GLOBAL WELLNESS INSTITUTE™

CLEAN WATER INITIATIVE

ACCESS TO CLEAN DRINKING WATER FOR ALL IN INDIA

- A MATTER OF SUSTAINABILITY OF TECHNOLOGICAL AND OTHER INTERVENTIONS

AUGUST 2021 | WHITE PAPER

ACCESS TO CLEAN DRINKING WATER FOR ALL IN INDIA - A MATTER OF SUSTAINABILITY OF TECHNOLOGICAL AND OTHER INTERVENTIONS

from the Clean Water Initiative of the Global Wellness Institute

Every two minutes a child under the age of five dies of diarrhea in India. Providing safe drinking water can prevent these deaths. Yet only 50% of the population has access to improved drinking water source. Who are these people who lack access? What are the purification technologies available? Are they appropriate to these people? What are sustainable interventions?

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CLEAN WATER INITIATIVE

Foreword

Susie Ellis[1]

The Global Wellness Institute, whose mission is empowering wellness worldwide, defines wellness as the active pursuit of activities, choices and lifestyles that lead to a state of holistic health. I can't think of a more foundational necessity than all people having access to safe water in order to make the possibility of holistic health accessible to all.

Providing access to safe water, sanitation, and hygiene (WASH) can prevent most communicable diseases. Water Aid Global and Vivid Economics in their latest report have highlighted that achieving universal access to WASH could save more than US$ 2.6 trillion in health costs between 2021 and 2040[2]. Yet, providing access to safe drinking water to all has remained a global challenge, more so for the developing countries.

I am excited to write the foreword for this white paper as it will help bridge the gaps between stakeholders and lead to the last mile connectivity of clean and safe drinking water. This paper although focused on India has learnings that can be applied to any territory in the world where there are marginalized communities. The ambitious Jal Jeevan Mission launched by the Government of India is yielding good results[3]. Recently the famous city of Puri in Odisha state became the first city in the country to have city-wide safe tap drinking water[4]. The mission has achieved a milestone of providing tap water to every household in at least 100,000 villages across India within 23 months since its launch in August 2019[5]. This demonstrates that concerted efforts of partnership between the public and private sectors and the communities can achieve the most challenging tasks. However, there is so much more that remains to be done before all can have sustainable access to safe drinking water.

The white paper presents the status of drinking water scenario in India and discusses the authors' perspectives on the critical barriers that need to be addressed to achieve the goal of safe drinking water for all. They point out that clean water technologies are useful only if they are appropriate and sustainable to the target population. They define the marginalized masses, who for one reason or the other are unable to access the technologies. I agree with the authors' recommendations that public health interventions must be built on the foundations of Primordial Prevention strategies. These are very pertinent for today's world, where the Climate Change and Planetary Health challenge human existence on this planet.

This White Paper comes at the right time, anticipating some of the issues that will need to be addressed to work on the UN framework to speed up progress on water and sanitation goals[6] and the gaps highlighted in the Sustainable Development Report 2021[7]

I wish the authors and readers all the best in their pursuit to make clean water accessible to all. It is my hope that it encourages peoples and organizations to collaborate for necessary actions. The Global Wellness Institute is looking forward to doing its part in making this important Initiative and need more visible throughout the every-increasing world of wellness around the world.

[1] Susie Ellis is the Chairman and CEO of the Global Wellness Institute (GWI), and heads up the organization's annual Global Wellness Summit and Global Wellness Tourism Congress

[2] Water Aid Global and Vivid Economics Report – 'Mission-critical'
Invest in water, sanitation and hygiene for a healthy and green economic recovery
https://washmatters.wateraid.org/mission-critical Accessed July 28, 2021

[3] Jal Jeevan Mission is envisioned to provide safe and adequate drinking water through individual household tap connections by 2024 to all households in rural India https://jaljeevanmission.gov.in/ Accessed July 28, 2021

[4] First city in India to have safe water under Jal Jeevan Mission https://www.indiawaterportal.org/article/odishas-puri-becomes-first-city-country-have-safe-water-under-jal-jeevan-mission-urban Accessed July 28, 2021

[5] Jal Jeevan Mission, the government's flagship scheme to make piped water available to all, has achieved the milestone of providing tap water to every household in at least 100,000 villages across India within 23 months since its launch in August 2019 https://www.hindustantimes.com/india-news/at-least-100k-villages-got-tap-water-supply-within-2-years-jal-jeevan-mission-101627877965178.html Accessed August 02, 2021

[6] UN Sustainable Development Report 2021
https://s3.amazonaws.com/sustainabledevelopment.report/2021/2021-sustainable-development-report.pdf
Accessed August 02, 2021

[7] United Nations launches framework to speed up progress on water and sanitation goal
https://www.un.org/sustainabledevelopment/blog/2020/07/united-nations-launches-framework-to-speed-up-progress-on-water-and-sanitation-goal/ Accessed July 30, 2021.

Author Profiles

Prof. Padma Venkatasubramanian

Prof. Padma Venkatasubramanian is the Dean, School of Public Health, SRM Institute of Science & Technology (SRMIST), Chennai. Earlier, she was the Director, Foundation for Revitalization of Local Health Traditions (FRLHT) and Head, Research & Development Centre, Trans-Disciplinary University (TDU), Bangalore. She is a recipient of the Cambridge-Nehru Merit Scholarship for her doctoral work at Cambridge University, UK and McGill University scholarship for the International Masters for Health Leadership degree in Health Management. A Microbiologist by training, her career has grown from being a laboratory researcher to a public health leader. Her passion and research interests are to develop affordable and sustainable wellness interventions. She has conceived and implemented several national and international programs in drinking water, mother and childcare, anemia, and nutrition. Working with the grassroots in India and Kenya have taught her that socio-politico-economic and cultural mileu shape human behavior and public health interventions which do not get into contextual details of the people and the environment are likely to be unsustainable in the long run. TamRas (https://www.youtube.com/watch?v=VAgOtBSU9cU), a copper-based drinking water purifier developed and tested by Padma and her team, while at TDU, is an example of her conviction to create technologies that are not only affordable but also sustainable. She believes that indigenous knowledge systems can provide insights and solutions for sustainable living with nature, particularly during these Covid 19 times. At SRMIST she has rolled-out an innovative pedagogic framework called the University Wellness Program to promote campus wellness through students. She is a member of Government of India's National AYUSH R&D Working Groups for developing solutions for Covid-19. She is the Co-Chairperson of Clean Water Initiative of the Global Wellness Institute.

Dr. Keerthi Paneer Selvam

Dr. Keerthi Paneer Selvam, BDS, MPH, is Research Associate at the School of Public Health, SRM Institute of Science and Technology, Tamil Nadu, India. She is pursuing her PhD in Public Health, with a research focus on Health Policies. She is a Biostatistician who received a gold medal in her Postgraduate studies in Public Health. She served as a Project Associate for the SRM Institute of Science and Technology's Unnat Bharat Abhiyan Scheme, where she organised various workshops for women's empowerment from eight villages. Dr. Keerthi held numerous executive posts in various public organisations. Her research and publication interests include human wellbeing, women and child health, Planetary health, and gender equality.

Dr. Abhishek Jain

Dr. Abhishek Jain is Vice President, International Operations at the WTS International, LLC, USA. Dr. Jain is recognized as industry leader in the South Asian region and is regularly invited to speak at industry events such as Arabian Travel Market, World Spa and Wellness Convention, ITB Asia as well as national conferences such as Dept. of AYUSH, Federation of Indian Chambers of Commerce and Industry (FICCI) Wellness Conference and many others. His academic credentials include a 5.5-year full time professional Bachelor's degree in Holistic Medicine (RGUHS, Bangalore), Masters in Hospital & Health Systems Management (BITS, Pilani) and, Certificates in Strategic Management (Cornell, USA) & General Management (IIM, Ahmedabad). Early in his career he was involved in Research and teaching at National Institute of Naturopathy, Pune (Ministry of AYUSH, Govt. of India) followed by independent advisory to multi-specialty Hospitals, Corporate Houses and Sports Institutes. In following years, his particular interest was to explore and involve himself as Health and Wellness Management Professional in implementing continuous improvement processes to the operational systems while supporting organization's purpose. He achieved these most notably at world's leading Destination Spa - The BodyHoliday at LeSPORT, St. Lucia and, famous multi award winning ESPA at The Leela Palace Udaipur, India. For last 7 years he has been providing advisory services to Luxury Hospitality & Integrative Health industry Clients worldwide. He has handled overseas assignments in multiple regions including Americas, Middle East, Southeast Asia, and India and brings two decades of extensive experience in luxury hospitality, spa & wellness industries during which he worked on numerous feasibility studies, concept development, and design inputs for new properties as well as pre-opening and successful operations of award-winning properties worldwide. He is the Chairperson of Clean Water Initiative of the Global Wellness Institute.

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Abbreviations

BPL	Below Poverty Line
C&SPCB	Central and State Pollution Control Board
CSR	Corporate Social Responsibility
CPCB	Central Pollution Control Board
DALY	Disability Adjusted Life Years
DDWS	Department of Drinking Water and Sanitation
DWRRDGR	Department of Water Resources, River Development and Ganga Rejuvenation
DWSM	District Water Sanitation Mission
DE	Diatomaceous Earth
E. coli	*Escherichia coli*
FHTC	Functional Household Tap Connection
GPs	Gram Panchayats
HWT	Household Water Treatment
IEC	Information, Education and Communication
JMP	Joint Monitoring Program
JJM	Jal Jeevan Mission
JUSCO	Jamshedpur Utility Services Company Limited
KUWASIP	Karnataka Urban Water Supply Improvement Project
Mn	Million
MoEF&CC	Ministry of Environment, Forestry and Climate Change
MF	Microfiltration
NFHS	National Family Health Survey
NWP	National Water Policy
NWRC	National Water Resources Council
NGO	Non-Governmental Organization
NRDWP	National Rural Drinking Water Program
ODF	Open Defecation Free
OOPS	Out of Pocket Spending
PRS	Panchayat Raj Systems
PRIs	Panchayati Raj Institutions
PPP	Public Private Partnership
PET	Polyethylene Terephthalate
RO	Reverse Osmosis
S&UTs	States and Union Territories
SPCB	State Pollution Control Board
SWSM	State Water and Sanitation Mission
SBA	Swachh Bharat Abhiyan
SODIS	Solar Disinfection
SDG	Sustainable Development Goal
SRPP	Sector Reform Pilot Projects
U5	Under five-year-old children
UN	United Nations
UNICEF	United Nations International Children's Emergency Fund
UV	Ultraviolet

USD	United States Dollar
WASH	Water, Sanitation and Hygiene
WHO	World Health Organization
VWSC	Village Water and Sanitation Committee

Abstract

Close to 0.3 million children under the age of five (U5) die every year in India just due to infectious diarrhea. These children are mostly from socio-economically vulnerable communities. Drinking water that is contaminated with fecal pathogens and living in poor sanitation and hygiene (WASH) conditions are the main causes of diarrhea. Primordial preventive measures including sustained access to microbially safe drinking water, proper use of toilets and handwashing with soap can prevent these meaningless deaths.

Technological and other interventions by the public and private sectors to tackle the WASH challenge have achieved commendable success in improving the WASH situation in India over the last decade. Yet, half of India's population still does not have access to safely managed drinking water, and around the same number continues to defecate in the open. Improvement in the health outcomes including reduction in diarrheal deaths among U5 children has not been dramatic either.

This article presents a snapshot of the status of drinking water quality and the prevalence of diarrhea among U5 children in India. The appropriateness of some of the commonly used drinking water disinfection technologies for the vulnerable population has been assessed. While providing clean water through concerted public and private interventions, the critical role of communities has been emphasized. Fresh design thinking is seen as necessary to ensure sustainability of efforts.

Providing access to safe drinking water and WASH environment to the masses in India are no doubt complex, with multi-sectoral challenges. But, without securing these there can be no sustainable development. Public Health systems that are not built on the foundations of primordial prevention will continue to remain fragile.

Keywords: Safe drinking water, microbial contamination, under five-year-old children diarrhea, drinking water disinfection techniques, drinking water management, Corporate Social Responsibility, Public Private Partnership

1. Introduction

Drinking water or potable water is a very valuable natural resource. Providing access to safe drinking water for all is one of the most complex contemporary issues to solve, especially in a country like India. It is riddled with technological, environmental, and socio-politico-economic challenges. The logistics of water supply to every household is also a challenge. Freshwater, which is used for drinking purposes is disproportionately low on earth when compared to the 97% that occurs as saline or sea water. Two thirds of the freshwater remain frozen as glaciers and polar ice caps, leaving very little for direct use as surface water (in ponds, rivers, lakes etc.) or ground water (accessed through wells, bore wells etc.). Glaciers and rains replenish these water sources. Water can also be sourced artificially through desalination of sea water and condensation of atmospheric moisture. While the former is the predominant source of drinking water in many Middle Eastern countries, the air-to-water technologies are still emerging.

"Drinking water is the water intended for human consumption for drinking and cooking purposes from any source. It includes water (treated or untreated) supplied by any means that is for human consumption". (BIS, 2012)

Clean water is fundamental to human health and well-being. UN's Sustainable Development Goal # 6.1 is to provide all households with safe quality and adequate quantity of water by 2030. Equal and equitable access to safe and affordable drinking water is part of that goal. The governments of countries have the responsibility of providing access to safe drinking water to its populations through improved supplies. The Joint Monitoring Program (JMP) for Water Supply and Sanitation of WHO and UNICEF tracks and monitors global access to safe drinking water (Kostyla et al., 2015). For practical purposes of monitoring, the JMP classifies drinking water supplies as improved water and unimproved water (Table 1) (World Health Organization & UNICEF, 2017)

Improved water sources	• Piped supplies into their dwellings, yard, or plot • Public stand posts • Boreholes/tube wells • Protected wells & springs • Rainwater • Packaged water including bottled water and sachet water • Delivered water, including tanker trucks and small carts
Unimproved water sources	• No- Piped supplies – unprotected wells and springs • Surface water (rivers, lakes, ponds, stream, irrigation channel)

Table1: Classification of Drinking Water sources as per the Joint Monitoring Program

Nearly half the world's population is projected to live in extremely water-stressed regions by 2026. Globally, ~30% (785 million) of the people already lack access to drinking water (CDC, 2021) and every other Indian does not have access to safe drinking water. Inadequate quantities and poor quality of drinking water make people exposed to a variety of preventable illnesses and they remain trapped in morbidity and increased DALY (disability adjusted life years) (World Health Organization, 2019). In 2017, 1.6 million people worldwide died of diarrhea, of which >0.5 million were U5 children (Dadonaite et al., 2019). Incessant diarrhea also impacts the nutrition and growth of children, especially those living in socio-economically compromised environments (Mokomane et al., 2018). Microbial contamination of drinking water is closely related to poor water, sanitation, and hygiene (WASH), and influenced by the knowledge, attitude, and practices (KAP) of individuals and communities (Kuberan et al., 2015).

Safe drinking water is simply defined by WHO as "water that does not represent any significant risk to health over a lifetime of consumption, including different sensitivities that may occur between life stages" (WHO, 2006). Water becomes unsafe for consumption when it gets polluted with physical, chemical, biological, or radiological contaminants. Of these, microbial contamination is by far the major concern, especially in low-and-middle income countries like India.(MDGs, 2012) Pathogens such as bacteria, viruses, protozoa, cyanobacteria and helminths are examples of biological contaminants (Sharma & Bhattacharya, 2017). Diseases caused by microbial contamination include diarrhea, cholera, typhoid, dysentery, hepatitis A and E, poliomyelitis etc. (Sharma & Bhattacharya, 2017). Worldwide, infectious diarrhea caused by bacteria and viruses is a leading cause of mortality of children under the age of five (Francis et al., 2015) Diarrheagenic pathogens such as *Escherichia coli, Salmonella typhi, Shigella flexneri, Vibrio cholerae* and *Rotavirus* spread through water and food contaminated with human or animal feces.

Safely managed drinking water is defined as "drinking water from an improved water source that is located on-premises, available when needed and free from fecal and priority chemical contamination" (World Health Organization & UNICEF, 2017).

