Technology-specific wastewater safety plans for the two on-site pilots

Deliverable D2.4 – Final Version

WP2 Water Governance, stakeholder engagement and policy support
Task 2.4 Development of technology-based wastewater safety plans

Authors: Lena Breitenmoser (FHNW) & Claire Furlong (IHE-Delft), Anshuman (TERI), Paul Campling (VITO), Tineke Hooijmans (IHE-Delft)

Approved by WP Manager:	Tineke Hooijmans & Anshuman
Date of approval	31/1/2024
Approved by Project Coordinator	Paul Campling
Date of approval	31/1/2024
Due date of deliverable	31/1/2024
Actual submission date	31/1/2024

Project number (EU)	821051 (H2020-SC5-2018)
Project number (India)	BT/IN/EU-WR/39/AJ/2018
Project coordinator	Paul Campling
Scientific coordinator	Anshuman
Project Website	https://www.pavitra-ganga.eu/en

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 821051.
This project has been co-funded by Department of Biotechnology (DBT), Government of India.

Dissemination level		
PU	Public	X
CO	Confidential, restricted under conditions set out in Model Grant Agreement	
CI	Classified information as referred to in Commission Decision 2001/844/EC)	
R	Document, report	X
DEM	Demonstrator, pilot, prototype	
DEC	Web sites, patent fillings, videos, etc.	
OTHER	Software, technical diagram, etc.	
ETHICS	ETHICS	

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 821051.
This project has been co-funded by Department of Biotechnology (DBT), Government of India.

SUMMARY

This document provides the technology-specific wastewater safety plans, and a summary of the risk assessment results in Kanpur and Delhi. More detailed results for the case study sites are found in five MSc theses and three peer-reviewed publications (one published, two in preparation). The wastewater safety planning approach including the risk assessment templates has been disseminated at a workshop at the IWA Water reuse conference (Chennai, January 2023) and learning materials and exercised were prepared (see WP6). Two conference presentations on the wastewater safety approach were held in 2023 (IWA Water Reuse Conference January 2023 and UNC Water and Health October 2023).

The wastewater safety planning approach and results were presented in January 2024 to the National Mission of Clean Ganga in Delhi with the following outcomes: i) A webinar with STP operators on occupational safety and health is planned and ii) the wastewater safety planning for Kanpur will be repeated to assess the impacts of the newly commissioned Common Effluent Treatment Plant (CETP) for downstream irrigation.

Wastewater treatment and reuse schemes can pose health hazards to wastewater treatment plant operators and users, such as farmers. Although, Indian occupational health and safety rules and regulations exist, their enforcement is weak and adequate exposure and risk assessment frameworks are lacking. This document presents a risk assessment framework for wastewater treatment plant workers and farmers and shows its application at the two case study sites in Kanpur and Delhi.

The framework is based on the Sanitation Safety Planning Approach of the World Health Organization which provides a structured approach to i) identify hazards and disease pathways of exposure groups, followed by ii) a semi-quantitative risk assessment and iii) the development of management strategies to reduce the highest health risks. Management strategies in this document focus on the implementation of alternative wastewater treatment and reuse technologies (see WP5).

The primary treatment and the activated sludge systems (incl. PAS) have the highest number of risks due to the design of the processes. Less risks are detected for enclosed systems such as the membrane technologies Andicos, SFD-MBR and MBR, as there are e.g., no risks for physical hazards such as UV radiation or adverse weather and less accident hazards. Nature-based systems, such as CW+ have the lowest health risks, as they are least prone for accident hazards, such as burns related to heat and chemicals or electric shocks.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 821051.
This project has been co-funded by Department of Biotechnology (DBT), Government of India.

We adapted the occupational hazard checklists of the International Labour Organisation for wastewater treatment plant operators to the local contexts. For the risk assessment, we used a triangulated approach based on in-depth literature reviews, questionnaires combined with observational checklists (n=75), key informant interviews (n=19) and analysis of E.coli (n = 84) and chromium (n = 33) in the wastewater treatment and reuse system. These data were used to determine the likelihood and severity of hazards to calculate the risk scores. We compared the occupational health risks of the existing wastewater treatment and reuse systems to alternative solutions, as piloted in the Pavitra Ganga project (see WP5).

In Kanpur we assessed the occupational health risks for wastewater treatment plant workers at Jajmau STP and the farmers of the downstream agricultural irrigation scheme. High health risks were found for STP operators and farmers due to microbial and chemical contamination, i.e. high *E. coli* and chromium concentrations found in wastewater and sewage sludge. Alternative treatment technologies (i.e. membrane filtration + CW+) influenced the microbial concentrations in the effluent but not the chromium. Chromium accumulates in the sludge and high concentrations are further found in the irrigation water canals due to mixing of STP with CETP effluents. High health risks remain due to general working practices, related to e.g. ergonomic and accident hazards, both for operators and farmers. Future studies also need to investigate the sewage sludge handling in the area. The wastewater safety planning should be repeated to assess the impacts of a newly commissioned CETP, the rehabilitated sewer network and STP on the health of operators and farmers using the mixed wastewater.

In Delhi, we assessed the occupational health risks of wastewater treatment plant workers at Suez Okhla STP and the treated effluent to parks for irrigation. The effluent from Suez Okhla STP was mixed with effluent from other STPs, meaning there was no impact from implementing the novel technology. The main high risk for workers was related to exposure to pathogens in the treated effluent, this can be mitigated through the monitoring and control of the effluent quality from the other STPs. If this is not done the use of appropriate personal protective can reduce the risk for these workers. Parks that are irrigated with the treated wastewater should restrict irrigation to low-frequented times of the day and switch to drip irrigation rather than sprinkler to minimize risks for park visitors.

We found that at both sites, wastewater safety planning opened the discussions on occupational health and safety related to wastewater treatment and reuse. However, it should be a co-creative, participatory process to allow buy-in from stakeholders to bring about the necessary system transitions.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 821051.
This project has been co-funded by Department of Biotechnology (DBT), Government of India.

TABLE OF CONTENTS

SUMMARY III

Table of Contents.... V

CHAPTER 1 Introduction 2

2.1 Occupational health and safety.... 2
2.2 Wastewater related health risks.... 3
2.2.1 Health hazards and WASH-related diseases 3
2.2.2 Occupational health risks in wastewater treatment and management.... 3
2.3 Health risk assessment methods 5
2.4 Water reuse guidelines.... 7
2.4.1 Indian water reuse guidelines 7
2.1.2 International water reuse guidelines 8
2.1.3 Sanitation Safety Planning 8

CHAPTER 2 Wastewater safety planning 10

3.1.1 Identify disease pathways and affected people 10
3.1.2 Risk-based assessment 11
3.1.3 Management strategies to reduce the highest risks.... 11

CHAPTER 3 Technology-specific risk assessments.... 12

CHAPTER 4 Wastewater safety planning in Kanpur 16

4.1 System description.... 16
4.2 Risk assessment & management strategies 18

CHAPTER 5 Wastewater safety planning in Delhi 21

4.1 System description.... 21
4.2 Risk assessment and management strategies 22

CHAPTER 6 Conclusion 24

REFERENCES.... 25

ANNEX.... 27

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 821051.
This project has been co-funded by Department of Biotechnology (DBT), Government of India.

LIST OF FIGURES

Figure 1 Approaches for (microbial) health risk assessments (WHO, 2016)............ 6
Figure 2 The six steps of sanitation safety planning.. 9
Figure 3 Work approach for wastewater safety plans in Kanpur and Delhi 10
Figure 4 Total number of health risks and risk levels of different unit processes. 14
Figure 5 System boundary for Jajmau STP and the reuse scheme (Villarreal 2023, Babalola et al, 2023) 16
Figure 6 Map of communities alongside irrigation channels in Kanpur, India 17
Figure 7 The number and level of risks related to operating and maintaining the Jajmau STP and the novel Pavitra Ganga technology (Furlong et al., 2023)... 19
Figure 8 The number and level of risks related to farmers reusing the combined effluent from Jajmau STP and the CEPT, and the novel technology from the Pavitra Ganga project and the CEPT (Furlong et al., 2023). 20
Figure 9 System boundary for Suez Okhla STP and the reuse scheme (Sanyang, 2023).. 21

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 821051.
This project has been co-funded by Department of Biotechnology (DBT), Government of India.

LIST OF TABLES

Table 1 Occupational hazards and control measures for wastewater treatment plant workers (ILO, 2009, CUPE, 2015)........ 4
Table 2 Recommended norms of treated sewage quality for different uses (in mg/L unless specified) according to CPHEEO 2012 (Schellenberg et al., 2020) and EU (2020)........ 7
Table 3 Occupational hazards for wastewater treatment plant workers and severity score of potential disease outcomes........ 13
Table 4 Hazard identification risk assessment for workers reusing the mixed effluent from the DJB tank at Lodi Gardens (Sanyang, 2023)........ 22

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 821051.
This project has been co-funded by Department of Biotechnology (DBT), Government of India.

CHAPTER 1 INTRODUCTION

2.1 Occupational health and safety

Occupational health and safety management deals with all aspects of health and safety at the workplace with the aim to prevent hazards. The Occupational Safety and Health is handled by **Ministry of Labour & Employment (MoL&E), Government of India**. There is a National Occupational Safety and Health Advisory Board and a National and State Level OSH Supervision & Inspection System in place.
The Directorate General of Factory Advisory Services & Labour Institutes (DGFASLI) attached to the Ministry of Labour & Employment, Government of India serves as a technical arm in formulating national policies on occupational safety and health in factories and docks and advises factories on problems concerning safety, health, efficiency, and well-being of every employee.

Legislation and policies comprise:

- The **Indian Constitution** enshrines provisions for the rights of the citizens through "Directive Principles of State Policy". It forms the basis of workplace safety and health laws. It is the duty of the states to implement policies that encourage workplace safety and health of workers.
- **National Policy on Safety, Health and Environment at Workplace (NPSHEW); 2009,** which aims i) to establish a preventive safety and health culture in the country through elimination of the incidents of work-related injuries, diseases, fatalities, etc. recognizes safe & healthy working environment as a fundamental human right and ii) enhancing the well-being of employees & the society at large.
- **Main legislations covering Occupational Safety and Health (OSH) enforcement:**
    - The Factories Act, 1948, covering factories in the respective states,
    - The Mines Act, 1952 and Mines Rules, 1955 for mining industry,
    - The Dock Workers (Safety, Health and Welfare) Act, 1986 &1990 (Regulations) dealing with the major ports of India,

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 821051.
This project has been co-funded by Department of Biotechnology (DBT), Government of India.

