, Fuzail Ahmed, Laxmi Das, Anand Bharti.

VEOLIA WATER (INDIA) PVT LTD VEOLIA India, S. V. K. Babu, Priyanka Bhat, Vikas Gupta, Anuj Goel, Brune Poirson, Mélanie Grignon, Bodhisattwa Dasgupta, Naresh Kumar, Ashok Parashar, Bharat Bhushan Chadha.

ANNA UNIVERSITY CHENNAI ANNA India, Lakshmanan Elango, Parimala Renganayaki, K. Brinda, Rajesh Rajendran, Rajaveni Sundarapandian, M. C. Raicy, Jagadesan Gunalan, Indu S. Nair, G. Gowrisankar.

SPT CONSULTANCY SERVICES PARTNERSHIP SPT India, Thirunavukkarasu Munuswamy, Shenbaganandam Ganapathy, Saravanan Janakiraman, Arulprakasm Subramanian, Balaji Karuppaiah, Parimala Renganayaki Sundaram, Balasubramanian Krishnan.

MUNICIPAL CORPORATION OF RAIPUR RMC India, A. K. Malwe.

ARUN GULATI AJD India, Arun Gulati, Manish Gupta, Siddarth Kimothi.

COUNCIL OF SCIENTIFIC AND INDUSTRIAL RESEARCH NGRI India, Shakeel Ahmed, Ramaswamy Rangarajan, Vilasrao Somvanshi, Subash Chandra, Nepal Mondal, Tanvi Arora, Sahebrao Sonkamble, Sarah Sarah, Farooq A. Dar, Naziya Jamal, Deepa Negi Kapardar, P. Raghavendra, Tarun K. Gaur, Rekha Kumari, Rakesh K. Tiwari, Adeyuppu Pratyusha, Satyajit Raut, Akoju Ramadevi, Vikram Kumar, Deepak Kumar, Napasani Veerababu, Taufique Warsi, Md. Wajihuddin, Satya Chari.

INDIAN INSTITUTE OF TECHNOLOGY BOMBAY IITB India, Shyam R. Asolekar, Dinesh Kumar, Anana Hiremath, Pradip Kalbar, Richa Singh, Rahul Sutar, Shruti Ranjan, Sachin Pandey, Ankit Srivastava, Ashish Kumar, Deepak Vishawakarma, Lohit Reddy, Sanjeev Yendamui.

DHI – (INDIA) WATER & ENVIRONMENT PVT LTD DHI India, Bertram Moninkoff, Mohamed Fahimuddin.

KOMPENTENTZZENTRUM WASSER BERLIN GEMEINNUTZIGE GMBH KWB Germany, Bodo Weigert, Christoph Sprenger, David Stevens, Gesche Grützmacher, Hella Schwarzmüller, Maike Gröschke, Michael Rustler.

BUREAU DE RECHERCHES GEOLOGIQUES ET MINIERES BRGM France, Marina Alazard, Stéphanie Aulong, Alexandre Boisson, Abdel Majiit Bouzit, Alain Chevalier, Céline Cosson, Benoît Dewandel, Christine Flehoc, Wolfram Kloppmann, Thierry Laurioux, Jean-Christophe Maréchal, Jérôme Perrin, Marie Pettenati, Géraldine Picot-Colbeaux, Géraldine Quarton, Benjamin Tellier, Dominique Thierry, Matthieu Basset.

ZENTRUM FÜR UMWELTMANAGEMENT UND ENTSCHEIDUNGSTHEORIE CEMDS Austria, Markus Starkl.

HOCHSCHULE FÜR TECHNIK UND WIRTSCHAFT DRESDEN HTWD Germany, Thomas Grischek, Cornelius Sandhu, Ulrike Feistel, Rico Bartak, Thomas Voltz, Stephanie Fischer.

UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION – UNESCO IHE The Netherlands, Saroj Sharma, Maria Kennedy, Haziz Mutabuzi, Richard Missa, Charles Nyongo.

INTERNATIONAL WATER MANAGEMENT INSTITUTE IWMI Sri Lanka, Priyanie Amerasinghe, Mahesh Jampani.