Mixing of sewage with water bodies and pipelines, open defecation, unsafe disposal of human and animal wastes, poor water handling practices etc. are routes of drinking water contamination. According to WHO, microbially safe water is that with no detectable *E. coli* (an indicator of fecal contamination) in 100 ml of sample (WHO, 2017). Disinfection/removal pathogens are ways of making it safe to drink. Avoiding the contamination in the first place would however be a more sustainable way of providing microbially safe water. This requires structuring the country's growth and development on the fundamentals of primordial prevention including planning and monitoring for WASH in terms of structures, systems, and behaviors. Under the current scenario in India, purification is one of the ways to provide microbially safe drinking water. There are several techniques to disinfect/remove pathogens from drinking water including physical, chemical, biological or a combination of these. Disinfection can be performed at a centralized, community level facility at the water source, or at the household-level, or both.

In India, drinking water comes under the control of the State and Union Territories (S&UTs). S&UTs get schematic and financial support from the Central Ministry of Drinking Water and Sanitation (now called the Ministry of Jal Shakti). The Government of India has launched several schemes that are being implemented by the S&UTs to enhance the quality of drinking water, such as the Jal Jeevan Mission (to provide piped water to all rural households) and Swachh Bharat Mission (to provide toilets and stop open defecation). The Central and State Pollution Control Boards (C & S PCB) monitor India's primary drinking water sources, namely the surface and ground water sources (CPCB, 2020). Healthcare, which is closely related to safe drinking water, is also a matter of the state governments.

Several cost-effective techniques and innovations have been brought about in India to provide safe drinking water to the masses. Awareness among the public and the mission mode of operation to improve water, sanitation, and hygiene by the local, state, and central governments in India have helped improve the access to safe drinking water to a large extent. Over 100 million toilets were constructed and all villages in India were declared as open defecation free (ODF) by the Swachh Bharat Mission – Grameen (Rural) in 2019 on the 150th birth anniversary of Mahatma Gandhi (Ministry of Jal shakti, 2020). Yet, the recently published Phase -1 of the National Family Health Survey – 5 (NFHS-5) for 22 S&UTs in 2020, shows that the meaningless deaths due to U5 children diarrhea continue unabated in India, reflecting gaps in addressing factors other than toilet construction.

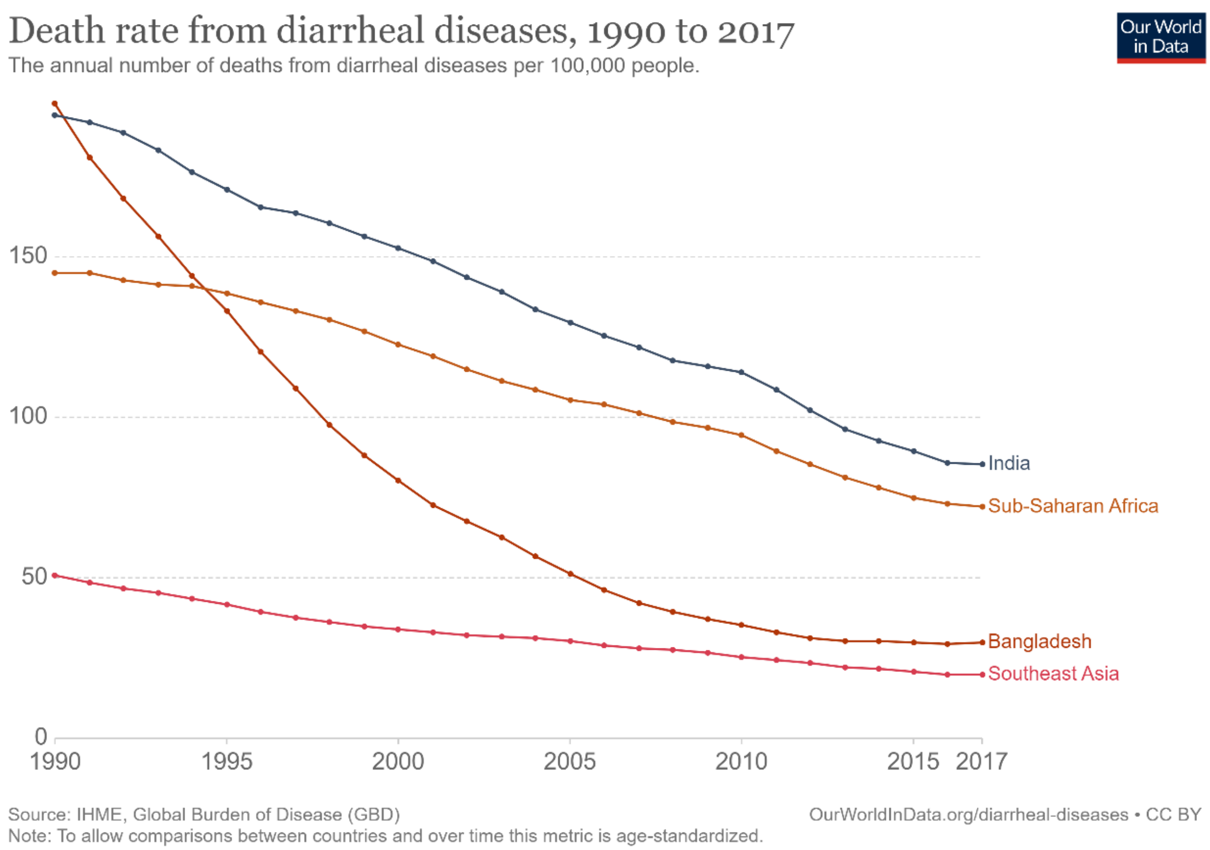


Fig 1: Diarrheal death rates in India and other similar income country/region (1990-2017)

Source: IHME, Global Burden of Disease (GBD)

India managed to reduce the diarrheal death rate from 193/100000 in 1999 to 86/100000 in 2017, which is no doubt quite a feat, but not adequate in comparison to other similar income or lower income countries (Fig 1). This indicates that there is a need to identify the critical gaps and implement appropriate and sustainable programs to address them. Diarrhea prevalence and deaths among the U5 children are important health outcomes not only to measure the impact of WASH interventions but also the overall performance of a country in health aspects.

The article reviews the status of microbial contamination of drinking water across the S&UTs of India and the prevalence of U5 children diarrhea. It assesses the appropriateness of existing drinking water disinfection techniques, for the eco-socio-economically vulnerable population. The article introduces key players in drinking water governance in India to better understand the operational contexts. It contends that India's development strategies need to be reformed to include primordial prevention approaches such as better WASH conditions, especially for the vulnerable population. The governance and regulatory systems to monitor and control pollution of water sources should be tightened. If not, achieving the goals of providing access to safe drinking water and health and wellbeing for all will remain a distant dream.

2. Defining the vulnerable population

Lack of access to safe drinking water and good WASH conditions particularly plague certain segments of India's population, because of the social/economic/environmental/political contexts they live in (Paul, 2020). The children who die of diarrhea in India are likely to be from the 260 Mn people living below the poverty line (BPL), 450 Mn migrant laborers, 1.2 Mn tribal population, 889 Mn living in rural villages, 5 Mn of the internally displaced people, and 65 Mn slum dwellers. Illiteracy among ~311 Mn people would also affect the WASH awareness and behavior (Fig 2). Any technological and other interventions to provide access to safe drinking water would therefore need to be appropriate to these contexts, to be sustainable. At the same time, the technologies would also need to consider the long-term impact on the environment, including the water sources themselves. Technologies that purify drinking water but pollute the environment are not sustainable in the long run.

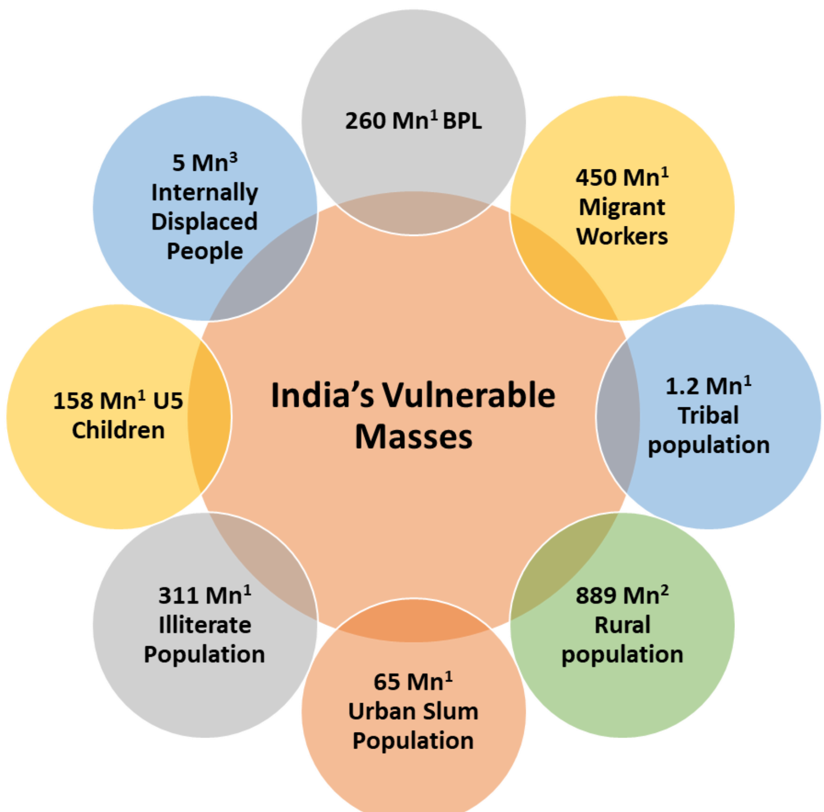


Fig 2: Defining the vulnerable population

Data Source: 1) India Census, 2011; 2) Statista, 2018; 3) UNICEF, 2020

3. Water Governance Systems in India

The first National Water Policy (NWP) established by the Government of India in September 1987 by the National Water Resources Council (NWRC), indicates the national level commitment to the importance of water and water utilization. It specifically mentions that water resource development should be taken up as multi-sectoral projects, giving top priority to drinking water. In NWP (2002), there was a commitment to providing access to safe drinking water facilities to the entire population (rural and urban), and that this should not be affected because of use by the agriculture and industrial sectors. NWP (2012) was enacted to address the growing disparities in not only the access to quality and quantum of drinking water, but also to access of water for sanitation. The need for efforts in conservation and better management of water were particularly highlighted in the 2012 policy.

India has a federal system of governance wherein water (including drinking water and other supplies, irrigation & canals, drainage and embankments, storage, and power) is a subject matter of the 28 States and 8 Union Territories (S&UTs), under Article 246 of the Constitution of India. However, the Central Government has an overall responsibility for appropriate functioning of water related activities. A third player in the drinking water sector is the non-governmental organizations (NGOs) including the civil society organizations, academia, research institutions, private industry, and the corporate social responsibility (CSR) units of private organizations (Fig 3).

The supply and management of water in the rural and urban areas are managed differently in India. The Municipalities/Corporations that come under the respective S&UTs are responsible for the urban water supply and management while a unique system called the Panchayati Raj System (PRS) manages the rural areas. The PRS is a 3-tier system with elected representatives at the District, Taluk (Block) and Gram (Village) level participation in governance and administration (Ahmed & Araral, 2019).

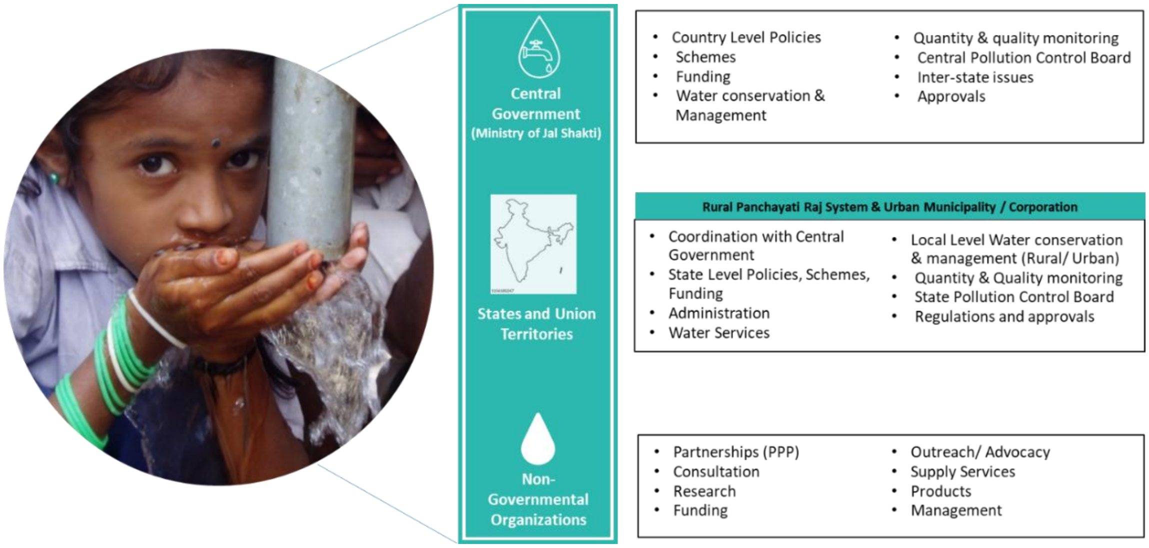


Fig 3: Key Organizational Players in Drinking Water Governance in India

3.1 Central Government

The Ministry of Water Resources, River Development, and Ganga Rejuvenation was renamed as the Ministry of Jal Shakti on June 14, 2019, with two departments: The Department of Water Resources, River Development, and Ganga Rejuvenation (DWRRDGR) and the Department of Drinking Water and Sanitation (DDWS) (Ministry of Jal shakti, 2021). The departments oversee regulation of the country's water resources, as well as establish policy guidelines and schemes. The central ministry's main functions are overall planning, policy development, collaboration, and guidance in the water resources sector; setting up of utilizable resources and formulation of policies for optimal usage, supervision of and assistance to state level activities in ground water development; and general organizational, technological, and scientific planning for development (Ministry of Jal shakti, 2017). It also frames schemes and funds the S&UTs for better water management and facilitates inter-state consultations to resolve disputes on water.

Water quality monitoring is a key component of water quality management. In India, there are 14 major rivers, 44 medium rivers, and 55 minor rivers, in addition to numerous lakes, ponds, and wells that are used as primary sources of drinking water. The Indian parliament enacted the Water (Prevention and Control of Pollution) Act, 1974, with the goal of maintaining and restoring the cleanliness of our water bodies. The Central Pollution Control Board (CPCB) initiated national water quality monitoring in 1978 (Wescoat et al., 2016). The CPCB monitors drinking water quality at district level in every S&UT and alerts the states. The CPCB comes under the Ministry of Environment, Forestry, and Climate Change (MoEF & CC), and its key responsibilities include preventing, tracking, and regulating water, as well as collaboration with State Pollution Control Boards (SPCBs) as and when necessary. One of the CPCB's mandates is to collect, compile, and disseminate technical and statistical data on water contamination and quality (CPCB, 2020).

The National Rural Drinking Water Program (NRDWP) was launched by the Department of Drinking Water Supply (DDWS) in April 2009. This was an effort to bring all rural drinking water initiatives under one umbrella to ensure drinking water security to the rural population in India. Recognizing the role of rural communities in managing the drinking water, it incentivizes the State Governments to hand over the responsibility of planning, maintaining, and managing drinking water to the Panchayati Raj Institutions.