- The Building & Other Construction Workers (Regulations of Employment and Conditions of Service) Act, 1996, covering construction workers,
- **The Occupational Safety, Health, and Working Conditions Code, 2020**, which outlines the responsibility of employers for maintaining health, safety and working conditions, i.e.
  - Hours of Work and Annual Leave with Wages
  - Maintenance of Registers, Records and Returns
  - Special Provisions for Contract Labour and Inter-state Migrant Workers

Although the institutional and legislative system is in place, the enforcement of it is an issue. Lack of awareness, lack of trained occupational health manpower, institutions, training courses, infrastructure, & budgetary provisions make the implementation of legislation a challenge. Further, undiagnosed/unreported occupational illnesses lead to inaccurate data on occupational diseases.

2.2 Wastewater related health risks

2.2.1 Health hazards and WASH-related diseases

Health risk related to wastewater management and reuse are well described e.g., by the World Health Organization's Guidelines (2006) on the safe use of wastewater, excreta and greywater, the Sanitation Safety Planning Manual (WHO, 2015) or the WHO Guidelines on Sanitation and Health (2018).

Wastewater related health risks occur due to biological (viruses, bacteria, protozoa, helminths, vector-related pathogens), chemical (toxic chemicals, heavy metals), and physical (sharp objects, inorganic material, malodours) hazards (WHO, 2015). Inadequate water, sanitation and hygiene (WASH, which includes the unsafe handling of untreated wastewater), can cause WASH-related diseases. Infectious microbial diseases (such as diarrhoea, malaria, filariasis, helminth infections) are the most prevalent. Diseases due to chemical hazards are less studied in low- and middle-income countries. Physical hazards are commonly an issue for occupational health (Section 2.2.2).

2.2.2 Occupational health risks in wastewater treatment and management

Exposure to toxic substances, pathogens and other hazardous materials are significant for wastewater treatment plant workers. They are also at higher risks for occupational injuries through accidents and

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 821051.
This project has been co-funded by Department of Biotechnology (DBT), Government of India.

ergonomic and psychological hazards. Table ***1***1 compiles typical hazards for wastewater treatment plant workers (ILO, 2009, CUPE, 2015).

Table 1 Occupational hazards and control measures for wastewater treatment plant workers (ILO, 2009, CUPE, 2015)

Accidents hazards
Falls, slips, and trips on the level on floors made wet and slippery during the handling of water
Falls due to working with a defective ladder and/or falls from heights while climbing and staying on an elevated industrial installation
Falls inside an industrial installation and/or into water well while inspecting them and/or taking water samples for analysis
Injuries caused by capture of work-clothes and/or various parts of body, in/between moving/ rotating unprotected parts of machinery
Electric shock caused by contact with "live" wires or defective electrical installations (the danger is especially high because the work is done in a wet and humid environment)
Exposure to hazardous substances due to the sudden release of toxic materials as a result of an accident or human error, such as addition of chemicals to an unsuitable installation (e.g. release of chlorine gas due to an insertion of disinfectants such as hypochlorite into installation with aluminium sulphate)
Fire hazard due to contact of a very strong oxidizer (disinfectant) with a flammable substance, as a result of improper storage of chemicals, human error, sudden release from process piping, etc
Explosion hazard, in the event of contact between ozone (very strong oxidizer) and organic chemical and strong reduction agents
Hazard of drowning when working inside reservoirs, or immersed in watercourses with a strong current
Suffocation hazard while carrying-out maintenance or installation works, such as working in a confined place (tank, boiler) or when doing excavation work (collapse of excavation or a tunnel)
Physical hazards
Exposure to high noise levels, from electro-mechanical equipment and a noisy environment
Exposure to adverse weather conditions: risk of catching a cold as a result of working in windy weather, at low temperatures and while raining; or as a result of over-sweating in the summer; and suffering heat and/or cold strokes
Exposure to UV radiation during water disinfection may be damaging for eyes and skin
Chemical hazards
Exposure to various disinfectants used for water disinfection: • Chlorine (gas): a very strong oxidizer and disinfectant. It is a toxic and corrosive gas that causes irritation of the eyes and the respiratory tract even at low concentrations; • Hydrofluoric acid: a very strong acid that is used in water fluoridation; • Sodium hypochlorite: it is used as a solution. The substance is toxic and corrosive, in particular of the respiratory tract; causes burns and irritation to eyes and skin; • Calcium hypochlorite: the substance is corrosive and very destructive of mucous tissues; may cause chemical pneumonia and lung oedema.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 821051.
This project has been co-funded by Department of Biotechnology (DBT), Government of India.

• Ozone is an oxidizing and an irritating gas; when inhaled, it may cause breathing difficulties, headaches, fatigue, eye irritation, tears and conjunctivitis; • Chlorine dioxide is a very corrosive gas that causes strong irritation of the respiratory tract and the eyes.
Exposure to coagulants (such as aluminium sulphate): these substances assist precipitation of suspended matter in the water
Biological hazards
Exposure to pathogenic micro-organisms: • due to accidental contact between drinking water and wastewater; • incidental hand-to-mouth contact; • Inhalation (aerosols) is less common but may occur when sewage is agitated or aerosolized near incoming wastewater inlets and sludge treatment areas. Exposure to rodents and insects that may transmit diseases
Ergonomic, psychosocial and organizational hazards
Musculoskeletal injuries caused by awkward working postures during the cleaning/inspection of the pipe system and/or the of installation
Overexertion while moving or handling heavy and bulky equipment or big packages of chemicals may affect various systems of the body
Psychological stress and pressure due to environmental factors: annoying noise, water splashing, odours, high humidity, etc.
Psychosocial problems due to increased workload, requirements of improving work output, constant need of high skill levels, lack of privacy due to the increased possibility of superiors to locate and reach the worker (by means of cellular phone or beeper, even after normal working hours), and due to the commitment to answer unexpected calls during emergency situations; requirement of doing shift work overtime

2.3 Health risk assessment methods

A range of health risk assessment (HRA) approaches are available from simple to more detailed and from more expert judgement to more evidence-based assessment of risks (**Error! Reference source not found.** 1).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 821051.
This project has been co-funded by Department of Biotechnology (DBT), Government of India.

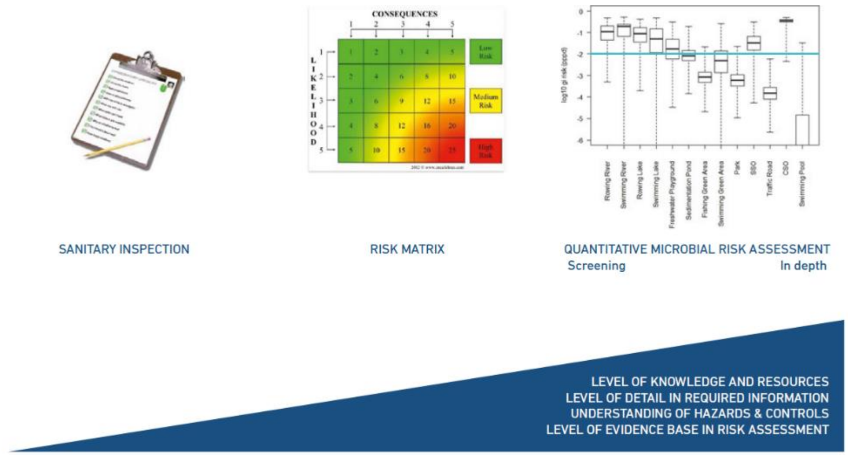


Figure 1 Approaches for (microbial) health risk assessments (WHO, 2016)

- **Sanitary inspection:** An on-site visual evaluation of observable features and conditions that can lead to the contamination of water, and human contact with or of ingestion of contaminated water. Sanitary inspections are typically based on standardized forms/checklists to identify the most common issues that may lead to the introduction of hazards into a system.
- **Risk matrix:** The risk assessment approach that makes a qualitative or semiquantitative evaluation of the likelihood that a hazardous event will occur and the severity or consequence of the hazard and combines them into a risk score or risk rating. The approach relies on expert judgement and can be undertaken at different levels of detail (Annex A.1)
- **Quantitative microbial risk assessment (QMRA)**: A formal, quantitative risk assessment approach that combines scientific knowledge about the presence and nature of pathogens, their potential fate and transport in the water cycle, the routes of exposure of humans and the health effects that may result from this exposure, as well as the effect of natural and engineered barriers and hygiene measures. All this knowledge is combined into a single assessment that allows evidence-based proportionate, transparent, and coherent management of the risk of waterborne infectious disease transmission.

All HRA approaches are valid. Their use is context-specific and will depend on human resources (personnel, skills, access to support institutions) and type of supply system. In general, risk assessments should be as simple as possible (WHO, 2016).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 821051.
This project has been co-funded by Department of Biotechnology (DBT), Government of India.

2.4 Water reuse guidelines

2.4.1 Indian water reuse guidelines

The Environment (Protection) Act of 1986 contains discharge standards for sewage treatment plants (STPs) and common effluent treatment plants (CETPs). These standards are introduced in PAVITRA GANGA Deliverable D2.1 (Table 4, p 26) and D3.1 (Table 4, p 14). Initial standards (1986) have provided different limits for different reuse purposes (e.g. inland surface water, land irrigation, marine coastal areas). The updated standards in place by the National Green Tribunal (2019) introduces one set only of (more stringent) standards for all envisaged reuse purposes.

The Ministry of Housing and Urban Affairs (MoHUA) has recommended norms for different wastewater reuse applications in their Manual on Sewerage and Sewage Treatment Systems (CPHEEO, 2012; Table 2). A national framework on water reuse has been lacking so far. Only few progressive Indian States (e.g. Maharashtra, Gujarat, Punjab) have legal instruments in place for mandatory reuse of treated wastewater. A pan-India framework/policy draft on the safe reuse of treated water is currently being set-up by the Ministry of Jal Shakti, the National Mission for Clean Ganga and other collaborators under the India-EU Water Partnership (IEWP).

Table 2 Recommended norms of treated sewage quality for different uses (in mg/L unless specified) according to CPHEEO 2012 (Schellenberg et al., 2020) and EU (2020)

Parameter	**STP effluent discharge class I/ other (NGT, 2019)**	**Recommended norms for water reuse (CPHEEO, 2012) - agriculture**			**EU Water quality class A* (EU, 2020)**	**EU Water quality class B** (EU, 2020)**
		Non-edible crops	**Edible crops - raw**	**Edible crops - cooked**		
pH	6.5-9.0					
TSS (mg/L)	30/50	30	0	30	≤10	<35
BOD (mg/L)	20/30	20	10	20	≤10	≤25
COD (mg/L)	100/150	30	Not specified	30	<125	<125
TN (mg/L)	15	10[a]	10[a]	10[a]		
TP (mg/L)	1	2	5	2		

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 821051.
This project has been co-funded by Department of Biotechnology (DBT), Government of India.

Fecal coliforms (MPN/100mL) - desirable	230/1000	230	0	230	≤10	≤100
Helminths (egg/L)	-	< 1	< 1	< 1	≤1	≤1
Legionella ssp (CFU/L)	-	-			<1000	<1000

2.1.2 International water reuse guidelines

International water reuse guidelines exist from the World Health organization, the Australian and US Health and Environment protection agencies and the European Commission (Table 2). They entail a set of parameters and limits for different reuse purposes. These parameters and limits per reuse category are summarized in the Annex (Annex A.2; Tables A.1-A.3).

