UNIVERSITY OF TECHNOLOGY SYDNEY

Energy Sensitive Urban Water Planning in Developing Countries: Unlocking the Potential of Distributed Recycled Water Systems to Reduce the Overall Energy Intensity for Urban Water Services

by Reba Paul

Thesis submitted in fulfilment of the requirements for the degree of

Doctor of Philosophy

under the supervision of Professor Pierre Mukheibir, UTS Institute for Sustainable Futures (Principal) and Dr. Steven Kenway, Associate Professor, The University of Queensland, Australia (Co-Supervisor).

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CERTIFICATE OF ORIGINAL AUTHORSHIP

I, Reba Paul, declare that this thesis is submitted in fulfilment of the requirements for the award of PhD, in the Institute for Sustainable Futures at the University of Technology Sydney.

This thesis is wholly my original work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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ABSTRACT

Energy is a significant operational expense for most water utilities, particularly in developing countries. The current linear approach to water management will further increase the overall energy intensity (kWh/kL) for water services as rapidly growing cities move towards remote sources of water, desalination or deep groundwater abstraction, all of which are energy intensive. This thesis firstly investigates the potential for distributed recycled water systems (decentralised systems connected to centralised systems) to reduce the overall energy intensity of urban water and wastewater systems in a developing country context.

The literature review revealed that the energy intensity of treatment plants decreases with the increase in capacity. It was found that in most cases, the existing recycled water schemes treat water to a higher level than required for a particular end-use, so the energy intensity could be further reduced if ‘fit for purpose’ water were produced.

Using Bengaluru as a case study, a water mass balance was prepared under the Urban Metabolism Framework, which demonstrated that in 2016/17, the recycled water in Bengaluru had the potential to replace 90% of the extracted water from the Cauvery River (1323 MLD), which is pumped more than 100km. Using energy density mapping based on primary sourced data and following the water use cycle, the average energy intensity of centralised water and wastewater services across all the service zones was 2.1 kWh/kL and for water supply only was 1.8 kWh/kL.

In the case study, distributed recycled water systems were demonstrated to offer a viable means for reducing the overall energy intensity for water services. The model analysis revealed that for a specific selected zone, the energy intensities varied from 0.83 to 1.64 kWh/kL for potable water supplies, and 0.38 to 1.10 kWh/kL for non-potable water supplies, depending on the size of the plant and the technology used – all of which have lower energy intensities than the energy intensity for the selected zone (2.03 kWh/kL) and also the average energy intensity of the centralised water services. These energy intensities were also found to be lower than the energy intensity for the proposed Indirect Potable Reuse Scheme and the new long distant water transfers.

The second objective was to investigate how the challenges and barriers of distributed recycled water systems could be overcome using the One Water framework. From the case study findings based on semi-structured interviews, an institutional framework has been proposed that provides for both internal (e.g. strong leadership, knowledge, less political interference) and external reforms (e.g. regulators and policy, pricing reform, external engagement and collaboration) in a developing country context.

The findings of this research demonstrates the potential of distributed recycled water systems to reduce the overall energy intensity for urban water services, thereby making urban water service systems potentially more cost efficient, sustainable and resilient.

This Thesis is Dedicated to Love and Hope

Love: To my past loving mother - my ideal Mrs Tarala Bala Paul who passed away in 2015 and my father Mr Harendra Nath Paul, the son of the soil who left this earth in 2012 and my loving eldest golden brother Engineer Dr Tapan Kumar Paul, who passed away in Michigan in 2010 who was a father-like-son in our family. Today, my brother would be so happy that I have done my PhD, which was also his dream, the same as of mine. I came to do my PhD after extensive experience working in various fields (water, energy and environment) in many government and international NGOs to fulfil my dream that I could not do earlier because of my high job responsibilities.

Finally, I dedicate this thesis to my great boss and mentor Engineer Mr Quamrul Islam Sidduqe who was a visionary leader in Bangladesh and who passed away in 2008 from a heart attack in New York on the way back to his country after attending the world water week at Stockholm. He left a great legacy in sustainable development in the country. I was very fortunate working directly under him among a number of whom he built with his own hand. The people surrounding him said to me that I was his right hand.