The Jal Jeevan Mission (JJM), a centrally funded initiative, was launched on August 15, 2019, by the Department of Drinking Water and Sanitation, with an aim to link every rural household to a functional household tap connection (FHTC) by 2024. The Jal Jeevan Mission (JJM) includes the State Water and Sanitation Mission (SWSM), District Water and Sanitation Mission (DWSM), Gram Panchayat and/or its Subcommittees, such as the Village Water and Sanitation Committee (VWSC)/Paani Samiti/User Group, and others (Jal Jeevan Mission, 2021). As of June 11th, 2021, more than 7 million rural households had access to tap water (FHTC, 2021). The Government of India launched the Swachh Bharat Mission (SBM), program in 2014 to achieve universal sanitation coverage in urban cities (SBM-Urban) and villages (SBM-Grameen). As a fitting tribute to Mahatma Gandhi's 150th birthday, the mission went on a drive to make all villages in all S&UTs in India as "open-defecation free" (ODF) by October 2, 2019 (Swachh Bharath Mission, 2020). To date, 6,03,004 villages have been declared Open Defecation Free (Swachh Bharath Mission, 2021).

In 2019, the Ministry of Jal Shakti and the Department of Drinking Water and Sanitation launched the Jal Shakti Abhiyan, a mission-mode water conservation campaign in India's water-stressed districts to raise awareness and improve water conservation interventions (Ministry of Jal Shakti, 2019). The Swajal scheme, launched by the Ministry of Jal Shakti, empowers communities to plan and design single village drinking water supply systems, as well as coordinate community ownership for operations and maintenance. The Ministry of Jal Shakti works with UNICEF to improve the Swajal and the NRDWP to target 0.5 million populations every year in aspirational districts in the 28 states of India (DDWS, 2021). Swajal scheme also would help in prioritizing integrated water safety planning, behavior change, water quality management and participation of the community.

S.No.	PROGRAM / SCHEMES	MONITORED BY	GOAL	ACHIEVEMENT AS OF JUNE 2021	REFERENCES
1	Jal Shakti Abhiyan	Ministry of Jal Shakti along with UNICEF	To establish a defined baseline and benchmark for state-level performance on rainwater harvesting, water body rejuvenation, reuse of treated wastewater, and plantation**.**	In 256 districts, nearly 3.5 lakh water conservation measures have been implemented. Water conservation and rainfall harvesting methods account for 1.54 lakh, traditional water body rejuvenation accounts for 20000, reuse and recharge structures account for over 65000, and watershed development initiatives account for 1.23 lakh.	1)http://ud.hp.gov.in/sites/default/files/JAL%20SHAKTI%20%20ABHYAN/Jal%20Shakti%20Abhiyan%20Urban%20Guidelines.pdf 2)http://164.100.47.193/Refinput/New_Reference_Notes/English/15112019_160206_102120367.pdf
2	Jal Jeevan Mission.	Ministry of Jal Shakti along with UNICEF	To achieve the target of functional household tap connection by 2024.	As of June 11th, 2021, more than 7 million rural households had access to tap water.	1)https://jalshakti-ddws.gov.in/sites/default/files/JJM_note.pdf 2)https://ejalshakti.gov.in/jjmreport/JJMIndia.aspx (Accessed on 11.06.2021)
3	National Rural Drinking Water Programme.	Ministry of Drinking Water & Sanitation	Its goal was to offer safe drinking water to all rural habitations, government schools, and anganwadis.	Safe drinking water was delivered to 44 percent of rural families and 85 percent of government schools and anganwadis, 18 percent of the rural population was given potable drinking water, and 17 percent of rural households were given household water connections.	https://www.prsindia.org/content/national-rural-drinking-water-programme-22
4	Swajal Scheme	Ministry of Jal Shakti	Programme involving the community to provide sustainable access to safe drinking water to people in rural areas.	As a result of this Scheme, 18.6 million people now have access to safe drinking water.	1)https://jalshakti-ddws.gov.in/sites/default/files/Swajal_guidelines.pdf 2)https://www.unicef.org/india/what-we-do/clean-drinking-water
5	Swachh Bharat Mission (SBM)	Ministry of Jal Shakti	To ensure that open defecation-free behaviours are maintained, that no one is left behind, and that solid and liquid waste disposal facilities are available.	To date, 6,03,004 villages have been declared Open Defecation free (SBM-Grameen).	1)https://swachhbharatmission.gov.in/SBMCMS/about-us.htm 2)https://sbm.gov.in/sbmdashboard/ODF.aspx (Accessed on 07.07.2021)

Table 2: Central Govt Schemes/programs for Drinking water & WASH

3.2 States & Union Territories

The S&UTs are responsible for water supply related operations, irrigation, funding water resource projects, and cost recovery from these projects. The central government does offer financial aid to state governments for the purpose of conducting and implementing national-level initiatives and other federally aided programs. However, the state must maintain and grow its water supplies primarily through its own funds. Most states manage their water supplies based on physical/administrative boundaries rather than hydro-geological ones (Bhatt & Bhatt, 2017).

Since 1999, a new form of community management with government funding was developed. The Indian government started the process of incorporating community management into its national strategy by launching sector reform pilot projects (SRPP) in 67 districts across 26 states (Hutchings et al., 2017). The Panchayati Raj Institutions including the Gram Panchayats (GPs) and the village water and sanitation committees (VWSCs) mobilize community participation (Fig 3). District and state level organizations who have well-trained personnel, in turn guide and train the drinking water committee members of the PRIs.

The State Pollution Control Boards (SPCBs) monitor the drinking water quality from the supply sources on a regular basis. While the SPCBs of some states like Tamil Nadu, Maharashtra and Kerala perform better in testing and sharing data online, a few others are lagging. However overall, the coverage of water testing and data sharing, particularly on the microbial quality is not real-time across the country. Since the impact of poor drinking water quality immediately affects health, the routine testing and monitoring of drinking water to be a routine feature of all SPCBs daily.

3.3 Non-Government Organizations

Civil society organizations, trusts, academic and research institutions, private industries, and their Corporate Social Responsibility (CSR) arms are the third kind of players who are involved in the drinking water services (Fig 3). They contribute to either directly or indirectly providing products or services for drinking water. Large trusts like the TATA Water Mission works with the state and central governments and undertake advocacy, communication, installation of purifiers and promote innovative projects for safe drinking water (Tata Trusts, 2021).

Private enterprises or individuals can also finance and own a venture completely, that is fully responsible for all water related services. They charge a price that customers are willing to pay. Private businesses may streamline operations by establishing consistent ownership and control over activities, resulting in cost-effective services that can be maintained by revenue. Most are referred to as social entrepreneurs because they have a stated objective that is obviously beyond a profit motive. Naandi Community Water Services, Healthpoint Services, Sarvajal, Waterlife, and Spring Health are all notable examples (Bandyopadhyay, 2016).

In recent times, *Community managed systems* have been experimented in India, wherein the communities have been engaged especially in managing drinking water purification plants. Government/ NGOs provide capital support, the community invests a part of it and the technology partner assists with device setup and training the community-based enterprise group in operations and maintenance of the plant. The recurring costs are recovered as small customer charges. This model is used by NGOs, many of which are funded by *Corporate Social Responsibility* (CSR). As per

Section VII of the Company Act, the central government has mandated all companies to dedicate CSR funds for societal programs including clean water, sanitation, and hygiene initiatives (Bandyopadhyay, 2016).

Public-Private Partnership (PPP) is essential for outreach and sustaining technology interventions for safe drinking water at the ground level if governments are unable to deliver in a timely and quality manner. Given the government's financial constraints and the private sector's increased productivity, public-private partnership has emerged as one of the trending ways for the government to improve the infrastructure (H. Li et al., 2019). Almost every aspect of India's economy has changed because of economic reforms, privatization, and globalization. Multi-national as well as national corporates are bidding for taking charge of water supply services. Although this way of operation started in 1991 in sectors such as power, it has recently extended to include the water sector, amid severe protests from civil society organizations. The protests are valid considering that right to water is a basic human right, that cannot be denied if unable to pay. *Privatization of water* can mean the exchange of ownership from the government to a private sector, for profit companies (Bhattacharya & Banerjee, 2015). PPP which is sometimes viewed as a means of achieving sustainability goals, can be counter-productive if solely profit driven. The objectives of serving people and conserving the natural resources need to be stated explicitly in the agreements between the government and the private parties. Penalty for violation, and closure clauses are also important to be put in place. Unless the governments are on their toes with appropriate and robust monitoring and regulatory mechanisms, the PPP model can go horribly wrong over time. The PPP water supply model used by three Karnataka cities—Belgaum, Gulbarga, and Hubli-Dharwad—has prompted water delivery reforms in other Karnataka towns as well as Nagpur, Maharashtra. In the PPP project, the Karnataka Urban Water Supply Improvement Project (KUWASIP) was seen as an opportunity to explore and learn. Another company called Veolia has formed a joint venture with JUSCO (a Tata company subsidiary) and operates in Nagpur, Maharashtra (The World Bank, 2014). Other than the PPP model with large private players, there are innumerous enterprises who own licensed drinking water purification and packaging facilities that distribute drinking water through their own supply-chain systems. There are also small players who distribute water to the last mile customers through tankers.

4. Drinking Water Scenario in India

India accounts for approximately 16% of world population, 2.45% of the world's surface area and 4% of the world's water resources. The available surface water and replenishable groundwater is 1,869 cubic kilometers. Surface water comes from four major sources, namely rivers, lakes, ponds, and tanks. The country's total rain replenished groundwater resources are approximately 432 cubic kilometers. Groundwater is used extensively in the states of Punjab, Haryana, Rajasthan, and Tamil Nadu, through wells, boreholes, and hand pumps. However, some states, such as Chhattisgarh, Odisha, and Kerala, use more of surface water and only a small portion of their groundwater resources (Randall et al., 2008).

Severe water depletion and a lack of proper planning/implementation for water safety and security affect two-thirds of India's districts (UNICEF, 2021). According to WHO, 37.7 Mn Indians are getting infected by waterborne diseases each year, accounting for 70–80 % of the country's overall disease burden and 780,000 deaths due to polluted water (Bandyopadhyay, 2016). According to the National Family Health Survey 4 (NFHS 4, 2015-16), diarrhea was prevalent in 9.2 % of U5 children. NFHS 4 data further reports that 90% of Indian households have access to improved sources of drinking water, covering 91% of urban and 89% of rural households. In 18% of the households that do not receive water in their premises, the women, rather than men, fetch it from a distance. The recently published Phase 1 NFHS 5 data on 22 S&UTs indicates that 88% of households have an improved sanitation facility and 96% households have improved drinking water facility, which is better than before. However, the U5 children diarrheal prevalence at 5.6% indicates a high level of morbidity that in turn reflect contamination of drinking water at source and/or supply and/or at the point of use.

Testing of drinking water for fecal contamination, is monitored at the water source as well as other sites. However, real-time, daily data on fecal coliform counts in drinking water is not available in India (JJM, 2021).

The status of microbial quality of drinking water and diarrhea prevalence across S&UTs in India is presented in Figs 4 & 5. Since real-life temporal data/dashboard is not available for fecal coliform contamination in drinking water, the data available has been represented in the maps to highlight the kind and level of issues in each S&UTs.