2.1.3 Sanitation Safety Planning

Sanitation safety planning (SSP) is a step-by-step risk-based approach (Figure 2) developed based on the WHO 2006 Guidelines on the safe use of wastewater, excreta and greywater. It provides a structure to bring together actors from different sectors (local level authorities, regulators, health care providers, wastewater utilities, sanitation-based enterprises, community-based organizations, farmers associations, NGOs) to identify health risks in a sanitation system and agree on improvements and regular monitoring. It provides (technological and behavioural) measures to reduce human health risks and set microbial target qualities if wastewater, excreta, and greywater are reused.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 821051.
This project has been co-funded by Department of Biotechnology (DBT), Government of India.

Figure 2 The six steps of sanitation safety planning

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 821051.
This project has been co-funded by Department of Biotechnology (DBT), Government of India.

CHAPTER 2 WASTEWATER SAFETY PLANNING

We will adapt the SSP process scheme to develop the wastewater safety plans for the two test sites. (Figure 3).

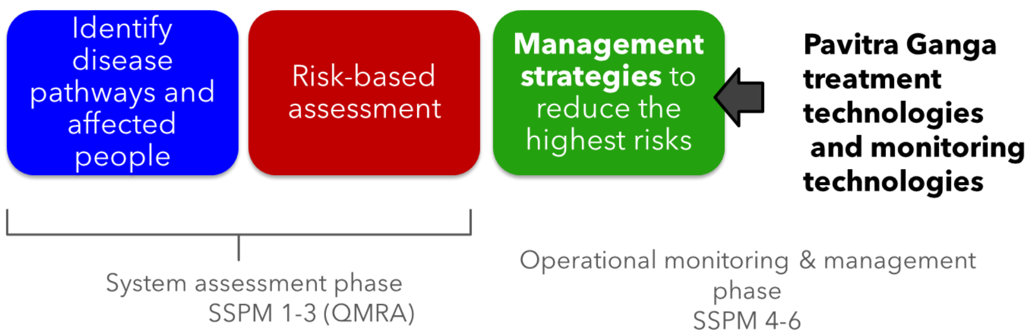


Figure 3 Work approach for wastewater safety plans in Kanpur and Delhi

3.1.1 Identify disease pathways and affected people

We will assess the presence of local health hazards and related diseases for identified exposure groups (wastewater treatment plant workers, communities, end-users like farmers) of the wastewater management and reuse systems at the test sites. Assessments will rely on:

- literature reviews of peer-reviewed and grey literature;
- water quality monitoring (linked to WP4 and WP5);
- exposure group questionnaires (wastewater treatment plant workers, communities, end users); and observational checklists; and,
- key informant interviews with local health care providers and the wastewater treatment plant operators.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 821051.
This project has been co-funded by Department of Biotechnology (DBT), Government of India.

3.1.2 Risk-based assessment

Based on the identification of disease pathways and affected people, we will pursue the following risk-based assessments.

- For **community health risks**, we will couple the household questionnaire to sanitary inspection forms and water quality monitoring. We will take into account different exposure routes, i.e. drinking water, wastewater and sanitation. Results will then be used for a **semi-quantitative risk matrix**.
- For **occupational health risks**, we will use a **semi-quantitative risk matrix** to evaluate critical control points in existing wastewater treatment and reuse systems. Table 2 will serve as checklist (non-exhaustive) for hazards encountered. Existing control measures for each occupational hazard will also be taken into account. The risk matrix will be filled out by selected PAVITRA GANGA project partners and local stakeholders (e.g. wastewater treatment plant operators, health care providers, etc.)
- We will further have a **specific focus on microbial disease burdens** related to wastewater treatment and reuse. Using microbial treatment performance data of existing treatment systems (WP5) we will apply a **quantitative microbial risk assessment** to evaluate the expected disease burden for wastewater treatment plant operators and for other exposure groups under different reuse options (Hajare et al., 2021). This work is presented in Deliverable 5.5 of the project.

3.1.3 Management strategies to reduce the highest risks

Our Pavitra Ganga treatment and monitoring technologies are technological solutions to reduce health risks related to water reuse.

- We will compare occupational health risks of existing wastewater treatment systems with those of the Pavitra Ganga treatment technologies, if scaled up. The same hazard checklist (Table 2) will be filled out by technology providers. This will help to show where changes in risks scores of the risk matrix of existing systems can be expected.
- Using microbial treatment performance data from the Pavitra Ganga pilots in WP5, we will show to what extent the disease burden of wastewater treatment plant operators and other exposure groups under different reuse options could be reduced (Deliverable 5.5)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 821051.
This project has been co-funded by Department of Biotechnology (DBT), Government of India.

CHAPTER 3 TECHNOLOGY-SPECIFIC RISK ASSESSMENTS

Technology-specific wastewater safety plans were developed, using a risk-assessment template based on common hazards for operators of wastewater treatment plants (Table 3). A total of 19 hazards have been identified and categorized, i.e., accident hazards (n=8), biological hazards (n=5), chemical hazards (n=2), ergonomic and psychological hazards (n=2), and physical hazards (n=3). The technologies assessed are well-described in Deliverables of WP3 and WP5.

The identified hazards were rated for their severity and likelihood, following the WHO Sanitation Safety Planning approach (Annex A.1). For the severity scores, global burden of disease studies related to the hazards were used. Disease burden numbers (in DALYs per person per year) were then adapted to the severity scale (1 = insignificant, 2= minor, 4 = moderate, 8 = major and 16 = catastrophic). The likelihood scores have been done revisiting operation & maintenance manuals (cf. e-learning materials in WP6) of the respective technologies or by expert judgement (Pavitra Ganga technology providers). The severity and likelihood scores used in the technology-specific risk assessment are thus from a 'global perspective', while for the Kanpur and Delhi case studies, both have been contextualized using a participatory approach (Balbalola, 2022; Sayanag, 2022).

The hazards and related hazard severities (S) are seen in Table 3. The likelihood and resulting risk scores are shown in Annex A.3.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 821051.
This project has been co-funded by Department of Biotechnology (DBT), Government of India.

Table 3 Occupational hazards for wastewater treatment plant workers and severity score of potential disease outcomes

Hazard Identification					
Category	No	Hazardous event	Hazard	Exposure route	S
Accident hazards	**1**	Exposure to hazardous gases when working in confined places	Hydrogen sulfide & malodor	Inhalation	8
	2	Accidents from contact with sharp objects, electrical devices (naked wires), spillages during daily inspection and sample collection	Falls, slips	Skin or eye contact, accidental ingestion	2
	3		Electric shock		4
	4		Cuts and pricks		2
	5		Burns (heat, chemicals)		8
	6		Other injuries (especially for the eyes, e.g. by flying particles, splashes of liquids)		8
	7	Falling into the open vessels	Drowning		16
	8		Acute posoning/intoxication		16
Biological hazards	**9**	Exposure to aerosols	Microbial pathogens	Inhalation	8
	10	Exposure to untreated sewage or sludge during operation and maintenance of the system	Microbial pathogens, skin irritants	Skin or eye contact, accidental ingestion	8
	11	Mosquito breeding in surface or standing water	Vector-related diseases	Mosquito bites	4
	12	Exposure to animals (rodents, snakes) proliferating on STP premises	Vector-related diseases	Animal bites	8
Chemical hazards	**13**	Exposure to chemicals required for the process.	Chemicals	Accidental ingestion. Inhalatio or skin contact	8
	14	Exposure to chemicals in the wastewater/sludge			8
Ergonomic and psychological hazards	**15**	Musculoskeletal disorder from taking uncomfortable postures during operation and maintenance.	Musculoskeletal injuries	Uncomfortable working postures, overexertion	4
	16	Discomfort and psychological problems due to prlonged wear of protective clothing/ working in 'smelly', 'dirty', 'not-respected' and 'risky' environment	Psychological disorder	n.a.	4
Physical hazards	**17**	Exposure to high noise level from electro- mechanical infrastructure	Noise	ears	2
	18	Exposure to UV irradiation	UV	skin and eye contact	4
	19	Exposure to adverse weather conditions	low and high temperature, storms	skin and eye contact	2

Technology-specific risks (number of risks and risk levels) are seen in Figure 4.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 821051.
This project has been co-funded by Department of Biotechnology (DBT), Government of India.

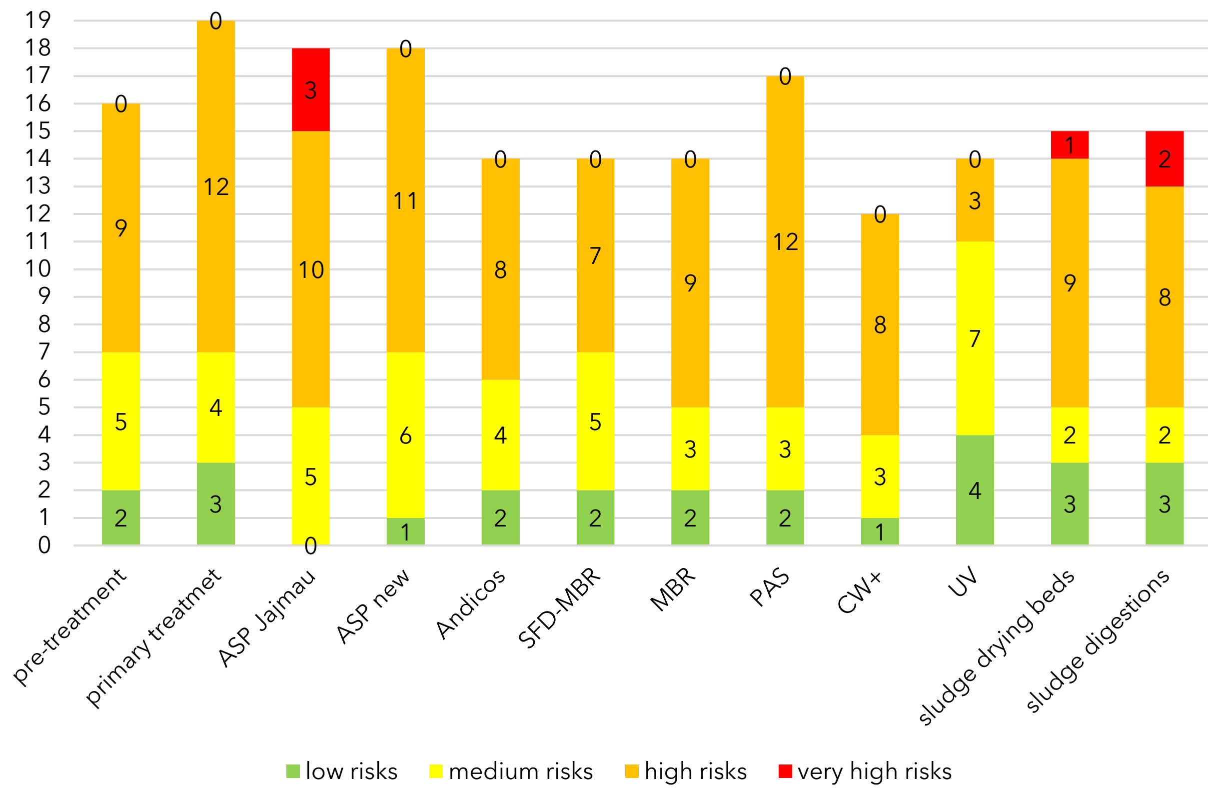


Figure 4 Total number of health risks and risk levels of different unit processes

The primary treatment and the activated sludge systems (incl. PAS) have the highest number of risks (n=17 -19 risks). This is due to the design of the processes. Less risks are detected for enclosed systems such as the membrane technologies Andicos, SFD-MBR and MBR, (n=14 risks) as there are e.g. no risks for physical hazards such as UV radiation or adverse weather and less accident hazards. The risks for vector-related diseases (mosquito-breeding, animal bites) are lower for membrane systems than for the 'open' activated sludge systems. Nature-based systems, such as CW+ (n=12 risks) have the lowest health risks, as they are least prone for accident hazards, such as burns related to heat and chemicals or electric shocks.