Hope: This thesis hopes to contribute to building sustainable cities through reducing energy for water services and provide cost-effective urban water services particularly in developing countries, and to especially help the poor people to access water and have good health.

This research provides good evidence for planners and decision makers to consider distributed recycled water systems in their water supply portfolio and to rethink the pros and cons of the expansion of conventional centralised systems. The significant benefits of distributed systems and their potential to reduce the overall energy intensity for urban water services and thereby making urban water service systems more sustainable and cost efficient for increased access to water supplies and helping achieving the SDGs for water supply and sanitation.

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Publications during the Candidature

Peer Reviewed Journal Articles included in this thesis

1. Paul, R., Kenway, S. and Mukheibir, P. (2019), How scale and technology influence the energy intensity of water recycling systems-An analytical review, Journal of Cleaner Production, Vol.215, p1457-1480.

2. Paul, R., Kenway, S., McIntosh, B., Mukheibir, P. (2018), Urban Metabolism of Bengaluru city: A Water Mass Balance Analysis, Journal of Industrial Ecology, 22(6), 1413–1424.

Article 1 (attached at the end of the thesis) informs Section 2.4, 2.5 and 2.6 in Chapter 2 and Article 2 (attached at the end of the thesis) informs Section 3.5.1 and 3.5.2.1 and 3.5.2.2 in Chapter 3 and Section 5.5 in Chapter 5.

Conference Proceedings

1 Paul, R. and Mukheibir, P. 2019, Direct Potable Reuse – a more cost effective water supply option than long distant water transfer or Desalination, presented at Next Water 2019 (12-13 Feb 2019), Water Research Australia in Melbourne, Australia.

2 Paul, R., Mukheibir, P., Kenway, S. 2018, Water-Energy Nexus in Bengaluru City and Improved Water Services: Building Urban Resilience, ResNexus 2018 (6-7 Nov 2018), The Wageningen University, the Netherlands.

3 Paul, R., Mukheibir, P., Kenway, S. 2017, Potential of Distributed Recycled Water System to reduce Energy Intensity of Overall Urban Water and Wastewater system, OzWater 2017 (16-17 May, 2017), Australia Water Association, Sydney, Australia.

Conference paper 1 inform Section 5.3.1, 5.3.2 and 5.3.3 in Chapter 5; Paper 2 inform Section 1.3 in Chapter 1 and part of Section 6.1.2 in Chapter 6 and Paper 3 (article 1).

Unpublished Paper

1. Addressing Water-Energy Nexus in Bengaluru City for Improved Water Services: Building Urban Water Resilience submitted to the Journal of Integrative Environmental Science.

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Glossary

Advanced Oxidation is one of the processes that can be used as a safety barrier in the water purification process. Hydrogen peroxide, ultraviolet (UV) light and other processes are used in combination to form a powerful oxidant that provides further disinfection of the water and breaks down the remaining chemicals and microorganisms and provides further disinfection of the water.

Advanced oxidation: Oxidation processes relying on hydroxyl radical oxidation to destroy recalcitrant contaminants.

Advanced treatment: Additional treatment provided to remove suspended and dissolved substances that persist through conventional secondary treatment. Often this term is used to mean additional treatment after tertiary treatment for the purpose of further removing contaminants of concern to public health. In many cases, this includes membrane filtration, reverse osmosis (RO), and advanced oxidation/disinfection with ultraviolet light (UV) and hydrogen peroxide (H2O2).

Augmentation: The process of adding recycled water to an existing raw water supply (such as a reservoir, lake, river, wetland, and/or groundwater basin) after receiving advanced treatment. This water could eventually be used for drinking water after further treatment.

Beneficial use: The application of water necessary to accomplish the purpose of the appropriation, without waste. Some common types of beneficial use are agriculture, municipal, wildlife, recreation, and mining.

Biological Oxygen Demand (BOD): A measure of the amount of oxygen consumed in the biological processes that break down organic matter in water. Used as an indicator of the amount of organic material in the waste stream. The greater the BOD, the greater the degree of pollution. Usually expressed in milligrams per litre.