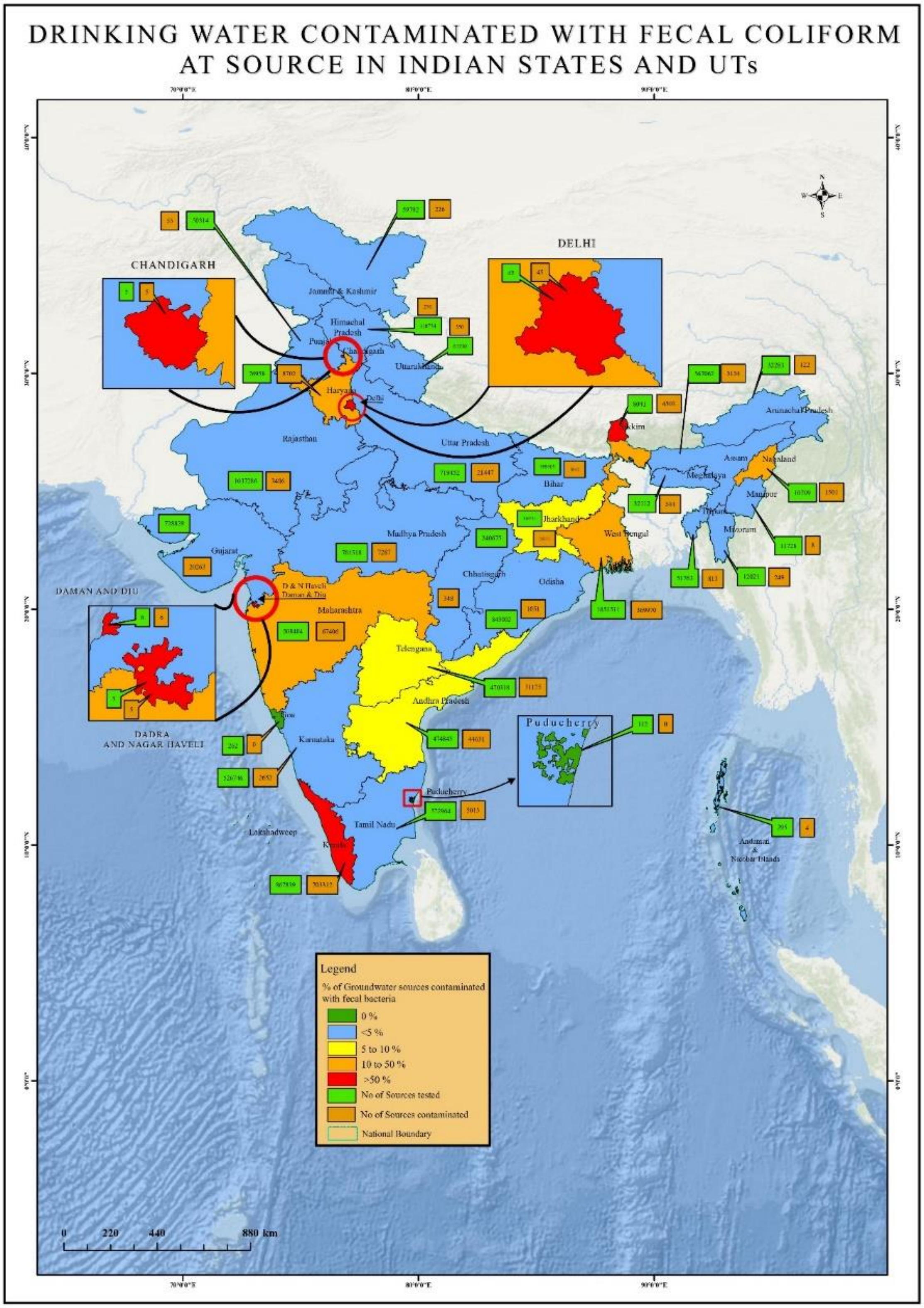


Fig 4: Fecal contamination in drinking water sources in Indian S&UTs

Data Source:1) JJM, 2021; 2) NWMP, 2019

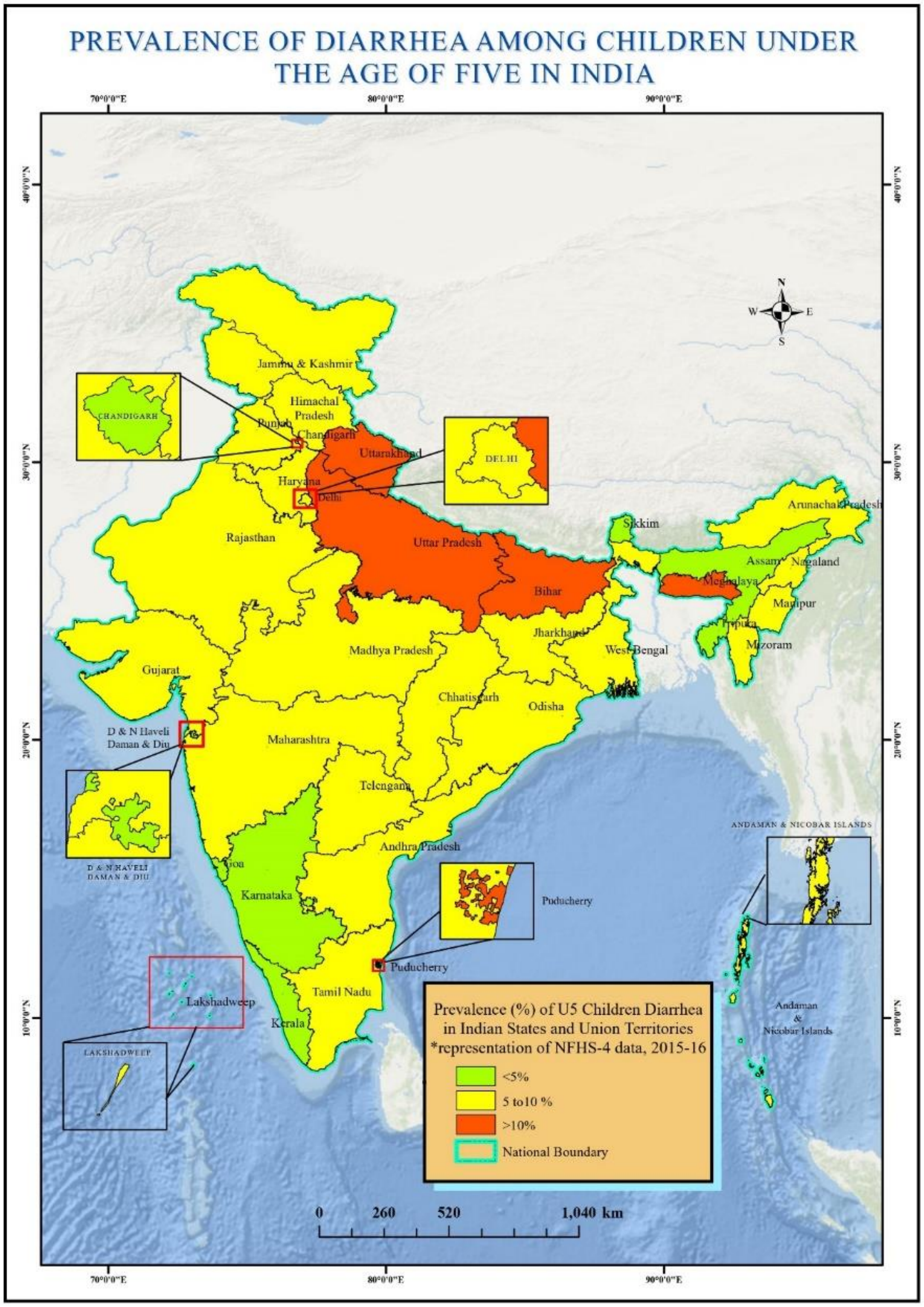


Fig 5: Prevalence of diarrhea among U5 children in S&UTs in India

Data Source: NFHS-4, 2015b

Of the Indian S&UTs, >50% of the ground water sources that supplied drinking water in Kerala, Delhi, Chandigarh, Sikkim, Dadra & Haveli, Daman & Diu were contaminated with fecal coliforms (>1/100 ml; Fig 4). Kerala for example, had almost 80% of the tested samples contaminated. In most other states, <5% of the ground water sources tested were contaminated. Only Goa and Puducherry had all tested sources of ground water free of fecal contamination. It is, however, striking to note the positive deviance that even though Kerala and Sikkim had poor drinking water quality in the samples tested, the U5 children diarrheal prevalence in both states was well controlled (<5%; Fig 5). This compels one to further explore the drinking water purification techniques/practices in these two states. On the other hand, S&UTs like UP, Bihar, Meghalaya, and Puducherry had high prevalence of U5 diarrhea (>10%) despite having reasonable drinking water quality (Figs 4 & 5). In fact, Puducherry had no contamination at the source of drinking water, and still had high (>10%) U5 diarrhea prevalence. This needs to be again explored further.

Do Indian households treat their water before drinking?

Majority (62%) of the Indian households do not treat their water before drinking (Fig 6). Treatment is less common in rural households (29%) as compared to urban (47%). Some households practice simple water treatment procedures like cloth filtration (14%), boiling (10 %) and other methods (13%) including alum, bleach/chlorine, electric purifier, and filters (ceramic/sand etc.) (NFHS-4, 2015a)

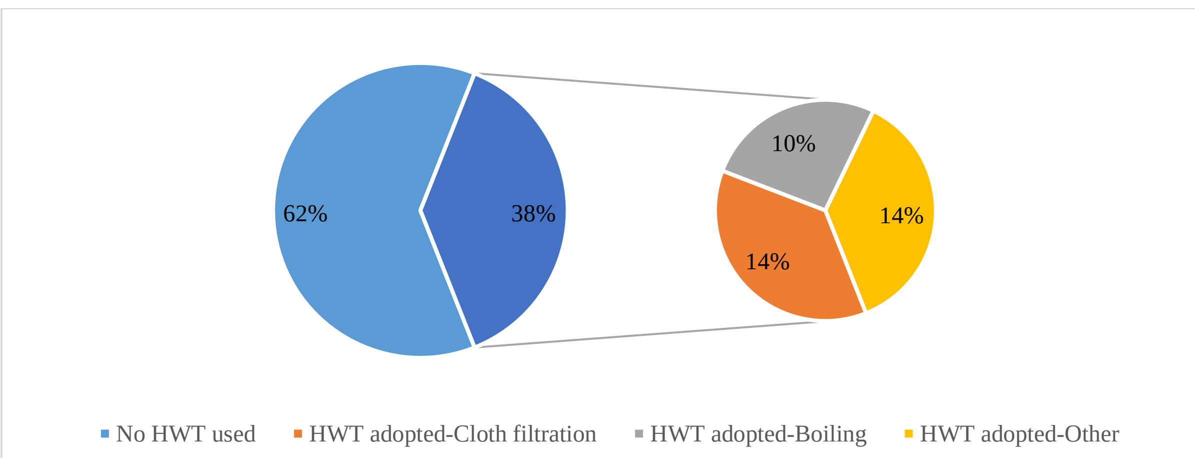


Fig 6: Household water treatment practices in Indian households

Data Source: NFHS-4, 2015a

5. Drinking Water Purification Methods

Drinking water treatment technologies focus on removal of physical (e.g., turbidity, suspended particles etc.), chemical (e.g., arsenic, iron, fluoride etc.), and biological (bacteria, virus, protozoans, helminths etc.) contaminants. The focus in this section is mainly on the commonly methods/technologies used in India for the removal and/or killing of microbial pathogens from drinking water, and their appropriateness for the vulnerable population. The reasons for this focus are that unlike physical or chemical contaminants, microbial pathogens in drinking water multiply and spread rapidly, killing 6000 U5 children every day globally through diarrheal diseases. Cholera for e.g., can take away a child's life in a few hours if not treated immediately. Simple technology and other interventions that provide microbially safe drinking water can thus have a huge public health impact (UNICEF, 2010).

Diarrhea and drinking water contamination with pathogens burden the socio-economically vulnerable populations more than those well-off, and therefore any water treatment/intervention promoted should be simple, easy to use, intuitive, and affordable. While being effective, they should be safe and sustainable. Dependence on external resources should be minimal, instead local resources should be used as far as possible. It is extremely difficult to identify technologies that meet all the required criteria and therefore one or more appropriate technologies are being integrated. However, academic, and industrial organizations are constantly innovating to simplify existing technologies and in making them appropriate for the target population (DDWS, 2013).

Treatment technologies can be classified based on the methods used as Physical, Chemical, and Integrated (Fig 7).

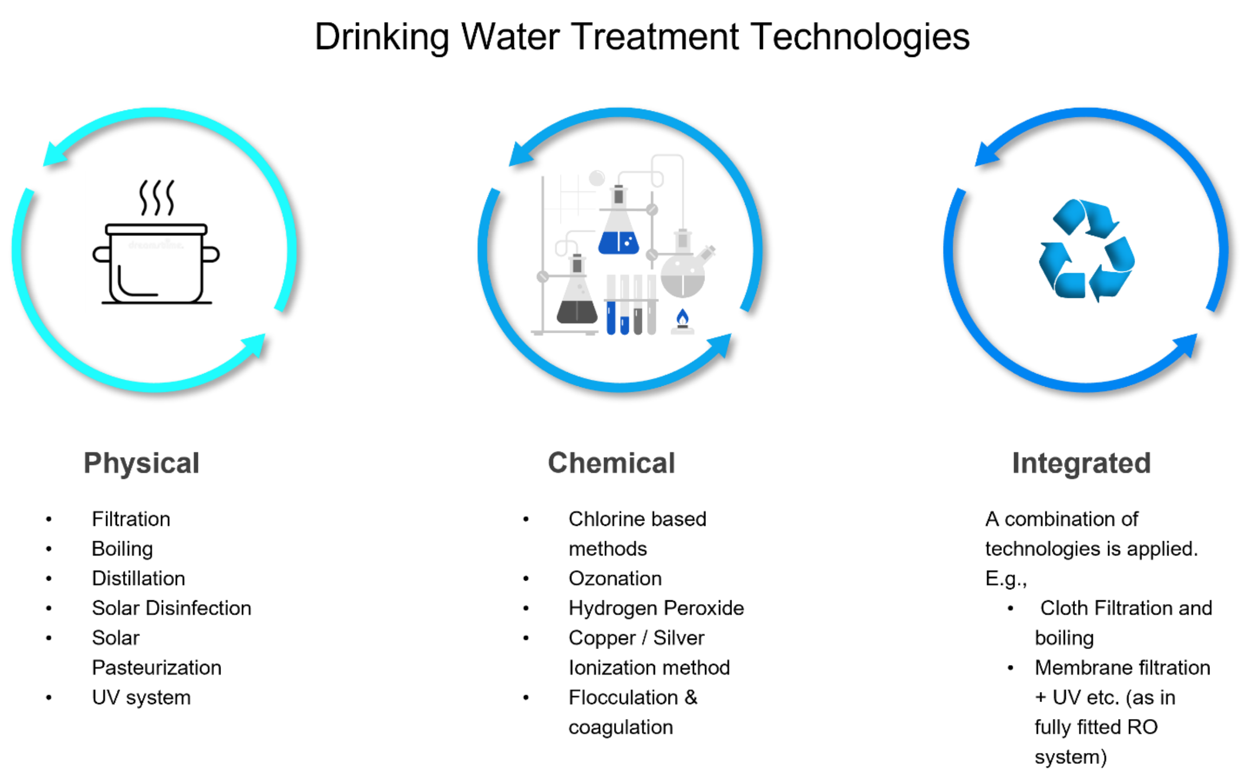


Fig 7: Drinking Water Treatment Technologies

5.1 Physical Methods

Physical methods use heat to kill or materials to filter the microbial contaminants from drinking water.

5.1.1 Boiling

Boiling has been one of the most common and oldest methods of disinfecting household water for drinking and cooking purposes. Most water-borne pathogens are killed by bringing the water to a roll boil for at least 1 min, even though most are killed at lower temperatures (e.g., 70 °C) (Trösch, 2009). Thus, boiling is a simple and effective treatment method, especially as a household method (DDWS, 2013). However, the time and cost of heating, taste changes, recontamination due to bad handling, and scaling up are some of the limitations.

Distillation Systems

The most common separation technique is distillation. The mixed components in water are separated using heat (Sharma & Bhattacharya, 2017)), which is a method of heating water to the point of boiling and then collecting the water vapor as it condenses, leaving behind several pollutants. This method is extremely effective against pathogens like protozoa, bacteria, and viruses, as well as the most common chemical pollutants like arsenic, barium, lead, nitrate, and a wide range of organic chemicals (CDC, 2009). However, the cost of heating and the loss of minerals are the main limitations, particularly when scaling up.

Solar Disinfection

Most pathogens are destroyed by ultraviolet (UV) radiation from the sun and increasing the temperature of the water increases the effectiveness of the radiation (Trösch, 2009). Solar energy is the most abundant renewable energy source on earth, and it also happens to be the most abundant in areas that require clean water. i.e., the developing countries. The method, which is based on radiation intensity, temperature, water muddiness, and water height, is simple and inexpensive. It involves exposing water in clear plastic bottles (usually synthetic resin terephthalate, PET) to the sun for at least six hours (Fig 8). (Pichel et al., 2019) There are no recurring expenses. SODIS and Solvatten are two well-established products using solar disinfection. They reduce fecal contaminant load and prevent diarrhea among children (Solvatten, 2021). The limitations of SODIS are the small volumes of purification, incomplete disinfection on cloudy days, recontamination and leaching from the PET bottles. Supply of spare parts and the product itself is an issue with Solvatten.

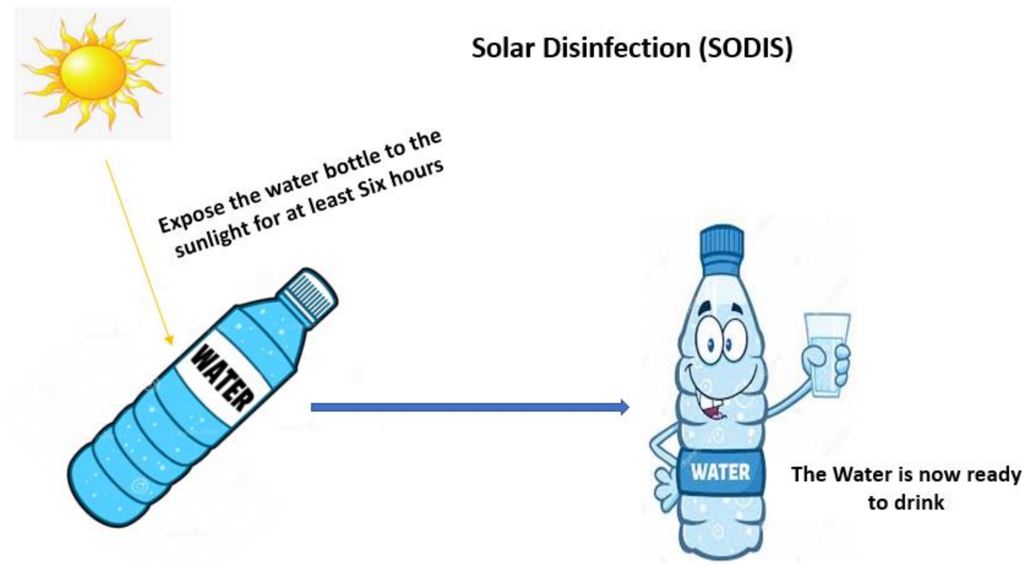


Fig 8: Solar Disinfection Method

5.1.2 UV sterilization

A UV disinfection system for water treatment typically consists of one or more UV lamps and a pipe or duct through which the water is exposed to radiation. UV light can pass through the cell walls of microorganisms and be absorbed by proteins and nucleotides, interrupting the structure of the microorganism's DNA or RNA and helping in its inactivation (Li et al., 2017). The use of UV disinfection to treat water is very successful and is a part of many communities use and household water purifiers. UV disinfection is a chemical-free procedure that produces no byproducts and has little effect on the mineral content and organoleptic character of water. It is amenable to be standardized and scaling up, making it a viable industrial option for large scale water disinfection process (Li et al., 2019). However, there is an initial investment on the product and maintenance cost of replacement of the lamp. Most important limitation is the need for electricity, which may not be available in certain areas.

Solar Pasteurization

Solar Pasteurization Systems are one of the new technologies that can be used to prevent or reduce drinking water pollution (Rossi et al., 2019). It works by using solar energy to heat water to a sufficiently high temperature for a set period, inactivating or destroying pathogenic microorganisms. This method is well known in developing countries where electricity or firewood are not available. It can be implemented using simple devices such as water containers placed in a dark box and covered with a transparent material (Pichel et al., 2019).

5.1.3 Filtration

Suspended particles, dissolved gases and certain liquids in drinking water are removed by adsorption and filtration through materials with varying pore size. Low-cost filtering materials include cloth, sand and gravel, vegetable husk, ion exchange resins etc. There are sophisticated synthetic nano and ultra-filtration membranes, with varying pore size to exclude particulate matter including microbes.

Cloth Filters

The seminal work by Dr. Rita Colwell demonstrated that even a simple, traditional filtering method using old saree cloth removes *Vibrio cholerae* and can reduce the incidence of cholera among U5 children in Bangladesh (Colwell et al., 2003). Cloth filters however do not remove bacteria/protozoans/viruses and can cause fouling if not cleaned properly.