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FREIE UNIVERSITAET BERLIN FUB Germany, Christoph Sprenger, Thomas Taute, Lutz Thomas, Maike Gröschke, Theresa Frommen, Mario Eybing, Kolja Bosch, Florian Brückner.

Glossary

Anicut A dam made in a stream for maintaining and regulating irrigation.

Artificial Storage and Recovery Injection of water into a well for storage and recovery from the same well.

Artificial Storage, Transfer and Recovery Injection of water into a well for storage, and recovery from a different well.

Bank filtration A process whereby the subsurface serves as a natural filter and also biochemically attenuates potential contaminants present in the surface water. Bank filtration can occur naturally due to higher surface water levels compared to groundwater levels, or it can be induced by lowering groundwater levels by pumping from wells.

Caisson well A well of a comparatively larger diameter (1–10 m) and shallow depth (5–10 m) that has a circular concrete, reinforced concrete or brick-lined caisson as a casing. The well is constructed by building the casing on the ground surface and subsequently sinking it (using weights or jacks) as an open caisson by excavating the interior. On account of their large diameter, caisson wells usually have a high water storage capacity.

Check dam Structure constructed across the river to harvest run-off water for groundwater recharging and regulating irrigation.

Constructed wetlands Treatment systems that use natural processes involving wetland vegetation, soils, and their associated microbial assemblages to improve water quality.

Contour trench Structures used to break the slope at intervals and reduce the velocity of surface run-off. The water retained in the trench helps to increase the soil moisture content and ground water recharge.

Disinfection Removal or inactivation of pathogenic microorganisms.

Disinfection by-products A chemical compound formed by the reaction of a water disinfectant with a precursor (e.g. natural organic matter) in a water supply system.

Duckweed pond Pond used for wastewater treatment in which thin mat of duckweed grows at the surface of water which maintains anaerobic conditions in the pond.

Escherichia coli (*E. coli*) Coliform bacteria of faecal origin used as an indicator organism in the determination of (waste) water pollution.

Gravity injection well Ordinary bore wells and dug wells used for pumping may also be alternatively used as recharge wells.

Infiltration Downward movement of water in unsaturated zone.

Injection well Structure similar to a tube well but with the purpose of augmenting the groundwater storage of a confined aquifer by pumping in treated surface-water under pressure.

Karnal Technology A method of land-treatment/disposal of wastewater which involves growing tree on ridges 1m wide and 50 cm high and disposing of the treated effluent in furrows.

Managed Aquifer Recharge Intentional storage of water into the aquifers for subsequent recovery or environmental benefits.

Nalahs bund Structures constructed across streams (Nalah or Nala) to check the flow of surface water in the stream channel and to retain water for longer durations in the previous soil or rock surface.

Natural Treatment Systems Multi-objective treatment systems employing natural processes and components (soil/aquifer, vegetation and sunlight) to improve water quality.

Open well Dugwell, commonly used at household level.

Organic micropollutants organic contaminants which are present in water, soil and environment in the range of mg/L to ng/L (also known as trace organics).

Oxidation pond Also known as lagoons, are stabilization ponds generally used to treat primary effluents (from septic tanks) by heterotrophic bacteria.

Pathogen indicators Bacteria like faecal coliform and E. coli. Their presence indicates that water may be contaminated by human or animal faecal matter.

Percolation tank Artificially created surface water body submerging a highly permeable land area so that the surface run-off is made to percolate and recharge the ground water storage.

Pre-treatment Treatment steps to improve quality of source water before employing natural treatment systems to enhance their performances.

Polishing ponds Pond systems are used to improve the quality of effluents from efficient anaerobic sewage treatment plants like UASB reactors, so that the final effluent quality becomes compatible with legal or desired standards.

Post-treatment Treatment steps to further improve quality of water after the natural treatment systems to meet the water quality standards/guidelines and regulations.

Recharge shaft Structure constructed to increase recharge into unconfined aquifers where water levels are much deeper or into confined aquifers, which are overlain by strata having low permeability.