Biosolids is the nutrient-rich organic material (by-product) made from the stabilized

Centralised Water and Wastewater System: A network of pipes, pumps, and storage and treatment facilities designed to deliver potable water to homes, schools, businesses, and other users in a city or town and to remove and treat waste materials.

Climate: Meteorological conditions, including temperature, precipitation, condensation, and wind.

Demand Management: Obtaining the benefits of water more efficiently, resulting in reduced demand for water. Sometimes called “end-use efficiency”.

Direct Potable Reuse (DPR) water is distributed directly into a potable water supply distribution system downstream of a water treatment plant or into the source water supply immediately upstream of the water treatment plant. It needs monitoring to be safe for augmenting drinking water supplies. The source water for advanced treatment is often clean water from a wastewater treatment or resource recovery plant. Purification processes can involve a multistage process such as microfiltration, reverse osmosis and advanced oxidation, as well as Soil Aquifer Treatment. Any of these options are capable of producing water quality that has been verified through monitoring to be safe for augmenting drinking water supplies.

Discharge is the release of effluent, which meets regulatory standards, and designated by a regulatory permit to be safely discharged into the environment without causing harm.

Disinfection: Water treatment which destroys or inactivates potentially harmful bacteria.

Distributed recycled water systems: A number of Decentralised (usually mid-scale) systems connected with existing sewerage to network which can share resources among them and final effluent is carried to centralised wastewater plant for safe disposal.

Decentralised Wastewater/ Recycled water systems: Stand-alone systems to treat wastewater for safe disposal or reuse of the treated water.

Domestic Wastewater/Sewage is used water from washing our food, dishes, clothes and bodies, and for toilet flushing. The used water that goes down the drain or is flushed down the toilet is called sewage. Because a considerable amount of water is used to carry away only a quite small quantity of waste, domestic sewage is mostly water. It is referred to as "wastewater" in most places.

Drought: A long period of below-average precipitation.

Dual Media Filtration is a filtration method that uses two different types of filter media, usually sand and finely granulated anthracite.

Ecosystem: A community of plants and animals and the physical environment in which they live.

Effluent: The water leaving a wastewater treatment plant. If the effluent has been treated to a sufficiently high standard, it may be used for recycled water applications.

Energy Intensity: Energy use or consumption per unit volume of water or wastewater processes

Evaporation: The process of changing a liquid to a gas (vapour); for example, when water turns into steam or water vapour.

Evapotranspiration (ET): Process by which water is evaporated from soil surface and water is transpired by plants growing on that surface.

Filtration: A process that separates small particles from water by using a porous barrier to trap the particles while allowing the water to pass.

Granular Activated Carbon is used to remove chemicals that are dissolved in the used water.

Greywater is the term used to describe water segregated from a domestic wastewater collection system and reused on site. This water can come from a variety of sources such as showers, bathtubs, washing machines, and bathroom sinks. It contains some soap and detergent, but is clean enough for non-potable uses. Water from toilets or wash water from diapers is not considered to be greywater. Kitchen sink water is not considered greywater in many states. Many buildings or individual dwellings have systems that capture, treat and distribute greywater for irrigation or other non-potable uses.

Ground water: Water found below the surface of the Earth. Ground water, as opposed to surface water, is water that does not run off, and is not taken up by plants, but soaks down into an aquifer; a supply of fresh water under the earth's surface which forms a natural reservoir.

Groundwater Recharge occurs naturally as part of the water cycle and/or is enhanced by using constructed facilities to add water into a groundwater basin.

Imported Water: Water that has originated from one hydrologic region and is transferred to another hydrologic region.

Indirect Potable Reuse (IPR) water is blended with other environmental systems such as a river, reservoir, or groundwater basin, before the water is reused.

Industrial Wastewater and Commercial Wastewater/Sewage is the liquid waste generated by industries, small businesses and commercial enterprises and can be discharged to a sewer upon approval of a regulating authority. Some industrial wastewater may require pre-treatment before it can be discharged into the sewer system, while other industrial and commercial wastewaters are explicitly excluded. Controlling the release of harmful chemicals into the wastewater collection system is known as Source Control.

Infiltration: Water moving into the ground from a surface supply such as precipitation or irrigation.