Sand Filters

Slow sand filters are a modest, easy-to-operate method that allows water to pass through a sand medium (Hoslett et al., 2018). Slow sand filtration is one of the oldest water treatment processes used to provide microbiologically safe water in rural areas. It utilizes the purifying action of a superficial biological film called hypogeal layer or *Schmutzdeke* that forms on the filter medium, which excludes over 99% of the organisms. The output is microbially safe provided it is periodically (1-3 months) cleaned and maintained by scraping and replacing with fresh sand (Collivignarelli et al., 2018). It does not remove turbidity or color of water.

Rapid sand filters on the other hand uses coarser sand so that the flow rate is faster (~3000LPH). The method is effective for removing suspended solids after the water has been cleared with coagulation/flocculation (Trösch, 2009). The only filtration that occurs because of sand particles preventing large suspended colloidal particles from passing through the intra-granular space, as well as some physicochemical interactions between the sand and the contaminants (Ramsundram & Khanam, 2019). Construction is complicated and maintenance requires skilled manpower. The efficiency in removal of microbes is moderate when compared to slow sand filters.

Ceramic Filters

Due to economic and ecological issues, exploration of ceramic filters are gaining popularity, using clay materials. Recent works by several authors report the use of clay materials within the manufacture of water filters (Akowanou et al., 2019). A ceramic filter may be obtained by the blending of dry clay with organic material (such as used coffee powder, tea leaves, husk or rice shells) with the addition of water to get a rigid mixture. The ceramic filters are extensively tested for effectiveness in reducing varied waterborne microbial contaminants and found to be good (Collivignarelli et al., 2018). Moreover, the ceramic filters are also a good way to recycle agricultural waste.

Diatomaceous Earth Filters

Diatomaceous Earth (DE) is the skeletal remains of diatoms or aquatic, single celled microscopic organisms. After the diatoms die, the porous exoskeletons that are made of silica remain as sediments, which are collected and processed. DE being low density, high porosity and relatively inert, make for a good filter material. The interior pore size can be as small as 0.1 μm and comfortably removes water borne pathogens including protozoans and bacteria. The low-cost DE candles are installed in conventional household filters and, also in food and beverage industries to purify water. It however requires periodic replacement.

Membrane Filters

Membranes are made of various materials, which give rise to specific filtering characteristics (e.g., pore size, surface charge, and hydrophobicity) that determine the type of contaminant that can be excluded. Ultrafiltration (UF), nanofiltration (NF), microfiltration (MF), and reverse osmosis are the four types of membrane filtration (RO) (Rodriguez-Narvaez et al., 2017) Membranes made from synthetic materials including cellulose acetate, polyamide, polypropylene, polytetrafluoroethylene (Teflon) etc. are customized per the requirement by the manufacturers. Hydrostatic pressure is used in membrane processes to remove suspended solids and high molecular weight solutes while allowing water and low molecular weight solutes to pass through.

The performance of the membrane filters varies depending on the membrane form and the type of contaminant (WHO, 2017). Microfiltration is a sub-micron extension of traditional filtration. Microfiltration can sieve out particles larger than 0.05 mm in diameter, and is effective in removing protozoans, moderately effective in removing a few bacteria but do not remove viruses. To tackle the new emerging water contaminants that are smaller (in the range of 0.001-0.05 μm), ultrafilters were developed. These are effective in removing the protozoans, and bacteria and moderately effective in removing the viruses. Nanofiltration membranes that combine the properties of reverse osmosis and ultrafiltration membranes, with pore sizes ranging from 0.008 to 0.01 μm, remove particles based on size, weight, and charge. They are highly effective in removing bacterial, viral, and protozoal contamination (CDC, 2009). Micro/ultra/ nano-filters are used online in sophisticated reverse osmosis (RO) plants. The smaller the pore size, more the effectiveness in removal of pathogenic bacteria, protozoans, and viruses (Fig 9). There are several commercially available purifiers with appropriate membrane filters fitted to suit the households as well as communities. The disadvantages of these filters are mainly the costs of initial investment, replacement and maintenance, and the environmental damage during water purification and replacement of parts.

Reverse osmosis (RO) is a water purification method that has been one of the widely used technologies in the world in recent times. In regular osmosis, water moves from its higher concentration to a lower concentration, thereby diluting a concentrated solution. In RO on the other hand, the impure water is pushed through a semi-permeable membrane under pressure and the pure water comes out. It typically eliminates salts, heavy metals (like Arsenic), organic contaminants, dyes, pesticides, and microbes from household water(Sharma & Bhattacharya, 2017).The biggest disadvantages of RO systems are that they are environmentally damaging, wasting 4x of water to obtain 1x of pure water and the prohibitive investment and maintenance costs for a rural community (WWD, 2012). Besides water from RO systems is devoid of minerals which can further lead to poor bone health and other deficiencies due to prolonged use (Verma & Kushwaha, 2014). Disposal of the brine effluent with toxic contaminants from the RO system is a matter to be tackled. The other disadvantages are that RO requires online electricity, and the process strips the water of all minerals.

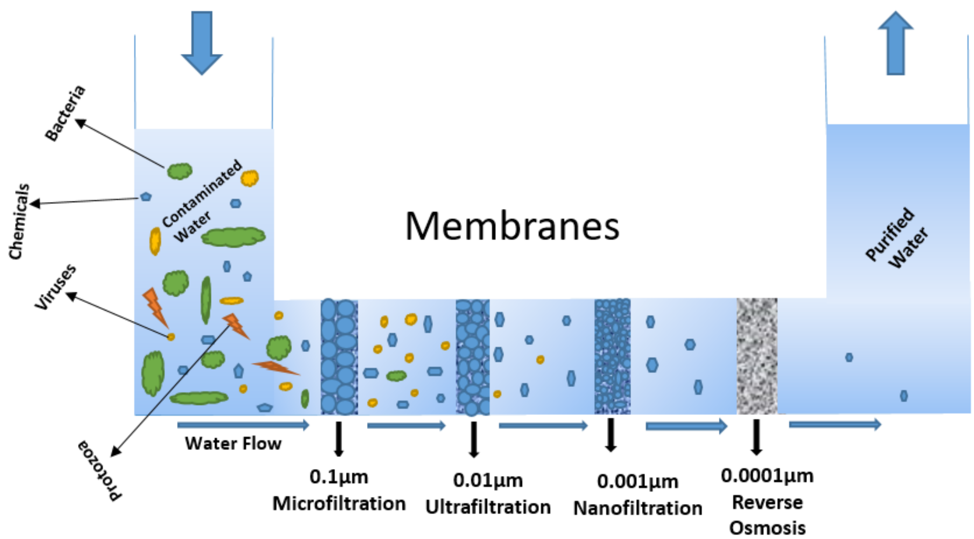


Fig 9: Membrane filters and representative water contaminants removed

Vegetated Strips filtration

The filter strips are intended to be land areas of either planted or indigenous vegetation located between a potential pollutant-source area and a surface-water body that receives runoff. Vegetated filter strips (also known as grassed filter strips, filter strips, and grassed filters) are vegetated surfaces that are used to treat sheet flow from adjacent surfaces (Sharma & Bhattacharya, 2017). Patches of the vetiver grass (*Vetiveria zizinoides*) planted is a cost-effective way of purifying water in water stressed, polluted areas.

Table 3 summarizes the advantages and disadvantages of the physical methods of disinfection/removal of pathogens from drinking water.

Physical Methods	Advantages	Disadvantages
Boiling	• Highly effective against most of the pathogens (CDC, 2009). • Technically easy to use (DDWS, 2013). • Good household method	• The cost of fuel, time required to boil and cool, recontamination possibility, and scalability (Trösch, 2009
Distillation	• Highly effective in killing microbes (CDC, 2009).	• Cost of heating and Scalability (Trösch, 2009) • Recontamination
Solar Pasteurization	• Simple and cheapest method & easily available (Pichel et al., 2019)	• Time consuming process (Ramsundram & Khanam, 2019)
Cloth Filters	• Physical removal of particulate matter and associated microbes • Cloth filter- Simple, cost effective, household level removal of some pathogens when associated with planktons (Colwell et al., 2003)	• Low effective for most microbes • Cloth filters can foul and contaminate if not cleaned properly
Ceramic Filters	• Highly effective against pathogens (Trösch, 2009) • Low cost, simple maintenance	• Replacement of cartridge required Fabrication skills are required (DDWS, 2013)
Slow sand filtration	• Simple, low-cost & effective in removing microbes from water (Ramsundram & Khanam, 2019)	• Some households do not use this technology effectively, resulting in contaminated water (Trösch, 2009) • It requires proper operation and maintenance
Rapid sand filtration	• Cost effective and easily available (DDWS, 2013)	• Less effective compared to slow sand filters against microbes • Requires frequent backwashing (Ramsundram & Khanam, 2019)
Solar Disinfection	• Technically simple and low cost (Zhang et al., 2018) • Recognized as appropriate water disinfection method by WHO (Pichel et al., 2019)	• Time consumption (needs 6h), dependent on climatic conditions, scaling up, recontamination (DDWS, 2013) • Plastic (PET) bottles disintegrate and leach chemicals over time
UV sterilization	• It effectively kills bacteria and viruses and has a short contact time (Sorlini et al., 2015) • No harmful byproducts are produced, and there is no reliance on chemical access (Pichel et al., 2019)	• Need for consistent supply of electricity • Dependent on external resources- replaceable parts (lamp) cost and maintenance (WHO, 2017). • Lamps contain mercury, which is toxic (Pichel et al., 2019)
Membrane filtration	• RO: high water quality output • Very effective against microbes (Pichel et al., 2019)	• Filters must be cleaned regularly • RO: high energy consumption, high costs, demineralizes water, technical expertise required, and the chemicals used for membrane cleaning (Pichel et al., 2019)
Vegetated strips filtration	• Capture nutrients through plant uptake as well as soil particle adsorption (Sharma & Bhattacharya, 2017)	• Design is important, and proper vegetation is required (Sharma & Bhattacharya, 2017)

Table 3: Advantages and disadvantages of physical methods of treating drinking water

5.2 Chemical Methods

Chemicals are used to kill or coagulate and flocculate the microbial and other contaminants from drinking water.

Chlorine based methods

Chlorination is the most common process for disinfecting drinking water. It includes adding chlorine or chlorine byproducts (sodium hypochlorite or calcium hypochlorite) to water, where the chlorine reacts to create hypochlorous acid (HClO) and hypochlorite ion (ClO^-), both products that can destroy pathogenic microorganisms (Pichel et al., 2019).

Another bactericidal agent with a disinfectant strength equal to or greater than chlorine is chlorine dioxide. Chlorine dioxide has a high oxidizing strength, which explains why it has such a high germicidal potential. Disinfection mechanism involves the inactivation of enzymatic systems or disruption of protein synthesis due to the high oxidative strength (Collivignarelli et al., 2018).

Chloramines are another type of chlorine-based product that is formed when ammonia containing water is chlorinated or when ammonia is added to chlorine containing water. They are powerful and fast acting microbicides. Typically, 99 % of the Chloramine forming reactions get completed within a few minutes. The chemicals used to produce chloramine from ammonia and chlorine gas vary according to the ammonia-based chemical used (Sorlini et al., 2015).

The dosing of chlorine-based products is critical for effective and safe usage. Exposure to residual chlorine is known to cause adverse effects including cancer and skin ailments (Harjan, 2019).

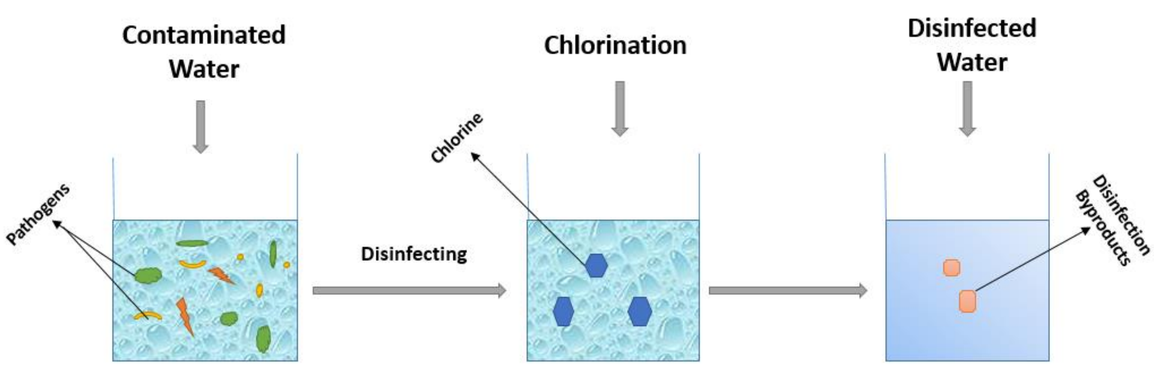


Fig 10: Chlorination Technique

Hydrogen Peroxide

Hydrogen peroxide (H_2O_2) is a powerful oxidizer that is used to control biological growth in water. The potency of H_2O_2 is greatly influenced by temperature, peroxide concentration, and response time. Combining H_2O_2 with ozone or UV light has become a practice to circumvent its limitations in recent times. Usage of these new technologies is increasing worldwide for groundwater treatment, potable drinking water, and industrial water treatment (DDWS, 2013).

Copper and Silver based methods

Copper and silver have well established antimicrobial properties and have been used as drinking water storage vessels in ancient civilizations. It is a traditional practice in India to store drinking water in copper or silver pots. Simple, passive storage of drinking water in copper pots has been shown to kill water-borne diarrheagenic pathogens, including *Vibrio cholerae, E. coli, Salmonella typhi, Shigella flexneri* and Rotavirus (Preethi et al., 2009, Preethi et al., 2011, Preethi et al., 2012). A low-cost (USD 3) copper based, point-of-use device was found to be effective in disinfecting household drinking water (Grand Challenges Canada, 2014). Further, a copper-based product called TamRas was manufactured that was found to be safe and effective in disinfecting pathogens at the community level (Gill, 2017). TamRas is simple to use, affordable product (USD 20), requiring no recurring expenses, and lasts a lifetime. Since the copper treated water does not get re-contaminated, it is ideal for use in poor rural or urban slum households.

Technologies applying the copper – silver ionization principle have evolved significantly over the years, in the drinking water purification sector. In this technique, electrically charged copper particles in the water neutralize particles of inverse polarities, like microorganisms and fungi. Copper particles infiltrate the cell walls and make a passageway for silver particles, which enter the core of the microorganisms and make them inert (DDWS, 2013).

Coagulation and Flocculation

Dissolved solids and suspended particles in water that do not settle naturally are aided in sedimentation by coagulants and flocculants. Aluminum sulfate (Alum) is one of the best-known coagulants used in drinking water treatment. Ferric sulfate and Sodium aluminate are also regularly used coagulants. The coagulants when added to water and mixed, neutralize the negatively charged dissolved and small sized particles, like microbes, and make them stick together or floc. Flocculation is followed by decantation and filtration (WHO, 2007). Certain herbal ingredients are also known to be used traditionally. E.g., the seeds of *Strychnos potatorum* (nirmali) and *Moringa oleifera* (drumstick) (Ghebremichael, 2007).

Coagulation/Flocculation is used as a pre-treatment on a large scale. Even though this process does not kill pathogens, it helps remove turbidity and reduce the pathogen load. The safe disposal of the sludge that is formed is an issue to be tackled. Commercialization of herbal coagulants are yet to be explored due to issues of storability of the water for > 24 h and changes in the taste and odor.