The existing ASP system in Jajmau (see Chapter 4) entails two high risks related to the hazards of falling into open vessels (i.e., risks for drowning or acute intoxication). Exposure to aerosols are also high for

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 821051.
This project has been co-funded by Department of Biotechnology (DBT), Government of India.

the existing ASP system in Jajmau, due to the existing aeration systems. For new ASP, this risk can be minimized (from very high to high risk level) due to a more efficient aeration systems producing less aerosols (Deliverable 7.2).

High risks in the treatment trains relate to the sludge management, where contact to biological and chemical hazards is highly likely and needs safety measures when handling the sewage sludge. Both sludge treatment options entail n=15 risks. Digestion of sludge compared to sludge drying beds reduces the physical hazards but increases accident hazards related to burns or heat.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 821051.
This project has been co-funded by Department of Biotechnology (DBT), Government of India.

CHAPTER 4 WASTEWATER SAFETY PLANNING IN KANPUR

4.1 System description

The system diagram for Jajmau STP and the reuse scheme can be found in Figure 5. Note that STP effluent was combined with the effluent from the common effluent treatment plant (CETP) which co-treats sewage and waste from local tanneries (Babalola et al, 2023). The farmers were therefore irrigating with a mixture of STP and CEPT effluent as detailed in Babalola et al, 2023.

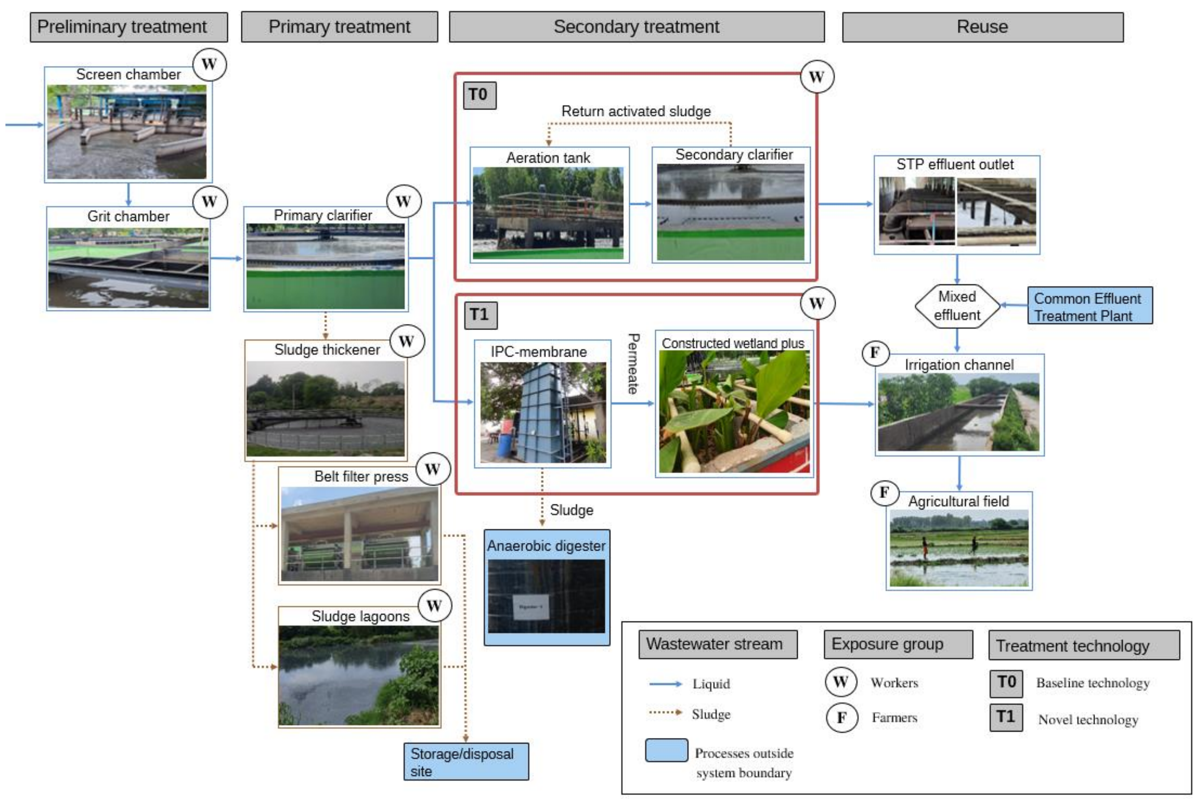
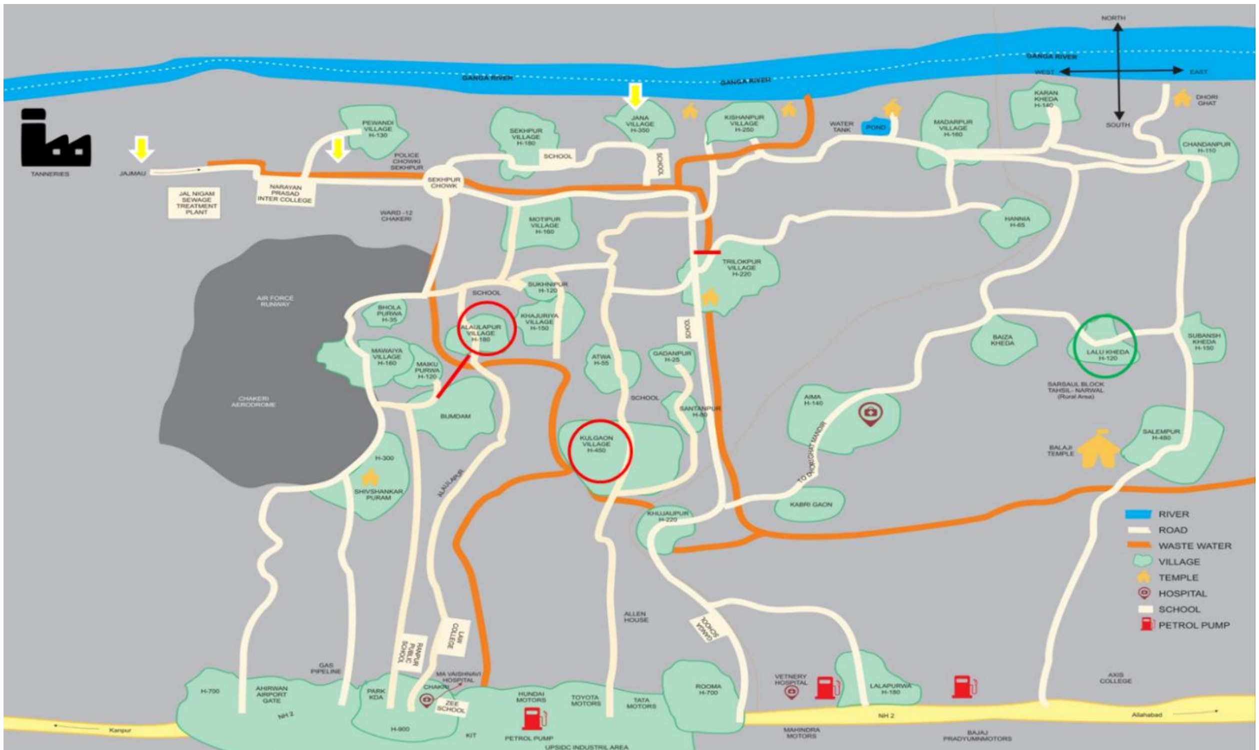


Figure 5 System boundary for Jajmau STP and the reuse scheme (Cedeno-Villarreal 2023, Babalola et al, 2023)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 821051.
This project has been co-funded by Department of Biotechnology (DBT), Government of India.

There are 40 villages located in the peri-urban areas with access to irrigation channels (Figure 6) with a farming community of ca. 4,000 members. Villages chosen for household questionnaires, sanitary inspection, and water quality monitoring (pH, EC and *E.coli)* are Alaulapur and Kulgaon which use the irrigation channel water (circled in red, Figure 6) on their agricultural fields. Kalu Kheda is not using the irrigation channel water and thus was the control community for E. coli monitoring (circled in green, Figure 6).



Name of village	No. of households	Irrigation water
Alaulapur	180	Concrete + earthen channels
Kulgaon	450	earthen channels
Kalu Kheda	120	bore wells

(Source: Solidaridad)

Figure 6 Map of communities alongside irrigation channels in Kanpur, India

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 821051.
This project has been co-funded by Department of Biotechnology (DBT), Government of India.

A baseline assessment in Alaulapur, Kulgaon and Kalu Kheda is conducted in February 2022 to identify:

- available infrastructure (drinking water, sanitation, drainage channels)
- exposure to irrigation channels
- sampling points for E.coli monitoring

During the field visits, drinking water and sanitation infrastructure/exposure to irrigation channels/possible E.coli sampling points were documented with photographs and GPS locations (with a smartphone). Interviews with households helped to identify drinking water and sanitation infrastructure/exposure to irrigation channels and *E. coli* sampling points.

Upon completion of the baseline survey, two follow-up visits (dry and rainy season) to the selected villages was done for the E.coli monitoring of identified sampling points (10 for each village). The results of the baseline survey (Annex A.4) were used for the four MSc theses in Kanpur.

4.2 Risk assessment & management strategies

The risk assessment was based on sampling E.coli and total chromium in the summers of 2022 and 2023, this was combined with data from key informant interviews and structured and unstructured observations (Villarreal 2023, Babalola et al, 2023) and data from the village baseline study (Annex A.4). From these results, a semi-quantitative risk assessment was made which included microbiological, chemical (related to chromium), physical, and ergonomic risks (Furlong et al., 2023).