Irrigation: Diverting or moving water from its natural course in order to use it for crops or landscapes.

Microfiltration: A physical separation process where tiny, hollow, straw-like membranes separate particles from water. It is used as a pre-treatment for reverse osmosis.

Milligram Per Litre (mg/L): A measurement describing the amount of a substance (such as a mineral, chemical, or contaminant) in a litre of water. One milligram per litre is equal to one part per million.

Million Gallons Per Day (MGD): A measure of flow. This term is used to describe the volumes of water treated and discharged from a treatment plant in a day.

Multi-barrier Processes are purification processes that consist of several barriers to ensure sufficient reduction and/or elimination of the various substances that need to be controlled. As in all processes, monitoring is important in order to check that the processes are working properly and efficiently. Membrane filtration, reverse osmosis, advanced oxidation, riverbank filtration, Soil Aquifer Treatment, and constructed wetlands all may be parts of a multi-barrier purification process. Not all of these processes are needed in all situations.

Nano filtration (NF): A filtration process that utilizes membranes that is used most often with low total dissolved solids water such as surface water and fresh groundwater, with the purpose of softening (polyvalent cation removal) and removal of disinfection by-product precursors such as natural organic matter and synthetic organic matter. It is commonly used in conjunction with desalination.

Nephelometric Turbidity Unit (NTU): A unit of measure related to the individual particles suspended in water.

Non-potable Reuse refers to reclaimed water that is not used for drinking, but is safe to use for irrigation, industrial uses, or other non-drinking water purposes.

Non-Potable Reuse (NPR): Includes all recycled water applications except those related to drinking water.

Non-Potable: Water not suitable for drinking.

Ozonation: The process of applying ozone (0_3) for the disinfection of water. Ozone (O_3) is a strong oxidant.

Planned Potable Reuse is publicly acknowledged as an intentional project to reclaim water for drinking water. It is sometimes further defined as either **direct or indirect potable reuse**. It commonly involves a more formal public process and public consultation program than is observed with de-facto or unacknowledged reuse.

Potable Reuse (PR) refers to recycled water you can drink. The reclaimed water is purified sufficiently to meet or exceed federal and state drinking water standards and is safe for human consumption.

Potable water: Water that is considered safe for domestic human consumption; drinkable water.

Potable: Water that does not contain pollution, contamination, objectionable minerals or infective agents and is considered safe for domestic consumption; drinkable.

Primary Treatment: The first process in wastewater treatment where suspended solids are removed.

Raw Water: Untreated water.

Recycled Water: Water that is used more than one time before it passes back into the natural water cycle. Wastewater that has been treated to a level that allows for its reuse for a beneficial purpose..

Reservoir: A body of water used to collect and store water, or a tank or cistern used to store potable water.

Retrofit: The process for constructing and separating new potable and recycled/reclaimed pipelines that allows recycled water to be used for nondrinking purposes. A retrofit system separates recycled water from drinking water pipelines.

Reuse: To use again; recycle; to intercept, either directly or by exchange, water that would otherwise return to the natural hydrologic (water) system, for subsequent beneficial use. Water reuse often refers to potable reuse applications.

Reverse osmosis: A water treatment method used to remove dissolved inorganic chemicals and suspended particulate matter from a water supply. Water, under pressure, is forced through a semi-permeable membrane that removes molecules larger than the pores of the membrane. This treatment method is commonly used in desalination, a process that takes salt out of seawater or recycled water treatment.

Secondary Treatment: Treatment of wastewater to a non-potable level so that it may be discharged into the natural hydrologic system. Generally used to remove biochemical oxygen demand, further remove solids, and reduce, eliminate, or render pathogens inactive. Under this process, dissolved and suspended biological matter is removed to a non-potable level so that the water may be disinfected and discharged into a stream or river, or used for irrigation at controlled locations.

Sewage Sludge refers to the residual, semi-solid material that is produced as part of primary and secondary treatment. Sewage sludge is further treated by aerobic or anaerobic digestion and dewatered at a wastewater treatment plant or resource recovery facility to produce Biosolids and other byproducts such as methane gas and struvite recovery.