Chemical Methods	Advantages	Disadvantages
Chlorine	• Because chloride remains in water as residual chlorine after dosing, its disinfectant activity is maintained throughout the distribution and storage systems (Pichel et al., 2019) • Low cost (DDWS, 2013)	• Produce disinfectant by-products • Taste and odor issues (Pichel et al., 2019)
Chlorine dioxide	• Effective at killing almost all microbial pathogens and can be used as a pre-oxidant as well as a disinfectant(Sorlini et al., 2015)	• It is a dangerous substance that is lethal at concentrations as low as 0.1 percent by volume of air(Sorlini et al., 2015). • High cost (DDWS, 2013).
Chloramines	• Effective against bacteria (Sorlini et al., 2015)	• less effective than free chlorine against viruses and protozoa. • They may be harmful to humans and impart an unpleasant taste and odour to water (Sorlini et al., 2015).
Hydrogen peroxide	• Highly oxidative and biocidal efficiency(Sharma & Bhattacharya, 2017)	• Causes health issues like eye irritation and skin exposure cause blisters and burns (Sharma & Bhattacharya, 2017).
Copper Metal	• Effective (> 2 log removal) against bacteria and rotavirus (Preethi et al., 2009, Preethi et al., 2011, Preethi et al., 2012)	• Restricted use as point-of-use intervention and not as a large scale, community level solution • The copper metal part should be cleaned regularly, like a kitchen utensil
Copper – silver Ionization	• Easily available and technically easy to use • Low cost (DDWS, 2013)	• Less effective against microbes (DDWS, 2013).
Coagulation & Flocculation	• Good as a pre-treatment	• Less effective against microbes

Table 4: Advantages and disadvantages of chemical methods used to treat drinking water

5.3 Integrated Technology

Current trend in commercial drinking water purification technologies is to use integrated methods that combine the best of physical/chemical/biological techniques. A community level modern RO plant for example uses coagulant, chlorine-based product, UV lamps as well as membrane technologies. Several of the newer commercial RO units even dose back the lost minerals. Research is ongoing to reduce the water consumption making them less environmentally damaging. Since the demands from the governments are to make the technologies sustainable, the industrial players and academicians alike are investing substantially in innovative technologies for the target population.

For a poor, rural household for instance, which is not plagued by chemical pollutants in the drinking water source, filtration through a clean cloth to remove large, suspended particles, followed by boiling to kill the microbial pathogens and safe water handling practice at the point-of-use (PoU) to avoid recontamination can provide adequately safe drinking water. Similarly, cloth filter combined with copper-based products, like TamRas is a sustainable PoU practice for microbially safe drinking water.

6. Sustainability of Technological and Other Interventions

Despite several technological and other interventions, providing access to safe drinking water to all in India and preventing U5 children continue to be huge challenges for India. Shortfall in appropriateness of the interventions to the end user/target population is one of the main reasons for the failure to create the desired health outcome. For any technology to be sustainable, it must be appropriate not only to the target population but also to the environment in the long run.

6.1 Appropriateness of Technology Interventions

Technologies have contributed immensely to alleviation of human suffering and drudgery; they have become a part and parcel of our lives. This dependency will only increase in the coming decades. The appropriateness of some of the drinking water disinfection technologies/methods for the vulnerable/ target population (Section #2) has been assessed (Table 5).

The appropriateness of technologies was assessed on a 0-5 scale to capture their effectiveness, safety, risk of recontamination, investment costs, maintenance costs, scalability, and sustainability (social, economic, and environmental). E.g., technologies like the integrated RO system will gain a high score (4/5) for efficacy but score low on socio-economic-environmental viability for the target population and therefore unlikely to sustain. RO systems also operate on electricity, require heavy investments and maintenance, and a lot of fresh water to generate clean water (Esmaeilion, 2020).

Type of Purification Method	Household/ Community Level	Appropriateness Score*								Total Score	Remarks
		Removal/ Disinfection[1]	Safety[2]	Recontamination	Organoleptic qualities	Investment	Maintenance/ Recurring cost	Scalability	Environmental Sustainability[3]		
Physical											
Cloth Filter	Household	1	3	1	4	5	4	2	4	24	Removes microbes only when associated with planktons. Cloth can foul if not cleaned properly
Gravity Filters** (ceramic, diatomaceous earth, vegetable matter etc)	Household	3	4	3	5	4	2	4	3	28**	Gravity filters; Can be made from locally available plant waste; Local enterprise potential; Disposal of used filters is an issue

Type of Purification Method	Household/ Community Level	Appropriateness Score*								Total Score	Remarks
		Removal/ Disinfection[1]	Safety[2]	Recontamination	Organoleptic qualities	Investment	Maintenance/ Recurring cost	Scalability	Environmental Sustainability[3]		
Sand Filters**	Household/ Community	4	4	2	4	4	2	4	3	27**	Regular backwash and replacement of sand is required. Slow Sand Filters are better suited for rural environments as they are low-cost and easy maintenance, when compared to Rapid Sand Filters
Micro/ Ultra/ Nano filters	Household/ Community	4	4	3	3	2	2	4	2	24	Requires electricity; synthetic materials, technologies-external dependence; recurring expenses

Type of Purification Method	Household/ Community Level	Appropriateness Score*								Total Score	Remarks
		Removal/ Disinfection[1]	Safety[2]	Recontamination	Organoleptic qualities	Investment	Maintenance/ Recurring cost	Scalability	Environmental Sustainability[3]		
Reverse Osmosis	Household/ Community	4	3	3	2	1	1	4	1	19	RO systems are not suitable for the target population-demineralizes water, heavy investment and maintenance costs, technical expertise to operate, effluent sludge is toxic and wastage of precious water
Boiling	Household	4	5	1	4	3	2	1	3	23	Fuel cost
Distillation	Community	3	4	1	4	3	4	3	3	25	Fuel cost
Solar Dis-infection**	Household	3	5	1	4	4	3	3	3	26**	Vagaries of sunshine; Plastic bottles leaching

Type of Purification Method	Household/ Community Level	Appropriateness Score*								Total Score	Remarks
		Removal/ Disinfection[1]	Safety[2]	Recontamination	Organoleptic qualities	Investment	Maintenance/ Recurring cost	Scalability	Environmental Sustainability[3]		
UV Steriliza-tion	House/ Community	4	2	2	4	2	2	4	2	22	Lamp disposal and replacement are issues
Solar Pasteuriza-tion	Community	3	5	1	4	3	1	3	4	24	Dependent on electricity supply
Chemical											
Chlorine based methods**	Household/ Community	4	3	2	2	4	4	4	2	25**	Has been in effective use for centuries in public water distribution systems. Requires efficient management. Residual Chlorine- Changes to organoleptic qualities, toxicity; requires training

Type of Purification Method	Household/ Community Level	Appropriateness Score*								Total Score	Remarks
		Removal/ Disinfection[1]	Safety[2]	Recontamination	Organoleptic qualities	Investment	Maintenance/ Recurring cost	Scalability	Environmental Sustainability[3]		
Hydrogen Peroxide	Household/ Community	4	1	2	2	4	4	4	2	23	Powerful oxidant, toxicity; requires training
Copper Metal**	Household	3	4	4	3	3	3	4	3	27**	Recontaminati-on prevented; copper part has to be cleaned regularly
Copper/ Silver ionization	Community	3	4	3	3	2	2	3	3	23	Need for consistent electricity supply

*Appropriateness of the purification (disinfection/removal of pathogens) method for rural/urban poor households/communities; 0-worst and 5-best

[1]Effective: >2 log reduction in E. coli/WHO Drinking Water Purification Methods/Research publications on efficacy/effectiveness
[2]per WHO Drinking Water guidelines (2011)/Research publications
[3]Environmental Sustainability-including physical/ chemical/biological pollution; non-recyclable/biodegradable parts/waste
**are appropriate technologies that have the potential to be used individually or in combination

Table 5: Appropriateness of Technological Interventions for Providing Safe Drinking Water

There is no universal technological solution to provide safe water, due to variations in the quality and quantity of water resources in India. Technology that works under certain conditions may fail in other environments or users. The topographies vary from dry, arid areas to mountainous rocky terrains and coastal zones. Therefore, the local contexts must be understood, and appropriate interventions provided. Table 5 presents the appropriateness of commonly used technological interventions in India. The evaluation has taken into consideration, the socio-economic-environmental contexts of the target population, over and above safety and efficacy.

The Government of India has recommended some of the technologies that can be found on the Ministry of Jal Shakti website (Department of Drinking Water & Sanitation, 2021).

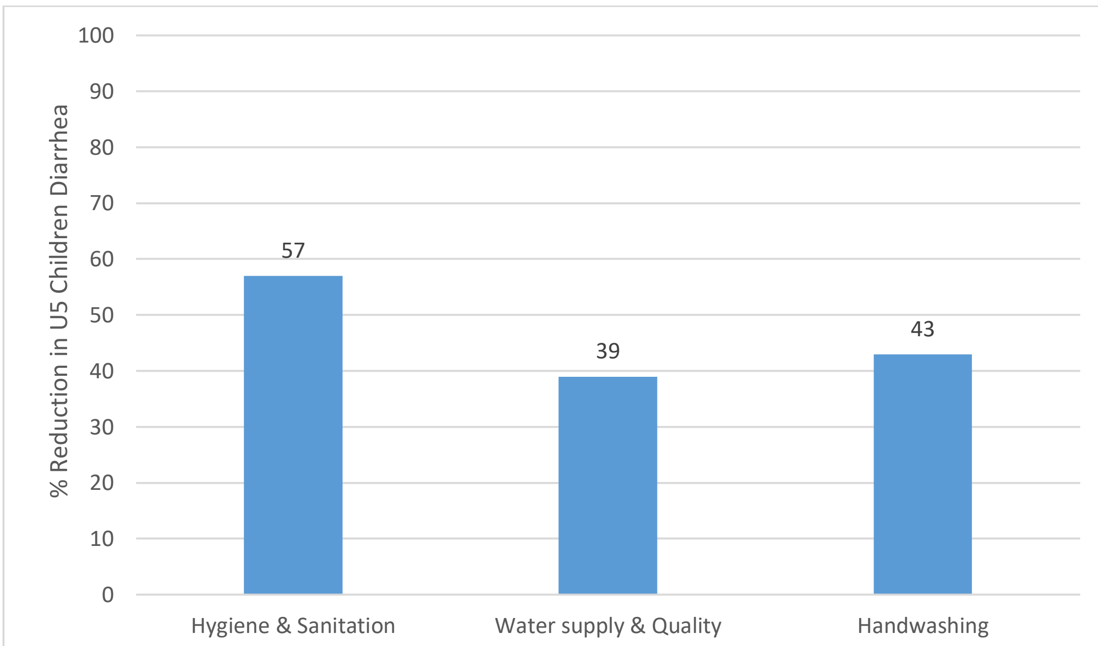


Fig 11: Impact of improving WASH on reduction in U5 children diarrhea

7. Discussion

There are no easy solutions to providing access to clean drinking water to all in India and achieving related health benefits like reduction in diarrhea among U5 year old children. Especially when the target population is already vulnerable facing socio-economic-environmental challenges. A whole-of-society approach involving changes in the KAP of governments, industries as well as the public would be required. Investments in behavior change strategies can sustainably benefit the health and economic outcomes for India (Townsend & Curtis, 2017). Technologies to purify drinking water can provide quick-fix relief of the curative kind. Even these need to be tested for the appropriateness for the target population and the environment. A sustainable solution for clean drinking water would require a clean environment (including WASH), and equitable and mindful water usage. Fresh water availability is finite on earth and must be conserved.

7.1 Governance

The nature of drinking water quality and related health issues in the Indian States and Union Territories vary and therefore require a customized approach (Menon et al., 2017). Three states Uttar Pradesh (UP), Bihar and Madhya Pradesh in India contribute the most with a total of 34000 deaths and USD 192 Mn as OOPS (Nandi et al., 2016).

Drinking water comes under the state governments, the Corporations (urban) and the Panchayat Raj Institutions (PRIs) which are the local bodies (rural). It is the function of the PRIs to plan, operate and monitor all safe drinking water related activities, including implementing the Central and State Government schemes in the villages. Such as increasing piped water supply to all households by 2030 (Har Ghar Jal) and ensuring the safety of drinking water. It is also the function of the Corporations and the PRIs to have a two-way dialogue between the citizens and the governments. There is no doubt that wonderful, decentralized schemes have been put in place in India for water management at the local level. However, a study points out that there is devolution of functions to the local bodies without the devolution of funds. There is also a definite lack of technical and management personnel and capabilities among the functionaries (Sewak et al, 2017). For better efficiency, a sustained ecosystem that nurtures (i) Institutions and capabilities (ii) Technical facilitation (iii) Financial support and (iv) Awareness (IEC) and training of both the functionaries and the community, would be required (Fig 12).

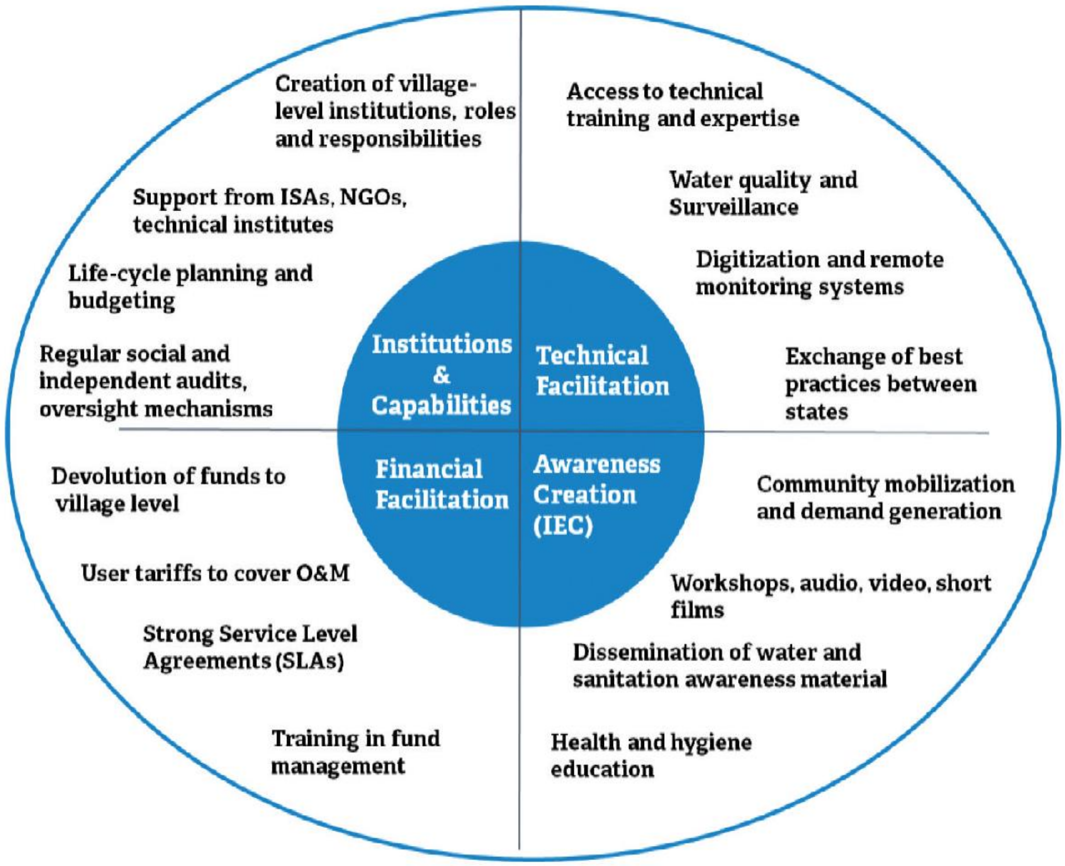


Fig 12: Ecosystem of support necessary for decentralized drinking water management

(Figure Credit: Choudhury, 2017)

7.2 Design Thinking

The concepts of design thinking and human centric design have been in practice for several decades by players in the industrial sector as strategies to tackle competition (Fig 13). Companies vie with each other and invest hugely into innovations in products and services to provide users with unique experiences.

> **"What is design thinking? It means stepping back from the issue and taking a broader look. It requires system thinking; realizing that any problem is part of a larger whole, and the solution is likely to require understanding the entire system" - Don Norman, American Design Researcher**

The Apple products (phones, music, personal computers, and watches) are classical examples of this, where the users themselves had not sought such products but nevertheless loved them when they were introduced. These are high end products created with profit as the motive and not necessarily designed for public or planetary health.