The theoretical implementation of the novel secondary Pavitra Ganga technology (T1, Figure 7), was considered the technical management strategy. The impact of this technical mitigation measure on STP workers and farmers reusing the effluent can be seen in Figures 7 and 8.

The novel technology increased the number of risks that the STP workers were exposed to, due to this technology having two process steps and only affected the risks related to the secondary treatment as sludge practice remained the same (Figures 7). The number of high and medium-level risk were reduced (Figure 7), this risk reduction was related to the physical structure of the novel processes, which acted as a barrier to exposure to microbiological and chemical risks, and there

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 821051.
This project has been co-funded by Department of Biotechnology (DBT), Government of India.

was also a reduction of risky operation and maintenance activities. Of interest is that the riskiest process in the treatment train is sludge processing, this is because it was largely a manual process that has high risks related to microbiological, chemical, accidental, and ergonomics.

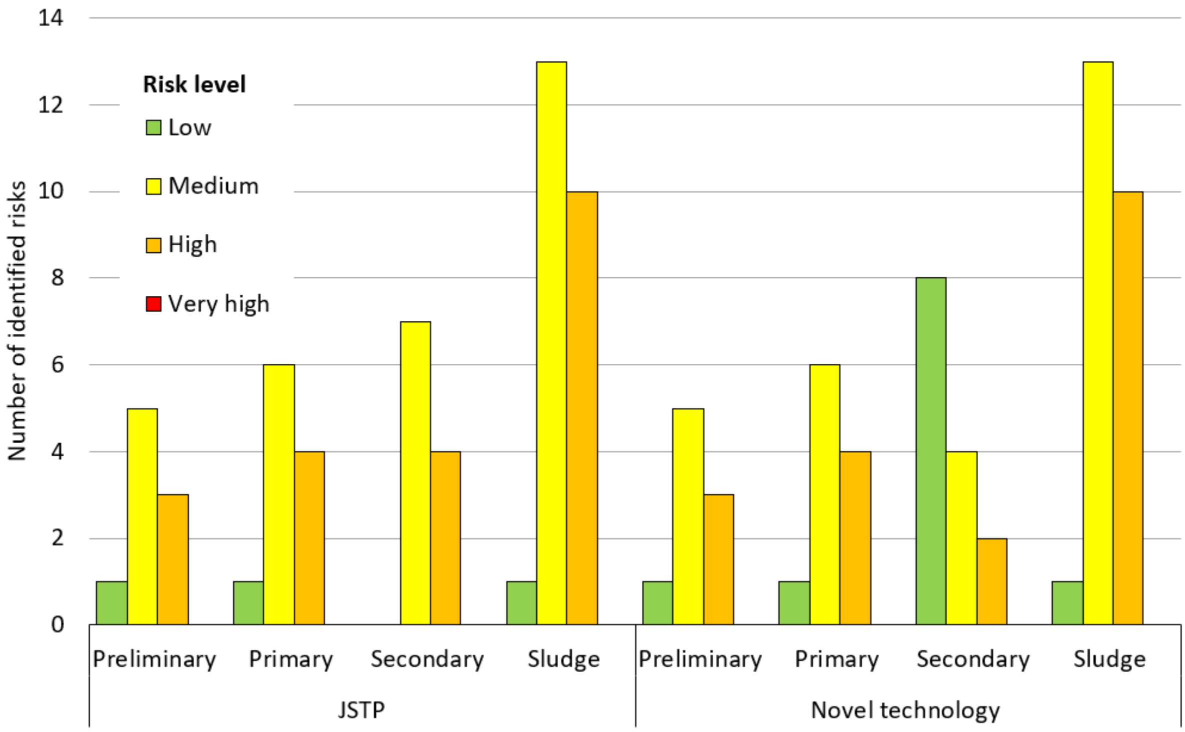


Figure 7 The number and level of risks related to operating and maintaining the Jajmau STP and the novel Pavitra Ganga technology (Furlong et al., 2023)

If the novel technology was implemented the number of risks would remain the same for the farmers, but the risk levels would decrease. The reduction in risk level was related to the reduced exposure to pathogens, due to the novel technology significantly reducing the *E. coli* in the effluent and meeting the discharge standards for India (Babalola et al, 2023). The risks related to exposure to chromium remained the same, as the main source of chromium in the effluent was from the CEPT. Other high-risk activities for the farmers were related to general farming practices and related to physical, accidents and ergonomic risks.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 821051.
This project has been co-funded by Department of Biotechnology (DBT), Government of India.

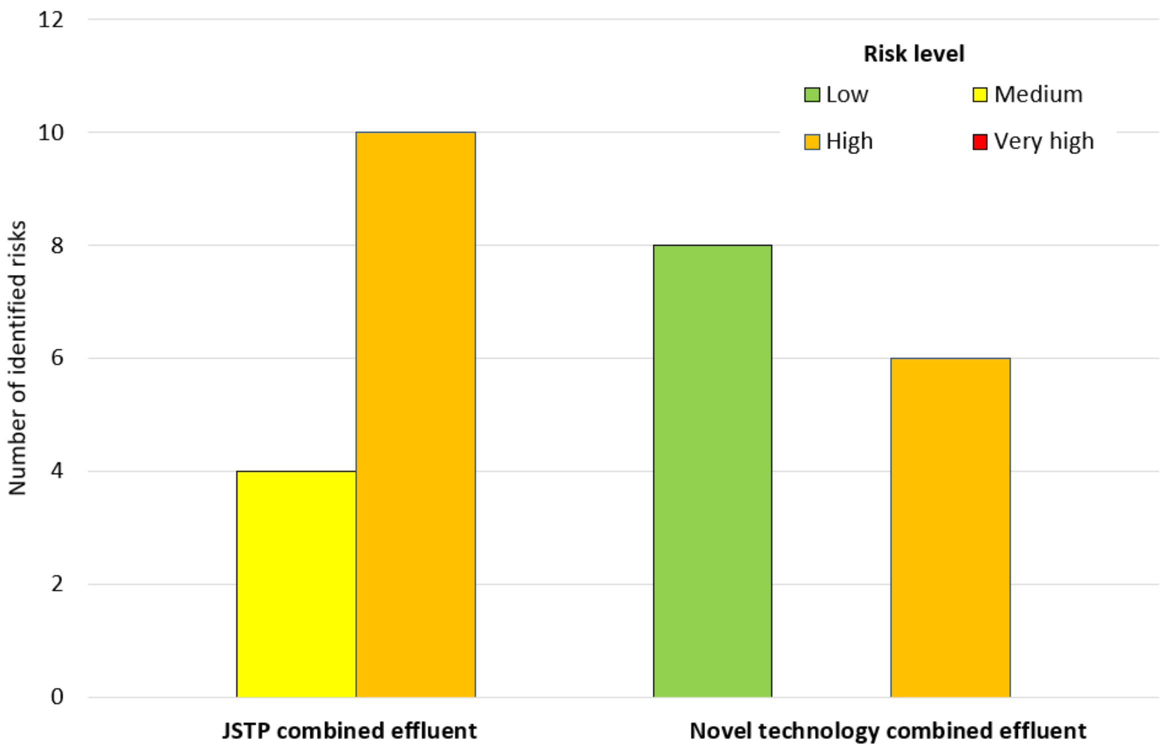


Figure 8 The number and level of risks related to farmers reusing the combined effluent from Jajmau STP and the CEPT, and the novel technology from the Pavitra Ganga project and the CEPT (Furlong et al., 2023).

One publication has already been published related to this work Babalola et al, 2023 and a further two are in preparation.

In December 2023, there was a new CETP and upgrade of STP commissioned at Jajmau, which is thought to improve the Cr and E.coli levels in the irrigation water. During a meeting with the National Mission of Clean Ganga in January 2024, it was concluded to do a follow-up risk assessment (post-project) to assess the impacts of those technological interventions on the downstream villages.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 821051.
This project has been co-funded by Department of Biotechnology (DBT), Government of India.

CHAPTER 5 WASTEWATER SAFETY PLANNING IN DELHI

4.1 System description

The current system diagram for Suez Okhla STP and the reuse scheme can be found in Figure 9, which includes all exposure groups. The effluent from the STP was transported and reused in several ways. There was a direct pipeline for reuse in horticulture (Figure 9). The treated effluent was also collected by tanker and taken to the Delhi Jal Board (DJB) underground storage tank which receives treated effluent from other STPs (Sanyang, 2023). The water in this tank was used by Delhi Development Authority, Municipal Cooperation of Delhi, Delhi Transport Cooperation, New Delhi Municipal Committee, Public Works Department, and railway companies (Sanyang, 2023). It was used for municipal horticulture and washing vehicles (Sanyang, 2023). Finally, tankers would collect the treated effluent and transport it for reuse for road cleaning and irrigating roadside greenery (Sanyang, 2023). Additionally, the treated effluent was sold by the plant for RS 7 per litre for non-drinking purposes and sludge was free for farmers (Sanyang, 2023).

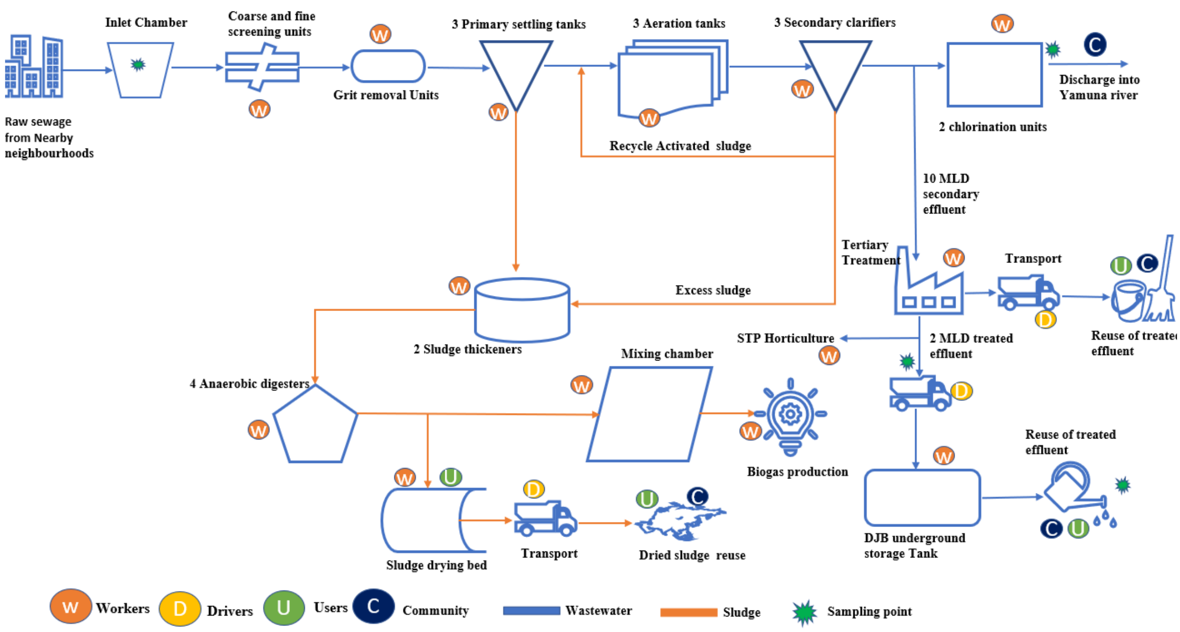


Figure 9 System boundary for Suez Okhla STP and the reuse scheme (Sanyang, 2023)

Due to the highly complicated reuse system and difficulties accessing data, the only reuse activity assessed in this study was the irrigation of parks from the DJB storage tank (Figure 9). The technical mitigation strategy being considered was the photo activated sludge systems (PAS) that

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 821051.
This project has been co-funded by Department of Biotechnology (DBT), Government of India.

was being trailed at the Barapullah drain (cross reference the deliverable). As this is a secondary treatment process, the impact on risks for the STP workers was compared for the current secondary process (activated sludge) and the PAS system only.