Soil Aquifer Treatment (SAT): The process of water being purified by percolating through soil and into an underground aquifer.

Standalone: Standing separate without any connection with other systems or network.

Surface water: Water on the surface of the ground (lakes, rivers, ponds, floodwater, oceans, etc.); precipitation which does not soak into the ground or return to the atmosphere by evaporation or transpiration.

Tertiary Treatment or Advanced Water Treatment refers to processes that purify water for uses such as irrigation or for water blended with other environmental systems such as a river, reservoir, or groundwater basin prior to reuse. It can also include treatment processes to remove nitrogen and phosphorus in order to allow discharge into a highly sensitive or fragile ecosystem (estuaries, low-flow rivers, coral reefs, etc.).

Tertiary Treatment: Treatment of wastewater to a level beyond Secondary Treatment but below Potable. Generally to remove specific pollutants such as nitrogen, phosphorus, colour, and odour.

Total Dissolved Solids (TDS): A measure of the residual minerals dissolved in water that remain after evaporation of a solution. Usually expressed in milligrams per litre.

Total Suspended Solids (TSS): A measure of the suspended solids in wastewater, effluent, or water bodies, determined by tests for "total suspended non-filterable solids." Usually expressed in milligrams per litre.

Treated water: Water that has been filtered and/or disinfected; sometimes used interchangeably with "potable" water.

Turbidity: A measure of suspended solids in water; cloudiness. Usually expressed as NTUs.

Ultrafiltration (UF): A membrane filtration process that falls between reverse osmosis (RO) and microfiltration (MF) in terms of the size of particles removed.

Ultraviolet Treatment (UV): The use of ultraviolet light for disinfection or as part of an advanced oxidation process. This usually renders the pathogens inactive (changes the DNA so that the pathogens cannot replicate).

Ultrafiltration (UV): The use of ultraviolet light for disinfection or as part of an advanced oxidation process. This usually renders the pathogens inactive (changes the DNA so that the pathogens cannot replicate).

Wastewater: Water that has been previously used by a municipality, industry, or agriculture and has suffered a loss of quality as a result of use. There are different types of wastewater: domestic, commercial, and industrial.

Water Cycle: The movement of water as it evaporates from rivers, lakes, or oceans, returns to the earth as precipitation, and either flows into rivers and evaporates again or percolated through the soil to join with groundwater or surface water. Also known as the hydrologic cycle.

Water Use Cycle: The 'water use cycle' of a water and wastewater water system is defined as the all flow processes from water sourcing/collection to water distribution and then wastewater collection, treatment and disposal/any recycling and in the case of a recycled water systems it starts with wastewater collection, conveyance if any and then treatment, reuse and also disposal of the final effluent.

List of Acronyms

A	
ABIDE	Agenda for Bengaluru Infrastructure and Development Task Force
ADB	Asian Development Bank
AECOM	American Multi-National Engineering Company
AGWR	Australian Guidelines for Water Recycling
ANU	Australian National University
AOP	Advanced Oxidation Process
ARC	Australian Research Council
ASE	Alliance to Save Energy
ASP	Activated Sludge Process
ATREE	Ashoka Trust for Research in Environment and Ecology
ATSE	Australian Academy of Technology and Engineering
AWT	Advanced Water Technology
B	
BAC	Biological Activated Carbon
BBC	British Broadcast
BBMP	Bruhat Bengaluru Mahanagara Palike
BDA	Bengaluru Development Authority
BESCOM	Bengaluru Electricity Supply Company Limited
BEL	Bharat Electronics Limited
BHEL	Bharat Heavy Electronics Limited
BIOME	BIOME Environmental Solutions Pvt. Limited
BMA	Bengaluru Metropolitan Area
BMRDA	Bengaluru Metropolitan Regional Development Authority
BMP	Bengaluru Metropolitan Police
BMR	Bengaluru Metropolitan Region
BNR	Biological Nitrogen Removal
BORDA	Bremen Overseas Research and Development Association
BUA	Bengaluru Urban Agglomeration
BWSSB	Bengaluru Water Supply and Sewerage Authority
C	
CAPEX	Capital Expenditure
CAS	Conventional Activated Sludge
CBF	Coal Bed Filtration
CDD	Consortium for DEWATS Dissemination Society
CDP	Comprehensive Development Plan
CEC	California Economic Commission
CGWB	Central Groundwater Board
CHEEO	Central Public Health and Environmental Engineering Organisation
CII	Confederation of Indian Industries
CKDN	Climate and Knowledge and Development Network
CLAR	Clarification
Cl_2	Chlorine
CMC	City Municipal Council
COD	Chemical Oxygen Demand
CSA	California Sustainability Alliance
CSBH	California State Board of Health
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CWSS	Cauvery Water Supply Scheme
CWT	Conventional Water Treatment Technology
D	
DAF	Dissolved Air Flotation
DC	District Columbia
DFID	Department For International Development
DFLT	Direct Filtration