Recharge pit Used in artificial recharge of phreatic aquifer from surface-water sources. They are excavated of variable dimensions that are sufficiently deep to penetrate less permeable strata.

Reclaimed water Wastewater that has been treated to a level that allows for its reuse for a beneficial purpose.

Risk Assessment Identification, evaluation, and estimation of the levels of risks involved in a situation (with or without certain intervention), their comparison against benchmarks or standards, and determination of an acceptable level of risk.

Soil Aquifer Treatment Artificial recharge of wastewater treatment plant effluents or storm water for further polishing its quality (in soil and aquifer) aiming at reuse.

Subsurface dam System for storing groundwater by a “cut-off wall” (dam body) set up across a groundwater channel.

Talabs Mainly natural ponds.

Tube well The typical name for vertical production wells in rural India with small diameters of 125 to 200 mm used mainly for irrigation.

Waste stabilization pond Large, shallow basins in which raw sewage is treated entirely by natural processes involving both algae and bacteria; generally consists of series of anaerobic, facultative or maturation ponds.

Wastewater Any water that has been adversely affected in quality by human influence. Wastewater can originate from e.g. domestic, industrial, commercial or agricultural activities and is often a combination thereof (often mixed with storm-water or surface run-off). Municipal wastewater is also known as sewage comprising faecal matter and urine.

Wastewater treatment plant Treatment systems consisting of different processes for improving quality of domestic and industrial wastewater (also known as sewage treatment plant).

Water table Level below which the formation is saturated with water.

Water reuse The general term for the beneficial use of treated or reclaimed (waste) water.

List of Abbreviations

AFTM	Audio frequency telluric method
AOP	Advanced oxidation process
ARR	Aquifer Recharge and Recovery
ASL	Above sea level
ASP	Activated sludge process
ASR	Aquifer Storage and Recovery
ASTR	Aquifer Storage Transfer and Recovery
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
$BaCl_2$	Barium chloride
BC	Boundary condition
BCM	Billion cubic metres
BF	Bank filtration
BIS	Bureau of Indian Standards
BOD	Biological oxygen demand
BOM	Biodegradable matter
CEC	Cation exchange capacity
CGWB	Central Ground Water Board
COD	Chemical oxygen demand
CMW	Chennai Metro Water
CMWSSB	Chennai Metro Water Supply and Sewerage Board
CPCB	Central Pollution Control Board
CSP	City Sanitation Plan
CURE	Centre for Urban & Regional Excellence
CW	Constructed wetland
CWC	Central Water Commission
DC	Direct current
DEM	Digital Elevation Model
DGPS	Differential Global Positioning System
DJB	Delhi Jal Board
DO	Dissolved oxygen
DOC	Dissolved organic carbon
DP	Duckweed pond
EC	Electrical conductivity
ERT	Electrical Resistivity Tomography
EUR	Euro
FAP	Facultative anaerobic ponds
FC	Faecal coliforms
FF-CW	Free floating constructed wetland