4.2 Risk assessment and management strategies

The reuse activity explored was irrigation in Lodi Garden. The E.coli levels in the treated effluent being used were found to be higher than those in the effluent being discharged from Suez Okhla STP (Sanyang, 2023). This was due to the effluent being mixed with effluent from other STPs in the DJB tank (Figure 9), this means that there will be no impact of the novel technology on the risk to those reusing STP effluent in Lodi Garden. The main activities that Lodi Garden workers engaged in were weeding, planting flowers, and watering using sprinklers connected to taps (Sanyang, 2023). None of the workers were observed using personal protective equipment (PPE) during watering (Sanyang, 2023). The risk assessment for these workers can be seen in Table 4. The main risk was related to exposure to pathogens in the treated effluent, this can be mitigated through the monitoring and control of the effluent quality from the other STPs that deliver effluent to the DJB tank. If this is not done the use of appropriate PPE can reduce the risk for these workers.

Table 4 Hazard identification risk assessment for workers reusing the mixed effluent from the DJB tank at Lodi Gardens (Sanyang, 2023)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 821051.
This project has been co-funded by Department of Biotechnology (DBT), Government of India.

Category	Hazards	Hazardous event	Exposure route	Consequence	Existing controls		Risk Assessment Matrix			
					Description of existing control	Validation of control	L	S	Risk Score	Risk Level
Biological Hazards	All microbial Pathogens	Use of water sprinklers resulting in exposure to treated effluent	Ingestion, Inhalation	Contracting faecal oral diseases	Nil	Observation	4	4	16	
	Hookworms		Skin penetration	Hookworm infection	Nil	Observation	3	4	12	
Chemical hazards	Chlorine	Exposure to chlorine during reuse of treated effluent	Ingestion Skin contact	Irritation, impaired vision, indigestion	Nil	Observation	3	2	6	
	Toxic heavy metals	Exposure to toxic heavy metals in treated effluent during reuse	Ingestion	Heavy metal poisoning, brain damage, kidney and liver failure, cancer	Nil	Observation	3	1	3	
Physical hazards	Foul odour	Foul odour generated from treated effluent during reuse	Inhalation	Headache, nausea, Eye nose and lung irritations, and other respiratory problems like coughing, wheezing	Nil	Observation	3	4	12	
	Extreme Heat from sunlight	Long-time exposure to direct sunlight	Environmental exposure	Wrinkles, skin cancer, cataract	Nil	Observation	2	2	4	

Disinfection of the effluents from other STPs should be in place or an additional disinfection of the storage tanks. This can be further supported through the monitoring and control of the effluent quality from the other STPs. If this is not done the use of appropriate personal protective can reduce the risk for these workers. Parks that are irrigated with the treated wastewater should restrict irrigation to low-frequented times of the day and switch to drip irrigation rather than sprinkler to minimize risks for park visitors.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 821051.
This project has been co-funded by Department of Biotechnology (DBT), Government of India.

CHAPTER 6 CONCLUSION

A wastewater safety planning approach was developed and applied to explore how the technologies trialed in the Pavitra Ganga project impact the risk for STP workers and those reusing the treated effluent. These technologies can therefore be considered technical mitigation measures. The approach facilitated a discussion on occupational health and safety related to wastewater treatment and reuse. However, to secure by-in from stakeholders to bring about changed it should be co-creative and participatory.

The occupational hazard checklists of the International Labour Organisation for wastewater treatment plant operators were successfully adapted and used as was the WHOs semi-quantitate risk assessment process. Technology-specific occupational health risks differ between activated sludge systems, membrane systems and the nature-based CW+, especially for accident and physical hazards. Biological, chemical and the ergonomic hazards are similar among the treatment technologies.

Two case studies were used to develop and trial this approach in Kanpur and Delhi. In Kanpur, the Pavitra Ganga technologies (Andicos UF membrane + CW+) reduced the number of high risks the STP operators were exposed to, this was related to the physical structure of these technologies. For the farmers reusing the treated effluent the Pavitra Ganga technology reduced the risks related to pathogen exposure. In Delhi there was no reduction in the risk for those reusing the effluent as it was mixed with effluent from other STPs which did not meet the discharge standards.

Outcomes of the wastewater safety planning tasks:

This task (WP2.4) also produced five MSc theses, three peer-reviewed publications and two conference papers (see references). A workshop at an international conference was used to disseminate the approach and an e- training course was developed. The results and approach were presented to the National Mission of Clean Ganga in Delhi and there will be two follow-up activities: a webinar with STP operators on occupational safety and health is planned and the wastewater safety plan for Kanpur will be repeated to assess the impacts of the newly commissioned CETP, the rehabilitated sewer network and STP for the STP workers and the users of the treated mixed wastewater.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 821051.
This project has been co-funded by Department of Biotechnology (DBT), Government of India.

REFERENCES

Outcomes:

Babalola FM (2022). Exploring the impacts of novel technology on the occupational and community health risks associated with wastewater treatment and reuse in Kanpur, India. MSc Thesis. IHE Delft, Institute for Water Education.

Babalola FM, Breitenmoser L, Furlong C, Campling P, Hooijmans CM (2023). Occupational Health Risk Assessment for Wastewater Treatment and Reuse in Kanpur, India. International Journal of Environmental Research and Public Health. https://doi.org/10.3390/ijerph20126072

Sanyang M (2022). Exploring the use of a novel wastewater treatment technology in reducing the occupational health risks of wastewater treatment plant workers and users of treated effluent. A New Delhi case study. MSc Thesis. IHE Delft, Institute for Water Education.

Cedeno-Villarreal M (2023). The Fate of Chromium in Wastewater Treatment and Reuse, and the associated occupation health risks in Kanpur, India. MSc thesis. IHE Delft, Institute for Water Education.

Cedeno-Villarreal M, Breitenmoser L, Hooijmans C, Furlong C (in preparation). The Fate of Chromium in a Wastewater Treatment and Reuse scheme in Kanpur, India. International Journal of Environmental Research and Public Health

Furlong, C., Cedeño Villarreal K. M., Babalola, F.M.; Breitenmoser, L., Anshuman; Bose, P., Campling, P., Hooijmans, C.M. (2023) Impact of a Novel Technology on Occupational Health Risks Related to Wastewater Treatment and Reuse in Kanpur, India. In Proceedings of the Water and Health, Chapel Hill, North Carolina, USA

Furlong, C., Cedeño Villarreal K. M., Babalola, F.M.; Breitenmoser, L., Anshuman; Bose, P., Campling, P., Hooijmans, C.M. (in preparation). Impact of a Novel Technology on Occupational Health Risks Related to Wastewater Treatment and Reuse in Kanpur, India.

Vilela DR (2023). Seasonal variation in occupational health risk for farming families reusing treated wastewater effluent in Kanpur, India. MSc thesis. IHE Delft, Institute for Water Education.

Nkhoma C (2023). Long term changes in wastewater reuse and health, a case study in Kanpur, India. MSc thesis. IHE Delft, Institute for Water Education.

Other references:

CPHEEO, Central Public Health and Environmental Engineering Organisation, Government of India (2012) Manual on sewerage and sewage treatment. Part A Engineering, New Delhi: Ministry of Urban Development.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 821051.
This project has been co-funded by Department of Biotechnology (DBT), Government of India.

CUPE (2015). Wastewater Treatment Plant – CPE Occupational Health and Safety Bulletin. Wastewater_Treatment_Plant_-_CUPE_Occupational_Health_and_Safety_Bulletin.pdf

Hajare R, Labhasetwar P, Nagarnaik P. Evaluation of pathogen risks using QMRA to explore wastewater reuse options: A case study from New Delhi in India. Water Sci Technol. 2021 Feb;83(3):543-555. doi: 10.2166/wst.2020.583. PMID: 33600360.

ILO (2012). Occupational Hazard Datasheets - Water treatment plant operator. http://www.ilo.org/wcmsp5/groups/public/@ed_protect/@protrav/@safework/documents/publication/wcms_190172.pdf

Schellenberg, T., Subramanian, V., Ganeshan, G., Tompkins, D. and Pradeep, R. (2020) Wastewater Discharge Standards in the Evolving Context of Urban Sustainability–The Case of India. Front. Environ. Sci. 8(30). doi:10.3389/fenvs.2020.00030.

WHO (2006). WHO Guidelines for the Safe Use of Wastewater, Excreta and Greywater (Volume IV: Excreta and greywater use in agriculture). World Health Organization (WHO), Geneva, Switzerland, ISBN: 92 4 154685 9

World Health Organization. (2015). Sanitation safety planning: manual for safe use and disposal of wastewater, greywater and excreta. World Health Organization. https://apps.who.int/iris/handle/10665/171753

World Health Organization. (2016). Quantitative Microbial Risk Assessment: Application for Water Safety Management. ISBN 978 92 4 156537 0

World Health Organization. (2018). Guidelines on sanitation and health. World Health Organization. https://apps.who.int/iris/handle/10665/274939. License: CC BY-NC-SA 3.0 IGO

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 821051.
This project has been co-funded by Department of Biotechnology (DBT), Government of India.