DGIS	Director General for International Cooperation
DM	Demineralisation
DMA	Directorate of Municipal Administration, Karnataka
DPR	Direct Potable Reuse
DOE	Department of Environment, USA
DOIS	Department of Industry and Science
DWR	Department of Water Resources
DRDO	Defence Research and Development Organisation
E	
EA	Extended Aeration
EDM	Energy Density Map
EI	Energy Intensity
ENV	Environment
EP	Equivalent Population
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute, USA
ESCL	Electric Supply Company Limited
EQR	Effluent Quality Requirement
ESMAP	Energy Sector Management Assistant Program
F	
FAO	Food and Agriculture Organisation
FLOC	Flocculation
FGD	Focus Group Discussion
G	
GDP	Gross Domestic Product
GHG	Green House Gas
GJ	Giga Joules
GL	Giga Litres
GOI	Government of India
GWA	Global Water Alliance
GWP	Global Water Partnership
GWR	Groundwater Recharge
GWRS	Groundwater Replenishment System
H	
HDR	Human Resources Development
HH	Households
HAL	Hindustan Aeronautics Limited
H_2O_2	Hydrogen Per Oxide
HQ	Head Quarter
HUDCO	Housing and Urban Development Corporation
HVAC	Heating, Ventilation and Air Conditioning
I	
IBM	International Business Machine Corporation
IBNET	International Benchmarking Network
ICLEI	International Centre for Local Environmental Initiatives
IDB	International Development Bank
IEA	International Energy Agency
IEUA	Inland Empire Utilities Agency
IIM	Indian Institute of Management
IIHS	Indian Institute for Human Settlements
IIIT	Indian Institute of Information Technology (IIIT)
IISc	Indian Institute of Science
IMD	Indian Meterological Department

INA	Info Not Available
ISEC	Institute for Social and Economic Change
ISRO	Indian Space Research Organisation
IPART	Independent Pricing and Regulatory Tribunal
IPR	Indirect Potable Reuse
IPRWTS	Internally Plumbed Rainwater Tank Systems
IRENA	International Renewable Energy Agency
IT	Information Technology
IUWM	Integrated Urban Water Management
IWA	International Water Association
IWCM	Integrated Water Cycle Management
IWRM	Integrated Water Resources Management
IWP	Institute for Water Policy
IWP	India Water Partnership
J	
JICA	Japan International Cooperation Agency
JBIC	Japan Bank for International Corporation
JNCASR	Jawaharlal Nehru Centre for Advanced Scientific Research
Jnnrum	Jaharalal Nehru National Urban Renewal Mission
K	
KERC	Karnataka Electricity Regulatory Corporation
KPCL	Karnataka Power Company Limited
KIADB	Karnataka Industrial Development Board
KPTCL	Karnataka Power Transmission Corporation Limited
KPWD	Karnataka Public Works Department
KSPCB	Karnataka State Pollution Control Board
KSWP	Karnataka State Water Policy
KUIDFC	Karnataka Urban Infrastructure Development and Finance Corporation
KUWSDB	Karnataka Urban Water Supply and Drainage Board
KWRD	Karnataka Water Resources Department
L	
LAC	Latin America and Caribbean
LCA	Life Cycle Analysis
LDA	Lake Development Authority, Karnataka
LIC	Life Insurance Corporation
LKYSPP	Lee Kuan Yew School of Public Policy
LVMAC	Living Victoria Ministerial Advisory Council
M	
MBR	Membrane Bioreactor
MDG	Millennium Development Goals
MDF	Media Filtration
MF	Micro-Filtration
MFLT	Membrane Filtration
MIS	Management Information System
MLP	Multi-Level Perspective
MoUD	Ministry of Urban Development
MoWR	Ministry of Water Resources
N	
NAL	National Aerospace Laboratories
NAR	Normal Annual Rainfall
NAS	National Academies
NBR	Netkal Balancing Reservoir
NDRL	National Defence Research Laboratory
NF	Nano- Filtration
NGO	Non-Government Organisation
NH3	Ammonia
NIAS	National Institute of Advanced Studies