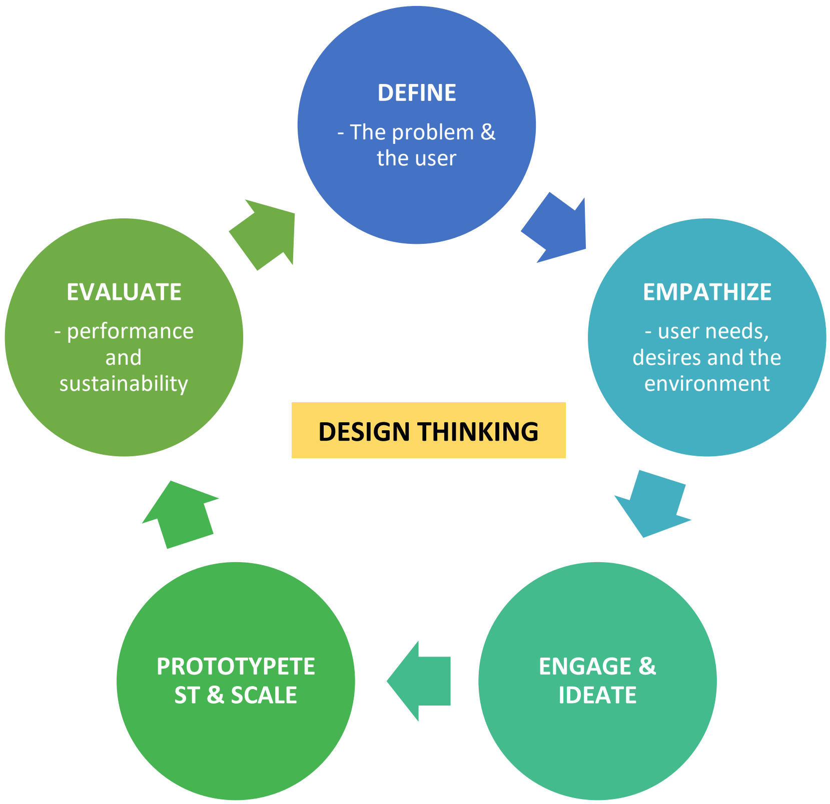


Fig 13: Design Thinking – an Iterative Process

On the other hand, investments into public health have traditionally been the mandate of the public sectors and charitable trusts, that have taken conventional beaten tracks of interventions, which have not necessarily been put through contemporary design thinking processes. However, this is changing, and design thinking concepts are increasingly being adopted for tackling public health issues as well (Roberts et al., 2016).

A holistic canvas incorporating the possible steps in providing access to safe drinking water can be designed (Fig 14).

Problem and User definition: The design thinking process begins with defining the problem and the user group for whom the interventions need to be designed. E.g., social-economic poor

Empathize: The user needs and desires, their physical and social environments need to be understood. E.g., poor WASH conditions, water-stressed terrain, lack of awareness about drinking water purification etc.

Engage & Ideate: Engage with the stakeholder groups, ideate, and exchange ideas with the groups. Discuss the possible products/services, the benefits, the feasibility/viability etc. Enhance receptivity and buy-in from the stakeholders. The safety of drinking water can be enhanced at the source, during transit and at the point-of-use. Conserving, safeguarding the purity, and better management of drinking water sources are vital functions of the local governing bodies/Panchayats and communities, because once the sources get polluted, it is a down-hill process. The knowledge, attitude and practices of the local communities and the governing bodies need to be enhanced appropriately for sustaining any efforts at drinking water purification.

Prototype, Test & Scale: Design and innovate holistic, sustainable interventions. This could be products and/or services. Pilot test them on ground, obtain feedback from stakeholders and modify, as necessary. Plan systems for execution and scale-up including addressing the end-to-end supply chain aspects, since lack of consistent supplies will beat the purpose. E.g., community level RO water purification systems installed in many Indian states have become defunct because of lack of ground water and high costs of maintenance. With the buy-in from local stakeholders, establish systems for sustainable management of quality and quantum of drinking water.

Evaluate and Improve: Any technology and/or other interventions have to meet at least two major success indicators, namely (i) sustainable access to safe drinking water (i.e., quantum and quality) and (ii) improvement in associated health outcome (e.g., the reduction in U5 children diarrhea). Identify gaps and improve constantly. This could involve diverse aspects including training/capacity building in total quality management, advocacy against pollution, technology -oriented surveillance systems etc. It is important to recognize that sustainability of reasonably effective efforts in providing access to safe drinking water is more important than a ‘perfect’ solution that is inconsistent in operation. E.g., a sustainable effort at community-level chlorination of drinking water supply sources that can lead to U5 children diarrhea reduction is better than an integrated RO system that stops functioning after six months (Semenza et al., 1998). Even though chlorination is not the ‘perfect’ solution, it may be more appropriate

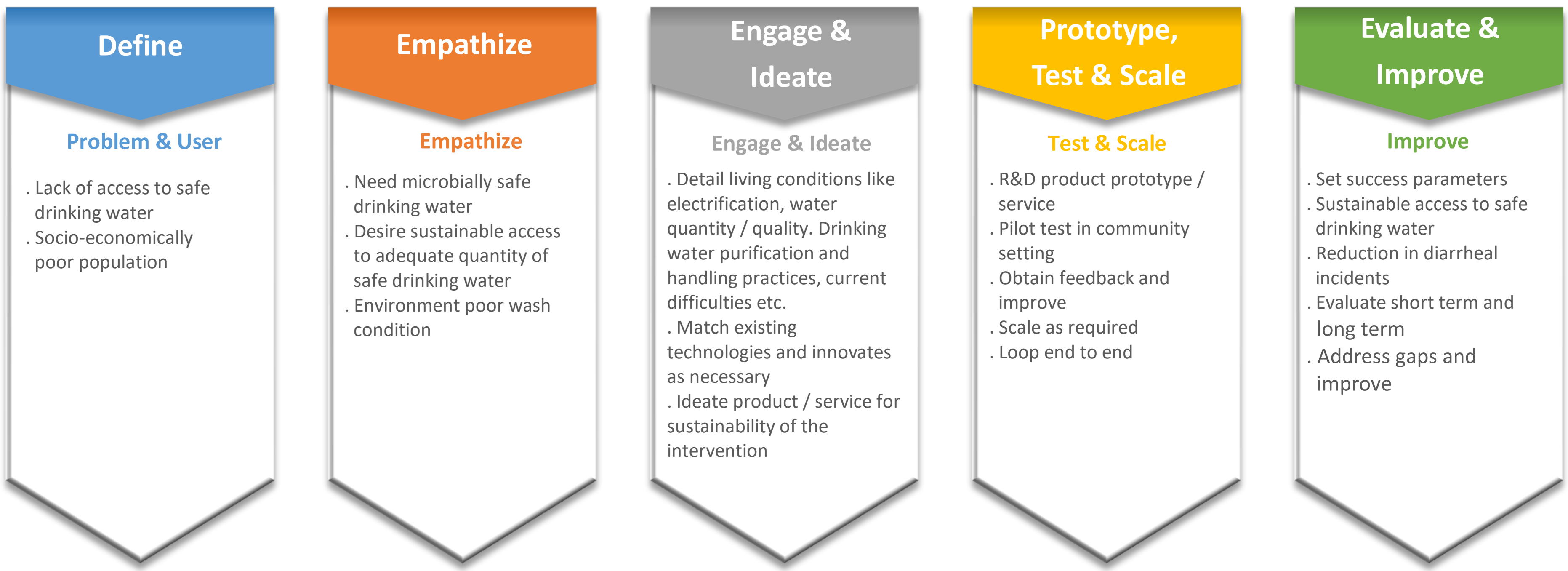


Fig 14: Sustainable Access to Safe Drinking Water Requires Design Thinking

7.3 Social and Behavior Change

Around 2 million deaths that occur annually among children under the age of five, is attributed to poor WASH conditions. Studies have shown that not only diarrhea but also stunting among children can be reduced by 13% and 27% respectively by providing safe drinking water, and improving sanitation and hygiene (Hill, 2015). Investments in improving WASH in India can avoid 76574 U5 diarrheal deaths in children and ~USD 400 Mn as out of pocket spending (OOPS) (Nandi et al., 2016). A meta-analysis published by Fewtrell et al., 2005 indicated that improving WASH can reduce U5 children diarrhea by 57%, and mere handwashing with soap reduces the incidence by 43% (Fig 11).

We are talking changing health behavior and steeped culture here and it is well known that it is one of the toughest barriers to cross in public health. Especially in a complex, diverse country like India, health behavior change requires a multi-pronged, region and community specific, systemic as well as customized interventions. It requires a scientific approach leading to a deep understanding of the motivational levers in people and the social and economic pressures (Kelly & Barker., 2016).

As a part of designing holistic interventions, we would like to emphasize on the importance of heralding behavioral change at the individual, family, and community levels to create capacities and ownership. Only when there is ownership, sustainable water management and safety water by the end-user can be ensured. A top-down 'providing' clean water by government/private/PPP is not adequate.

The 'Triggering' approach was found to be useful as a catalyst to achieve long term, sustainable behavior change. Triggering is based on stimulating a collective sense of disgust and shame among community members as they confront the crude facts about a particular behavior and its negative impacts on the entire community. Typical 3 steps have been described by Parmor, 2015, for behavior change in ODF (Parmor & Raghuram., 2015). These would be relevant also to clean drinking water as well

- Pre triggering – Selecting a community, introduction and building rapport
- Triggering – Participatory ignition moment
- Post Triggering – Action planning by the community and follow up

The Shikake approach, proposed by Matsumara uses physical (including technological) and psychological triggers to bring about a huge change in solving social and personal problems (Matsumura et al., 2015) E.g., painting a pair of watchful eyes at the washing area significantly increased the hand hygiene behavior in public restroom (Pfattheicher et al., 2018).

7.4 Primordial Prevention & Planetary Health

Achieving SDG #6.1 (clean water and sanitation to all) cannot be looked at in isolation. It is dependent on the progress made on the other SDGs (Fig 15). E.g., poverty (SDG # 1), gender (SDG no 5), education (SDG # 4) and the industry and infrastructure (SDG #9) and cities and communities (SDG #11) impact Clean Water Goal. Therefore, access to drinking water will need to be addressed holistically.

> **"Climate change is disrupting weather patterns, leading to extreme weather events, unpredictable water availability, exacerbating water scarcity and contaminating water supplies. Such impacts can drastically affect the quantity and quality of water that children need to survive." UNICEF, 13th March 2021 (https://www.unicef.org/stories/water-and-climate-change)**

Fig 15: Achieving SDG #6.1 (Clean Water & Sanitation to All) is dependent on all other SDGs

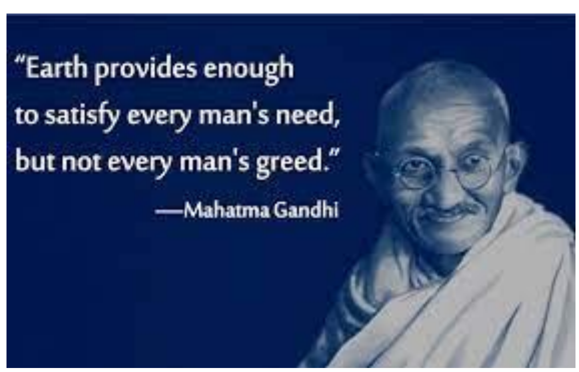
Health of humans is inextricably linked with Planetary Health and the former cannot sustain at the cost of the latter (Whitmee et al., 2015). Development oriented, economy driven anthropocentric activities have depleted natural resources, destroyed biodiversity, and marginalized certain segments of the population. Climate Change and rising temperatures adversely impact water quality, availability, and flooding (Delpla et al., 2009).

Public health and development programs that are not built on the foundations of primordial prevention and planetary health, would remain fragile. Sustainable use of planetary resources is an essential part of primordial prevention in healthcare. Technologies can provide solutions, for drinking water purification but they will only be of a temporary and not sustainable in the long run. For sustainable solutions, it is important to focus on primordial prevention strategies; to maintain clean environments, safeguard water bodies from contamination, conserve and better manage water. One cannot talk about clean water for all when freshwater bodies are being polluted by industrial effluents and sewage, in an unregulated manner. Controlling and preventing the risk of contaminating water bodies and better WASH practices, would be primordial prevention strategies for safe drinking water.

"Primordial Prevention includes "actions that minimize hazards to health and.... inhibit factors (environmental, economic, social, behavioral, cultural) that increase the risk of disease" (Dictionary of Epidemiology, Ed. Miquel Porta, V Ed. 2008).

The activities of individuals as well as local, national, and global communities directly or indirectly impact the drinking water quality. Conventionally, WASH has been thought of as a behavioral problem of the poor and downtrodden. This however is not necessarily true, because water contamination is primarily caused by rapid, unplanned developmental activities, improper disposal of human and industrial wastes, and pollution of water bodies by the industries (Jal Jeevan Mission, 2020). Therefore, the behavior of everyone needs to change in terms of water usage and management.

The philosophy of optimal vs maximal use of water should be adopted by each one of us. This will solve many issues of equity, quality and quantity of drinking water.



ACKNOWLEDGEMENTS

We would like to thank Dr. Vignesh for helping us with the spatial representation of data and Ms. Geetha Veliah for her valuable comments on the manuscript. Both are Faculty at the School of Public Health, SRMIST, Chennai, India.

References:

- Ahmed, M., & Araral, E. (2019). Water governance in India: Evidence on water law, policy, and administration from eight Indian states. Water (Switzerland), 11(10). https://doi.org/10.3390/w11102071
- Akowanou, A. V. O., Deguenon, H. E. J., Groendijk, L., Aina, M. P., Yao, B. K., & Drogui, P. (2019). 3D-printed clay-based ceramic water filters for point-of-use water treatment applications. Progress in Additive Manufacturing, 4(3), 315–321. https://doi.org/10.1007/s40964-019-00091-9
- Ashis Jalote Parmor, G. R. (2015) IIMA/BP0393 Case Study https://web.iima.ac.in/iima-cases.html
- Bandyopadhyay, S. (2016). Sustainable Access to Treated Drinking Water in Rural India. In Rural Water Systems for Multiple Uses and Livelihood Security. Elsevier Inc. https://doi.org/10.1016/B978-0-12-804132-1.00009-3
- Bhatt, N. J., & Bhatt, K. J. (2017). an Analysis of Water Governance in India: Problems and Remedies. International Journal of Advance Engineering and Research Development, 4(09). https://doi.org/10.21090/ijaerd.53541
- Bhattacharya, S., & Banerjee, A. (2015). Water privatization in developing countries: Principles, implementations and socio-economic consequences. World Scientific News, 4, 17–31. www.worldscientificnews.com
- BIS. Indian Standard Drinking Water Specification (Second Revision). Bur Indian Stand [Internet]. 2012; IS 10500(May):1–11. Available from: http://cgwb.gov.in/Documents/WQ-standards.pdf
- CDC. (2009). Healthy Water https://www.cdc.gov/healthywater/pdf/drinking/Household_Water_Treatment.pdf
- CDC. (2021). https://www.cdc.gov/healthywater/global/wash_statistics.html.
- Choudhury, S. (2017). EVALUATING THE CURRENT STATUS OF DECENTRALISED GOVERNANCE: TRANSFORMATIONS TO REACH HAR GHAR JAL BY 2030 Meeting India 's Piped Water Gap Funding Water Projects — Increased Fiscal Re-. June, 1–16 https://swealliance.org/wp-content/uploads/2021/02/EVALUATING-THE-CURRENT-STATUS-OF-DECENTRALISED-GOVERNANCE.pdf
- Collivignarelli, M. C., Abbà, A., Benigna, I., Sorlini, S., & Torretta, V. (2018). Overview of the main disinfection processes for wastewater and drinking water treatment plants. Sustainability (Switzerland), 10(1), 1–21. https://doi.org/10.3390/su10010086
- Colwell, R. R., Huq, A., Islam, M. S., Aziz, K. M. A., Yunus, M., Huda Khan, N., Mahmud, A., Bradley Sack, R., Nair, G. B., Chakraborty, J., Sack, D. A., & Russek-Cohen, E. (2003). Reduction of cholera in Bangladeshi villages by simple filtration. Proceedings of the National Academy of Sciences of the United States of America, 100(3), 1051–1055. https://doi.org/10.1073/pnas.0237386100