ANNEX

A.1 Risk assessment tables (likelihood, severity)

TOOL 3.3

Suggested risk definitions for semi-quantitative risk assessment

DESCRIPTOR		DESCRIPTION
Likelihood (L)		
1	Very Unlikely	Has not happened in the past and it is **highly improbable** it will happen in the next 12 months (or another reasonable period).
2	Unlikely	Has not happened in the past but **may occur in exceptional circumstances** in the next 12 months (or another reasonable period).
3	Possible	May have happened in the past and/or **may occur under regular circumstances** in the next 12 months (or another reasonable period).
4	Likely	Has been observed in the past and/or is **likely** to occur in the next 12 months (or another reasonable period).
5	Almost Certain	Has often been observed in the past and/or **will almost certainly occur** in most circumstances in the next 12 months (or another reasonable period).
Severity (S)		
1	Insignificant	Hazard or hazardous event resulting in **no or negligible health effects** compared to background levels.
2	Minor	Hazard or hazardous event potentially resulting in **minor health effects** (e.g. temporary symptoms like irritation, nausea, headache).
4	Moderate	Hazard or hazardous event potentially resulting in a **self-limiting health effects or minor illness** (e.g. acute diarrhoea, vomiting, upper respiratory tract infection, minor trauma).
8	Major	Hazard or hazardous event potentially resulting in **illness or injury** (e.g. malaria, schistosomiasis, food-borne trematodiases, chronic diarrhoea, chronic respiratory problems, neurological disorders, bone fracture); and/or may lead to legal complaints and concern; and/or major regulatory non-compliance.
16	Catastrophic	Hazard or hazardous event potentially resulting in **serious illness or injury , or even loss of life** (e.g. severe poisoning, loss of extremities, severe burns, , drowning); and/or will lead to major investigation by regulator with prosecution likely.

TOOL 3.4

Semi-quantitative risk assessment matrix

			SEVERITY (S)				
			Insignificant	Minor	Moderate	Major	Catastrophic
			1	2	4	8	16
LIKELIHOOD (L)	Very unlikely	1	1	2	4	8	16
	Unlikely	2	2	4	8	16	32
	Possible	3	3	6	12	24	48
	Likely	4	4	8	16	32	64
	Almost Certain	5	5	10	20	40	80
Risk Score R = (L) x (S)			<6	7–12		13–32	>32
Risk level			Low Risk	Medium Risk		High Risk	Very High Risk

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 821051.
This project has been co-funded by Department of Biotechnology (DBT), Government of India.

A.2 Water reuse guidelines

Table A.1: Water reuse quality requirements for agricultural reuse of different water reuse guidelines (Part 1)

		WHO (2006)							Australian guidelines for water recycling (2006)					US EPA (2012)			EC (2018)			
Parameter			unrestricted irrigation				restricted irrigation		Landscape irrigation	Commercial food cr	Commerc	Commerc	Non-food	Food crops	processed food crops and non-food c		Water quality	Water quality	Water quality	Water qualit
		root crops	leaf crops	high growing cr	drip irrigation	labour-intensive	Highly me	Septic tank									all food crops	Food crops co	Food crops co	Industrial, er
E.coli/100mL		≤1000	≤10000	≤100000	≤100000	≤10000	≤100000	≤1000000		<1					0 ≤ 200					
E.coli (CFU/100mL)									<1000		<100	<1000	<10000				≤ 10	≤ 100	≤ 1000	≤ 10000
Helminth eggs per L		≤1	≤1	n.a.	≤1	≤1		≤1									≤1	≤1	≤1	≤1
Legionella ssp (CFU/L)																	<1000	<1000	<1000	<1000
BOD (mg/L)									<20		<20	<20		≤ 10	≤ 30		≤ 10	<25	<25	<25
COD (mg/L)																		<125	<125	<125
SS (mg/L)									<30		<30	<30								
TSS (mg/L)															≤ 30		≤ 10	<35	<35	<35
pH				6.5-8.0										6.0-9.0	6.0-9.0					
Turbidity (NTU)														≤ 2			≤ 5			
Cl2 residual (mg/l)														1	1					
		no restriction on use	slight to moderat	severe restriction on use										no restriction on use	slight to moderate r	severe restriction on use				
Salinity ECw (dS/m) (electrical conductivity in de		<0.7	0.7-3.0	>3.0										<0.7	0.7-3.0	>3.0				
TDS (mg/L)		<450	450-2000	>2000										<450	450-2000	>2000				
TSS (mg/L)		<50	50-100	>100										>0.7 ECw	0.7-0.2 ECw	<0.2 ECw				
SAR (meq/L) (sodium adsorpt	0-3	>0.7 ECw	0.7-0.2 ECw	<0.2 ECw										>1.2 ECw	1.2-0.3 ECw	<0.3 ECw				
SAR (meq/L)	3-6	>1.2 ECw	1.2-0.3 ECw	<0.3 ECw										>1.9 ECw	1.9-0.5 ECw	<0.5 ECw				
SAR (meq/L)	6-12	>1.9 ECw	1.9-0.5 ECw	<0.5 ECw										>2.9 ECw	2.9-1.3 ECw	<1.3 ECw				
SAR (meq/L)	12-20	>2.9 ECw	2.9-1.3 ECw	<1.3 ECw										>5.0 ECw	5.0-2.9 ECw	<2.9 ECw				
SAR (meq/L)	20-40	>5.0 ECw	5.0-2.9 ECw	<2.9 ECw		*on the basis of FAO (1985)*								<3	>3					
Sodium (Na+) (meq/L)	Sprinkler irrigation	<3	>3											<3	3-9	>9				
Sodium (Na+) (meq/L)	Surface irrigation	<3	3-9	>9										<3	>3					
Chloride (Cl-) (meq/L)	Sprinkler irrigation	<3	>3											<4	4-10	>10				
Chloride (Cl-) (meq/L)	Sprinkler irrigation	<4	4-10	>10																
Chloride (CL2) (mg/L)	Surface irrigation	<1	1-5	>5																
Bicarbonate (HCO3-) (mg/L)		<90	90-500	>500																
Bicarbonate (HCO3-) (meq/L)														<1.5	1.5-8.5	>8.5				
Boron (B) (mg/L)		<0.7	0.7-3.0	>3.0																
Hydrogen sulfide (H2S) (mg/L)		<0.5	0.5-2.0	>2.0										<0.7	0.7-3.0	>3.0				
Iron (Fe) (mg/L)	Drip irrigation	<0.1	0.1-1.5	>1.5																
Manganese (Mn) (mg/L)	Drip irrigation	<0.1	0.1-1.5	>1.5																
Total nitrogen (TN) (mg/L)		<5	5-30	>30																
Nitrate (NO3-N) (mg/L)														<5	5-30	>30				
		Recommended maximum concentration							long-term trigger value (mg/L)	short-term trigger value (mg/L)				Maximum concentrations for irrigation						

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 821051.
This project has been co-funded by Department of Biotechnology (DBT), Government of India.

Table A.2: Water reuse quality requirements for agricultural reuse of different water reuse guidelines (Part 2)

Parameter	WHO (2006)							Australian guidelines for water recycling (2006)					US EPA (2012)		EC (2018)			
	unrestricted irrigation				restricted irrigation			Landscape irrigation	Commercial food cr	Commerc	Commerc	Non-food	Food crops	processed food crops and non-food c	Water quality	Water quality	Water quality	Water qualit
	root crops	leaf crops	high growing cr	drip irrigation	labour-intensive	Highly me	Septic tank								all food crops	Food crops co	Food crops co	Industrial, er
Aluminium (mg/L)	5.00							5.00	20.00				5.00					
Arsenic (mg/L)	0.10							0.10	2.00				0.10					
Barium (mg/L)																		
Beryllium (mg/L)	0.10							0.10	0.50				0.10					
Boron (mg/L)								0.50	0.5-15				0.75					
Cadmium (mg/L)	0.01							0.01	0.05				0.01					
Cobalt (mg/L)	0.05							0.05	0.10									
Chromium (III) (mg/L)																		
Chromium (VI) (mg/L)								0.10	1.00									
Chromium (mg/L)	0.10												0.10					
Copper (mg/L)	0.20							0.20	5.00				0.20					
Fluoride (mg/L)	1.00							1.00	2.00				1.00					
Iron (mg/L)	5.00							0.20	10.00				5.00					
Lithium (mg/L)	2.50							2.50	2.50				2.50					
Manganese (mg/L)	0.20							0.20	10.00				0.20					
Methylmercury (mg/L)																		
Mercury (inorganic) (mg/L)								0.00	0.00									
Molybdenum (mg/L)	0.01							0.01	0.05				0.01					
Nickel (mg/L)	0.20							0.20	2.00				0.20					
Lead (mg/L)	5.00							2.00	5.00				5.00					
Selenium (mg/L)	0.02							0.02	0.05				0.02					
Uranium (mg/L)								0.01	0.10									
Vanadium (mg/L)	0.10							0.10	0.50				0.10					
Zinc (mg/L)	2.00							2.00	5.00				2.00					

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 821051.
This project has been co-funded by Department of Biotechnology (DBT), Government of India.

Table A.3: Water reuse quality requirements for environmental, urban and industrial reuse of different water reuse guidelines

	environmental reuse			urban reuse							industrial reuse	
	US EPA (2012)			Australian guidelines for water recycling (2006)					US EPA (2012)		US EPA (2012)	
Parameter	Environmental	Impoundments - unrestricted	Impoundments- restricted	Dual reticulation, toilet flushing washing machines, garden use	Dual reticulation- outdoor use only or indoor use only	Municipal use- open spaces, sports grounds, golf courses, dust suppression, etc. or unrestricted access and application	Municipal use, with restricted access and application	Municipal use, with enhanced restrictions on access and application	Unrestricted	Restricted	Once-through cooling	recirculating cooling towers
E.coli/100mL	≤ 200	0	≤ 200	<1	<1	<1			0	≤ 200	≤ 200	≤ 200
E.coli (CFU/100mL)							<100	<100				
Helminth eggs per L												
Legionella ssp (CFU/L)												
BOD (mg/L)	≤ 30	≤ 10	≤ 30				<20	<20	≤ 10	≤ 30	≤ 30	≤ 30
COD (mg/L)												
SS (mg/L)							<30	<30				
TSS (mg/L)	≤ 30		≤ 30							≤ 30	≤ 30	≤ 30
pH		6.0-9.0							6.0-9.0	6.0-9.0	6.0-9.0	6.0-9.0
Turbidity (NTU)		≤ 2							≤ 2			
Cl2 residual (mg/l)	1	1	1						1	1	1	1

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 821051.
This project has been co-funded by Department of Biotechnology (DBT), Government of India.