NPR	Non Potable Reuse
NRC	National Research Council
NTV	National Television
NYSERDA	New York State Energy Resources and Development Agency
NSW	New South Wales
O	
O3	Ozone
OCWD	Orange County Water Department
OD	Oxygen Ditches
OECD	Organisations for Economic Cooperation and Development
O&M	Operation and Maintenance
OPEX	Operational Expenditure
P	
PUB	Public Utility Board
PS	Power Station
PSU	Public Support Undertakings
R	
RO	Reverse Osmosis
RWA	Residents Welfare Association
S	
SANDRP	South Asia Network for Dams, Rivers and People
SANDEC	Sanitation in Developing Countries (new name -Department of Sanitation, Water and Solid Waste for Development)
SBR	Sequential Batch Reactor
SCADA	Supervisory Control and Data Acquisition
SDG	Sustainable Development Goals
SEQ	South East Queensland
SMBR	Submerged Membrane Bioreactor
STP	Sewage Treatment Plant
SUWM	Sustainable Urban Water Management
SUEZ	French Based Utilities Company
T	
TC	Total Carbon
TERI	Tata Environment Research Institute
TIFR	Tata Institute for Fundamental Research
TMC	Town Municipal Council
TOC	Total Organic Carbon
TOX	Total Oxygen
TSS	Total Suspended Solids
U	
UAE	United Arab Emirates
UASB	Upflow Anaerobic Sludge Blanket
UF	Ultra Filtration
UFW	Unaccounted For Water
UK	United Kingdom
ULBs	Urban Local Bodies
UN	United Nation
UNECE	United Nations Economic Commission for Europe
UN-DPAC	United Nation
UNESCO	United Nation Educational, Scientific and Cultural Organisation
UNEP	United Nation Environment Programme
USAID	United States Agency for International Development
USDOE	United States Department of Environment
UNWWDR	United Nation World Water Development Report
W	
WEPA	Water Environment Partnership in Asia
WHO	World Health Organisation
WICA	Water Industry Competition Act

WIN	Water Integrity Network
WEFTEC	Water Environment Federation Technical Exhibition Conference
WERF	Water Environment Research Foundation
WRF	Water Research Foundation
WRRF	Water Reuse Research Foundation
WSP	Waste Stabilisation Pond
WSUD	Water Sensitive Urban Design
WTP	Water Treatment Plant
WWTP	Wastewater Treatment Plants
Z	
ZLD	Zero Liquid Discharge

Measurements and Acronyms

P	Power
V	Volume
E	Energy
EI	Energy Intensity
GL	Giga litres
GWh	Giga Watt Hour
HT	High Tension
ft	foot
kg	Kilogram
kL	Kilolitres
km	Kilometre
KW	Kilowatt
L	Litres
lpcd	Litres per capita per day
LT	Low Tension
m	meter
mm	Millimeter
MG	Million Gallons
MJ	Mega Joules
MLD	Million Litres per Day
ML	Million/Mega Litres
MW	Megawatt
MWh	Megawatt Hour
Sq km	Square kilometre

1 TMC = 28.32 GL

1 km = 1000 m

kWh = 1000 watt hours

1 MWh = 1000 kWh

1 GWh = 1000 MWh

1 HP = 0.746 kWh

1kWh =3.6 mega Joules

1 L water = 1 kg

g = 9.81 m/s^2

1 MG = 3.785 ML

1 ft = 30.48 cm

1 m = 100 cm

1 mm = 0.1 cm