- CPCB. (2020). Central Pollution Control Board: https://cpcb.nic.in/Introduction/.
- DDWS. (2013). HandBook_On_Drinking_Water_Treatment_Technologies_February_2013.pdf. https://ejalshakti.gov.in/misc/Docs/ProvenTech.pdf
- DDWS. (2021). Department of Drinking Water Sanitation. https://jalshakti-ddws.gov.in/
- Dadonaite, B., H. R. and M. R. (2019). Diarrheal diseases. Our World in Data. https://ourworldindata.org/diarrheal-diseases
- Delpla, I., Jung, A., Baures, E., Clement, M., & Thomas, O. (2009). Impacts of climate change on surface water quality in relation to drinking water production. Environment International, 35(8), 1225–1233. https://doi.org/10.1016/j.envint.2009.07.001
- Department of Drinking Water & Sanitation. (2021). View Innovations/Products/Technologies. https://ejalshakti.gov.in/misc/home.aspx
- Esmaeilion, F. (2020). Hybrid renewable energy systems for desalination. In Applied Water Science (Vol. 10, Issue 3). Springer International Publishing. https://doi.org/10.1007/s13201-020-1168-5
- Fewtrell, L., Kaufmann, R. B., Kay, D., Enanoria, W., Haller, L., & Jr, J. M. C. (2005). WASH interventions to reduce diarrhoea in less developed countries. Lancet Infection Diseases, 5(January), 42–52.
- FHTC, D. (2021). Jal Jeevan Mission Har Ghar Jal. 15–16. https://ejalshakti.gov.in/jjmreport/JJMIndia.aspx (Accessed on 11.06.2021)
- Francis, M. R., Nagarajan, G., Sarkar, R., Mohan, V. R., Kang, G., & Balraj, V. (2015). Perception of drinking water safety and factors influencing acceptance and sustainability of a water quality intervention in rural southern India. BMC Public Health, 15(1), 1–9. https://doi.org/10.1186/s12889-015-1974-0
- Ghebremichael, K. (2007). Overcoming the drawbacks of natural coagulants for drinking water treatment. 87–93. https://doi.org/10.2166/ws.2007.144
- Gill, M. (2017). TamRas. https://yourstory.com/2017/05/tamras/amp
- Grand Challenges Canada. (2014). Preventing infectious diarrhoea in Kenyan and Indian communities: testing a low-cost, point-of-use device for safe drinking water. https://www.grandchallenges.ca/grantee-stars/0259-01/
- Harjan, I. (2019). *HEALTH EFFECTS OF CHLORINATED WATER : A REVIEW ARTICLE*. *January*. https://doi.org/10.34016/pjbt.2019.16.3.24
- Hill, K. (2015). The effect of water and sanitation on child health: evidence from the demographic and health surveys 1986 – 2007. June 2011, 1196–1204. https://doi.org/10.1093/ije/dyr102
- Hoslett, J., Massara, T. M., Malamis, S., Ahmad, D., van den Boogaert, I., Katsou, E., Ahmad, B., Ghazal, H., Simons, S., Wrobel, L., & Jouhara, H. (2018). Surface water filtration using granular media and membranes: A review. Science of the Total Environment, 639, 1268–1282. https://doi.org/10.1016/j.scitotenv.2018.05.247
- Hutchings, P., Franceys, R., Mekala, S., Smits, S., & James, A. J. (2017). Revisiting the history, concepts and typologies of community management for rural drinking water supply in India.

International Journal of Water Resources Development, 33(1), 152–169. https://doi.org/10.1080/07900627.2016.1145576

- IHME, Global Burden of Disease (GBD) http://ghdx.healthdata.org/gbd-results-tool
- India Census, (2011). CENSUS OF INDIA 2011 https://www.censusindia.gov.in/2011Census/pes/Pesreport.pdf
- Jal Jeevan Mission. (2020). Margdharshika for Gram Panchayat & VWSC to provide safe drinking water in rural hoseholds. https://jalshakti-ddws.gov.in/Margdarshika/mobile/index.html
- Jal Jeevan Mission. (2021). Home. https://jaljeevanmission.gov.in/
- JJM. (2021). State wise tested sources. https://ejalshakti.gov.in/IMISReports/Reports/WaterQuality/rpt_WQM_GPwiseTesting_S.aspx?Rep=0&RP=Y (Accessed on 05.05.2021)
- Kelly, M.P., & Barker, M. (2016) Why is changing health-related behaviour so difficult ? Public Health, 136, 109–116. https://doi.org/10.1016/j.puhe.2016.03.030
- Kostyla, C., Bain, R., Cronk, R., & Bartram, J. (2015). Seasonal variation of fecal contamination in drinking water sources in developing countries: a systematic review. The Science of the Total Environment, 514, 333–343. https://doi.org/10.1016/j.scitotenv.2015.01.018
- Kuberan, A., Singh, A. K., Prasad, S., & Mohan, K. (2015). Water and sanitation hygiene knowledge, attitude , and practices among household members living in rural setting of India. 69–74. https://doi.org/10.4103/0976-9668.166090
- Li, H., Xia, Q., Wen, S., Wang, L., & Lv, L. (2019). Identifying Factors Affecting the Sustainability of Water Environment Treatment Public-Private Partnership Projects. Advances in Civil Engineering, 2019. https://doi.org/10.1155/2019/7907234
- Li, H. Y., Osman, H., Kang, C. W., & Ba, T. (2017). Numerical and experimental investigation of UV disinfection for water treatment. Applied Thermal Engineering, 111, 280–291. https://doi.org/10.1016/j.applthermaleng.2016.09.106
- Li, X., Cai, M., Wang, L., Niu, F., Yang, D., & Zhang, G. (2019). Evaluation survey of microbial disinfection methods in UV-LED water treatment systems. Science of the Total Environment, 659, 1415–1427. https://doi.org/10.1016/j.scitotenv.2018.12.344
- Matsumura, N., Fruchter, R., & Leifer, L. (2015). Shikakeology: designing triggers for behavior change. AI and Society, 30(4), 419–429. https://doi.org/10.1007/s00146-014-0556-5
- MDGs, SDGs. (2012). Waterborne Diseases. 2012, 790–790. https://doi.org/10.1007/978-3-319-95681-7_300165
- Menon, G. R., Singh, L., Sharma, P., Yadav, P., Sharma, S., Kalaskar, S., Singh, H., & Adinarayanan, S. (2017). Articles National Burden Estimates of healthy life lost in India, 2017: an analysis using direct mortality data and indirect disability data. The Lancet Global Health, 7(12), e1675–e1684. https://doi.org/10.1016/S2214-109X(19)30451-6
- Ministry of Jal shakti. (2017). Department of Water Resources, River Development & Ganga Rejuvenation. http://www.mowr.gov.in/about-us/functions
- Ministry of Jal shakti. (2019). Department of Drinking Water & Sanitation. https://ejalshakti.gov.in/JSA/JSA/Home.aspx

- Ministry of Jal shakti. (2020). https://jalshakti-ddws.gov.in/about-us. https://jalshakti-ddws.gov.in/about-us
- Ministry of Jal shakti. (2021). Department of Water Resources, River Development & Ganga Rejuvenation. http://www.mowr.gov.in/about-us/history
- Mokomane, M., Kasvosve, I., de Melo, E., Pernica, J. M., & Goldfarb, D. M. (2018). The global problem of childhood diarrhoeal diseases: emerging strategies in prevention and management. Therapeutic Advances in Infectious Disease, 5(1), 29–43. https://doi.org/10.1177/2049936117744429
- Nandi, A., Megiddo, I., Ashok, A., & Verma, A. (2016). Social Science & Medicine Reduced burden of childhood diarrheal diseases through increased access to water and sanitation in India: A modeling analysis. 1–12. https://doi.org/10.1016/j.socscimed.2016.08.049
- NFHS-4. (2015a). India http://rchiips.org/nfhs/pdf/nfhs4/india.pdf
- NFHS-4. (2015b). National Family Health Survey. http://rchiips.org/nfhs/factsheet_nfhs-4.shtml
- NWMP. (2019). Groundwater quality data India. http://www.cpcbenvis.nic.in/water_quality_data.html
- Paul, P. Socio-demographic and environmental factors associated with diarrhoeal disease among children under five in India. *BMC Public Health* **20,** 1886 (2020). https://doi.org/10.1186/s12889-020-09981-y
- Pfattheicher, S., Strauch, C., Diefenbacher, S., & Schnuerch, R. (2018). A field study on watching eyes and hand hygiene compliance in a public restroom. Journal of Applied Social Psychology, 48(4), 188–194. https://doi.org/10.1111/jasp.12501
- Pichel, N., Vivar, M., & Fuentes, M. (2019). The problem of drinking water access: A review of disinfection technologies with an emphasis on solar treatment methods. Chemosphere, 218, 1014–1030. https://doi.org/10.1016/j.chemosphere.2018.11.205
- Preethi, V. B., Ganesan, S., Pazhani, G. P., Ramamurthy, T., Nair, G. B., & Venkatasubramanian, P. (2012). Storing Drinking-water in Copper Pots Kills Contaminating Diarrhoeagenic Bacteria Bacterial strains. 30(1), 17–21. https://doi.org/10.3329/jhpn.v30i1.11271
- Preethi, V. B., Singh, K. O., Prasad, S. R., & Venkatasubramanian, P. (2009). Killing of enteric bacteria in drinking water by a copper device for use in the home: laboratory evidence. 10–13. https://doi.org/10.1016/j.trstmh.2009.01.019
- Preethi, V. B., Singh, K. O., Ramani, S., & Paul, A. (2011). Provided for non-commercial research and educational use only. Not for reproduction or distribution or commercial use. This article was originally published by IWA Publishing. IWA Publishing recognizes the retention of the right by the author (s) to. https://doi.org/10.2166/washdev.2011.030
- Ramsundram, N., & Khanam, N. (2019). Impact of climate change on reservoir inflow predictions: A case study. International Journal of Recent Technology and Engineering, 7(4), 132–135. https://www.ijrte.org/wp-content/uploads/papers/v7i4s/E1887017519.pdf

- Randall, G. W., Delgado, J. A., & Schepers, J. S. (2008). Water Resources المواردالمائية. 2008. https://ncert.nic.in/ncerts/l/legy206.pdf
- Roberts, J. P., Fisher, T. R., Trowbridge, M. J., & Bent, C. (2016). Healthcare The Leading Edge A design thinking framework for healthcare management and innovation. Healthcare, 1–4. https://doi.org/10.1016/j.hjdsi.2015.12.002
- Rodriguez-Narvaez, O. M., Peralta-Hernandez, J. M., Goonetilleke, A., & Bandala, E. R. (2017). Treatment technologies for emerging contaminants in water: A review. Chemical Engineering Journal, 323, 361–380. https://doi.org/10.1016/j.cej.2017.04.106
- Rossi, F., Parisi, M. L., Maranghi, S., Manfrida, G., Basosi, R., & Sinicropi, A. (2019). Environmental impact analysis applied to solar pasteurization systems. Journal of Cleaner Production, 212, 1368–1380. https://doi.org/10.1016/j.jclepro.2018.12.020
- Semenza, J. C., Roberts, L., Henderson, A., Bogan, J., & Rubin, C. H. (1998). Water distribution system and diarrheal disease transmission: A case study in Uzbekistan. American Journal of Tropical Medicine and Hygiene, 59(6), 941–946. https://doi.org/10.4269/ajtmh.1998.59.941
- Sewak et al. (2017). Har Ghar jal-Policy paper pdf. http://www.safewaternetworkindia.org/sites/default/files/Knowledge%20Compendium%202021_0.pdf
- Sharma, S., & Bhattacharya, A. (2017). Drinking water contamination and treatment techniques. Applied Water Science, 7(3), 1043–1067. https://doi.org/10.1007/s13201-016-0455-7
- Solvatten. (2021) What is Solvatten? https://solvatten.org/what-is-solvatten-2
- Sorlini, S., Rondi, L., Gomez, A. P., & Collivignarelli, C. (2015). Appropriate technologies for drinking water treatment in Mediterranean countries. Environmental Engineering and Management Journal, 14(7), 1721–1733. https://doi.org/10.30638/eemj.2015.183
- Statista. (2018). Population across rural and urban India from 2017 to 2022(in millions). https://www.statista.com/statistics/1012239/india-population-by-region/
- Swachh Bharath Mission. (2020). About us. https://swachhbharatmission.gov.in/SBMCMS/about-us.htm
- Swachh Bharath Mission. (2021). ODF . https://sbm.gov.in/sbmdashboard/ODF.aspx A
- Tata Trusts. (2021). WaSH- Creating a healthy future for underserved communities. https://www.tatatrusts.org/our-work/water-sanitation-and-hygiene
- The World Bank. (2014). Running Water in India's Cities: A Review of Five Recent Public-Private Partnership Initiatives. 72. www.worldbank.org
- Townsend, J., & Curtis, V. (2017). Costs of diarrhoea and acute respiratory infection attributable to not handwashing: the cases of India and China. 22(1), 74–81. https://doi.org/10.1111/tmi.12808
- Trösch, W. (2009). Water treatment. Technology Guide: Principles - Applications - Trends, 394–397. https://doi.org/10.1007/978-3-540-88546-7_73
- UNICEF. (2010). https://www.unicef.org/media/media_21423.html

- UNICEF. (2020).https://www.unicef.org/reports/lost-home-2020
- UNICEF. (2021). https://www.unicef.org/india/what-we-do/clean-drinking-water
- Verma, K. C., & Kushwaha, A. S. (2014). Demineralization of drinking water: Is it prudent? Medical Journal Armed Forces India, 70(4), 377–379. https://doi.org/10.1016/j.mjafi.2013.11.011
- Wescoat, J. L., Fletcher, S., & Novellino, M. (2016). National rural drinking water monitoring: Progress and challenges with India's IMIS database. Water Policy, 18(4), 1015–1032. https://doi.org/10.2166/wp.2016.158
- Whitmee, S., Haines, A., Beyrer, C., Boltz, F., Capon, A. G., De Souza Dias, B. F., Ezeh, A., Frumkin, H., Gong, P., Head, P., Horton, R., Mace, G. M., Marten, R., Myers, S. S., Nishtar, S., Osofsky, S. A., Pattanayak, S. K., Pongsiri, M. J., Romanelli, C., … Yach, D. (2015). Safeguarding human health in the Anthropocene epoch: Report of the Rockefeller Foundation-Lancet Commission on planetary health. The Lancet, 386(10007), 1973–2028. https://doi.org/10.1016/S0140-6736(15)60901-1
- WHO. (2006). Guidelines for Drinking-water Quality. https://www.who.int/water_sanitation_health/dwq/gdwq0506.pdf
- WHO. (2007). Physical removal processes: sedimentation and filtration. 21–50. https://www.who.int/water_sanitation_health/dwq/WSH02.07_5.pdf
- WHO. (2017). Guidelines for drinking water quality. https://www.who.int/publications/i/item/9789241549950
- World Health Organization. (2019). Water, sanitation, hygiene and health a primer for health professionals. 31. https://apps.who.int/iris/bitstream/handle/10665/330100/WHO-CED-PHE-WSH-19.149-eng.pdf?ua=1
- World Health Organization, & UNICEF. (2017). Progreso en agua potable, saneamiento e higiene. In Who (Issue February). http://apps.who.int/iris/bitstream/handle/10665/258617/9789241512893-eng.pdf?sequence=1
- WWD. (2012). REVERSE OSMOSIS WATER BENEFITS & DISADVANTAGES. https://www.wwdmag.com/membranes-reverse-osmosis/pros-and-cons-reverse-osmosis-water-filtration-systems
- Zhang, Y., Sivakumar, M., Yang, S., Enever, K., & Ramezanianpour, M. (2018). Application of solar energy in water treatment processes: A review. Desalination, 428(November 2017), 116–145. https://doi.org/10.1016/j.desal.2017.11.020

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