FTIR	Fourier transform infrared spectroscopy
GAC	Granular activated carbon
GCW	Groundwater circulation wells
GHMC	Greater Hyderabad Municipal Corporation
GoI	Government of India
GMWL	Global meteoric water line
GPS	Global Positioning System
HMWSSB	Hyderabad Metropolitan Water Supply and Sewerage Board
HRT	Hydraulic retention time
HSSF-CWs	Horizontal sub-surface flow constructed wetlands
IFCGR	Indo French Center for Groundwater Research
IGP	Indo Gangetic Plain
INR	Indian Rupees
IWDP	Integrated Wastelands Development Programme
IWMP	Integrated Watershed Management Programme
JMRPL	Jalmahal Resorts Pvt. Ltd.
JNNURM	Jawaharlal Nehru National Urban Renewal Mission
KSMWS	Kachiwani Singaram micro-watershed
KT-CW	Karnal type-constructed wetlands
LBF	Lake bank filtration
LMWL	Local meteoric water line
m a.s.l.	Meters above sea level
m bgl	Meters below ground level
MAR	Managed Aquifer Recharge
MF	Microfiltration
MGNREGA	Mahatma Gandhi National Rural Employment Guarantee Act
MHT	Monitoring boreholes
MLD	Million litres per day
MoEF	Ministry of Environment and Forests, Government of India
MoWR	Ministry of Water Resources, Government of India
MP	Maturation pond
MPN	Most probable number
NARBAD	National Bank for Agriculture and Rural Development
NCT	National Capital Territory
NERC	Natural Environment Research Council
NF	Nanofiltration
NGRI	National Geophysical Research Institute
NH_3	Ammonia
NH_3**-N**	Ammonia nitrogen
NH_4^+	Ammonium
NIH	National Institute of Hydrology
NO_2–	Nitrite
NO_3–	Nitrate
NRMMC-EPHC-NHMRC	Natural Resource Management Ministerial Council, Environment Protection Heritage Council, Australian Health Ministers Conference
NTS	Natural Treatment Systems
NTU	Nephelometric Turbidity Unit
ODEX	Overburden drilling with excentric bit
O&M	Operation & Maintenance
OMP	Organic micropollutants
PP	Polishing ponds
PPP	Public-private partnership
PVC	Polyvinyl chloride
QMRA	Quantitative Microbial Risk Assessment
RBF	River bank filtration
RCW	Radial collector well
RO	Reverse osmosis
RRR	Repair, Renovation and Restoration scheme

RSF	Rapid sand filtration
RWH	Rainwater harvesting
SAT	Soil aquifer treatment
SGT	Subsurface groundwater treatment
SEM	Scanning electron microscopy
SME	Small and medium enterprise
SSF	Slow sand filtration
SSP	State Sanitation Plan
SUVA	Specific Ultraviolet Absorbance
SWOT	Strengths, Weaknesses, Opportunities, Threats
TDEM	Time Domain Electromagnetic Methods
TDS	Total dissolved solids
TKN	Total kjeldahl nitrogen
TLERT	Time lapse Electrical Resistivity Tomography
TN	Total nitrogen
TOC	Total organic carbon
TP	Total phosphorous
TSS	Total suspended solids
TTC	Thermotolerant coliforms
UASB	Up-flow anaerobic sludge blanket
UGC	Upper Ganga Canal
UJS	Uttarakhand Jal Sansthan
ULB	Urban local body
UNDP	United Nations Development Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
USAID FIRE D	USAID Financial Institutions Reform and Expansion (FIRE), D stands for debt
UV	Ultraviolet
VES	Vertical Electrical Soundings
VF-CW	Vertical flow constructed wetlands
VFW	Vertical filter well
VLF	Very low frequency
VSMOW	Vienna Standard Mean Ocean Water
VSSF-CW	Vertical sub-surface flow constructed wetlands
WHO	World Health Organization
WP	Work package
WSP	Waste stabilization ponds
WTP	Water treatment plant
WWTP	Wastewater treatment plant

FURTHER INFORMATION

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Thomas Wintgens	thomas.wintgens@fhnw.ch (Editor)
Cornelius Sandhu	sandhu@htw-dresden.de
Ankush Gupta	ag343@cornell.edu
Maike Gröschke	maike.groeschke@fu-berlin
Anders Nättorp	anders.naettorp@fhnw.ch (Editor)
M. C. Raicy	raicygeo@gmail.com
Alexandre Boisson	a.boisson@brgm.fr
Dinesh Kumar	dinesh.poswal0197@gmail.com
Priyanie Amerasinghe	P.Amerasinghe@cgiar.org
Saroj Sharma	s.sharma@unesco-ihe.org
Christoph Sprenger	christoph.sprenger@kompetenz-wasser.de
Wolfram Kloppman	w.kloppmann@brgm.fr
Peter Dillon	pdillon500@gmail.com
Markus Starkl	markus.starkl@boku.ac.at
Shakeel Ahmed	shakeel.ngri@gmail.com
Elango Lakshmanan	elango@annauniv.edu (Editor)
Shyam R. Asolekar	asolekar@gmail.com (Editor)