A.3 Technology-specific risk assessment

Hazard Identification						pre-treatment		primary clarifier		ASP existing		ASP NEW		Andicos		SFD-MBR		MBR		PAS		CW		UV		sludge drying beds		digester	
Category	No	Hazardous event	Hazard	Exposure route	S	L	Score	L	Score	L	Score	L	Score	L	Score	L	Score	L	Score	L	Score	L	Score	L	Score	L	Score	L	Score
Accident hazards	1	Exposure to hazardous gases when working in confined places	Hydrogen sulfide & malodor	Inhalation	8	5	40	5	40	5	40	4	32	3	24	3	24	3	24	3	24	3	24	1	8	4	32	5	40
	2	Accidents from contact with sharp objects, electrical devices (naked wires), spillages during daily inspection and sample collection	Falls, slips	Skin or eye contact, accidental ingestion	2	3	6	3	6	4	8	3	6	2	4	2	4	2	4	3	6	2	4	1	2	3	6	2	4
	3		Electric shock		4	2	8	1	4	3	12	2	8	2	8	2	8	3	12	3	12	1	4	2	8	1	4	2	8
	4		Cuts and pricks		2	2	4	2	4	3	6	2	4	2	4	2	4	2	4	2	4	3	6	2	4	2	4	2	4
	5		Burns (heat, chemicals)		8	1	8	1	8	2	16	1	8	2	16	1	8	2	16	0	0	0	0	2	16	0	0	3	24
	6		Other injuries (especially for the eyes, e.g. by flying particles, splashes of liquids)		8	2	16	2	16	2	16	2	16	2	16	2	16	2	16	2	16	0	0	1	8	0	0	2	16
	7	Falling into the open vessels	Drowning		16	0	0	2	32	3	48	2	32	0	0	0	0	0	0	2	32	0	0	0	0	0	0	0	0
	8		Acute posoning/intoxication		16	0	0	2	32	3	48	2	32	0	0	0	0	0	0	2	32	0	0	0	0	2	32	1	16
Biological hazards	9	Exposure to aerosols	Microbial pathogens	Inhalation	8	3	24	4	32	5	40	4	32	2	16	3	24	2	16	4	32	3	24	1	8	2	16	2	16
	10	Exposure to untreated sewage or sludge during operation and maintenance of the system	Microbial pathogens, skin irritants	Skin or eye contact, accidental ingestion	8	3	24	3	24	4	32	3	24	2	16	2	16	2	16	3	24	3	24	1	8	5	40	5	40
	11	Mosquito breeding in surface or standing water	Vector-related diseases	Mosquito bites	4	4	16	5	20	4	16	4	16	0	0	0	0	0	0	4	16	4	16	0	0	1	4	0	0
	12	Exposure to animals (rodents, snakes) proliferating on STP premises	Vector-related diseases	Animal bites	8	3	24	3	24	3	24	3	24	1	8	1	8	1	8	3	24	4	32	1	8	4	32	3	24
Chemical hazards	13	Exposure to chemicals required for the process.	Chemicals	Accidental ingestion. Inhalatio or skin contact	8	0	0	2	16	0	0	0	0	2	16	2	16	2	16	0	0	0	0	2	16	2	16	2	16
	14	Exposure to chemicals in the wastewater/sludge			8	3	24	3	24	3	24	3	24	2	16	2	16	2	16	3	24	3	24	1	8	5	40	5	40
Ergonomic and psychological hazards	15	Musculoskeletal disorder from taking uncomfortable postures during operation and maintenance.	Musculoskeletal injuries	Uncomfortable working postures, overexertion	4	2	8	2	8	2	8	2	8	2	8	2	8	2	8	3	12	2	8	1	4	3	12	2	8
	16	Discomfort and psychological problems due to prlonged wear of protective clothing/ working in 'smelly', 'dirty', 'not-respected' and 'risky' environment	Psychological disorder	n.a.	4	3	12	3	12	3	12	3	12	3	12	3	12	3	12	3	12	3	12	3	12	4	16	4	16
Physical hazards	17	Exposure to high noise level from electro- mechanical infrastructure	Noise	ears	2	2	4	2	4	3	6	3	6	3	6	3	6	4	8	1	2	0	0	1	2	0	0	2	4
	18	Exposure to UV irradiation	UV	skin and eye contact	4	4	16	4	16	4	16	4	16	0	0	0	0	0	0	4	16	4	16	0	0	4	16	0	0
	19	Exposure to adverse weather conditions	low and high temperature, storms	skin and eye contact	2	4	8	4	8	4	8	4	8	0	0	0	0	0	0	4	8	4	8	0	0	4	8	0	0

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 821051.
This project has been co-funded by Department of Biotechnology (DBT), Government of India.

A.4 Results baseline survey and e.coli monitoring

	Alaulapur (% of HH)	Kulgaon (% of HH))	Lalu Kheda (% of HH)
Toilet available (Flush toilet with septic tank)	41%	73%	89%
Open defecation (outside house premises)	52%	24%	0%
Open defecation (into open drains)	7%	3%	11%
Sludge disposal (private trucks)	0%	55%	0%
Sludge disposal (pit collectors manually or with machine)	91%	41%	69%
Sludge disposal (other)	9%	4%	31% (twin pit)

Low risk score

Medium risk score

High risk score

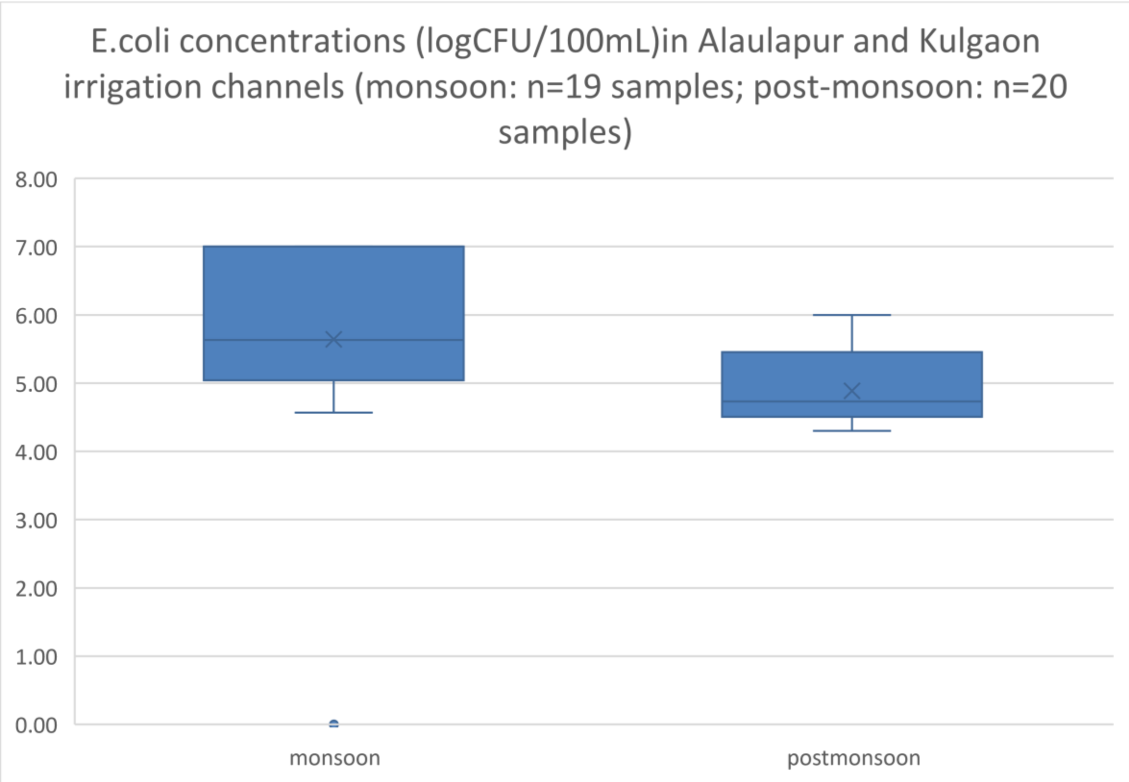
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 821051.
This project has been co-funded by Department of Biotechnology (DBT), Government of India.

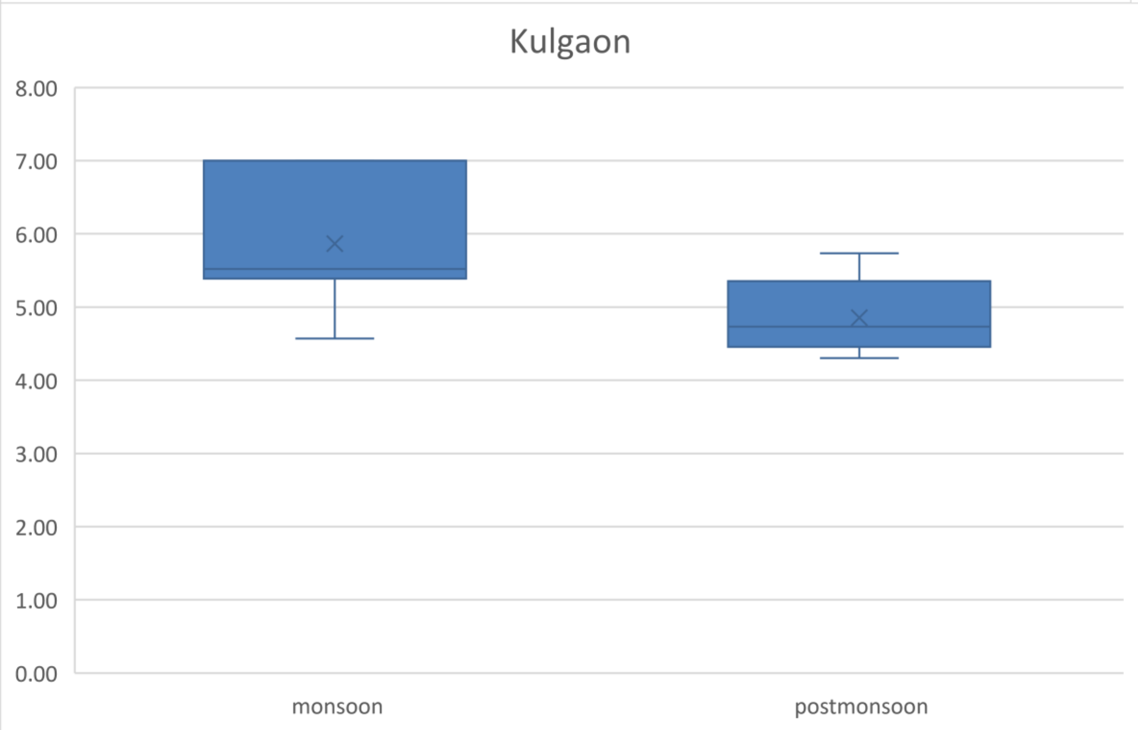
In all three villages drinking water is mostly collected from water source and stored in buckets/pots in the house → **Observational checklists for collection/storage containers**

	Alaulapur (% of yes observations)	Kulgaon (% of yes observations)	Lalu Kheda (% of yes observations)
Collection container is cracked, leaking or unclean	0%	0%	0%
Collection container is used to store any liquids other than drinking water	0%	0%	0%
When not in use, collection container is kept in a place where it may become contaminated	55%	30%	11%
The storage container is kept covered	30%	60%	44%
The storage container is kept at a height	26%	17%	6%
The container for collection and storage is clean	60%	57%	94%
There is a ladle kept near the storage container for use	4%	7%	11%
% of HH inserting hand with cup/mug/glass to withdraw water	63%	90%	84%
% of HH cleaning vessels daily	78%	93%	100%

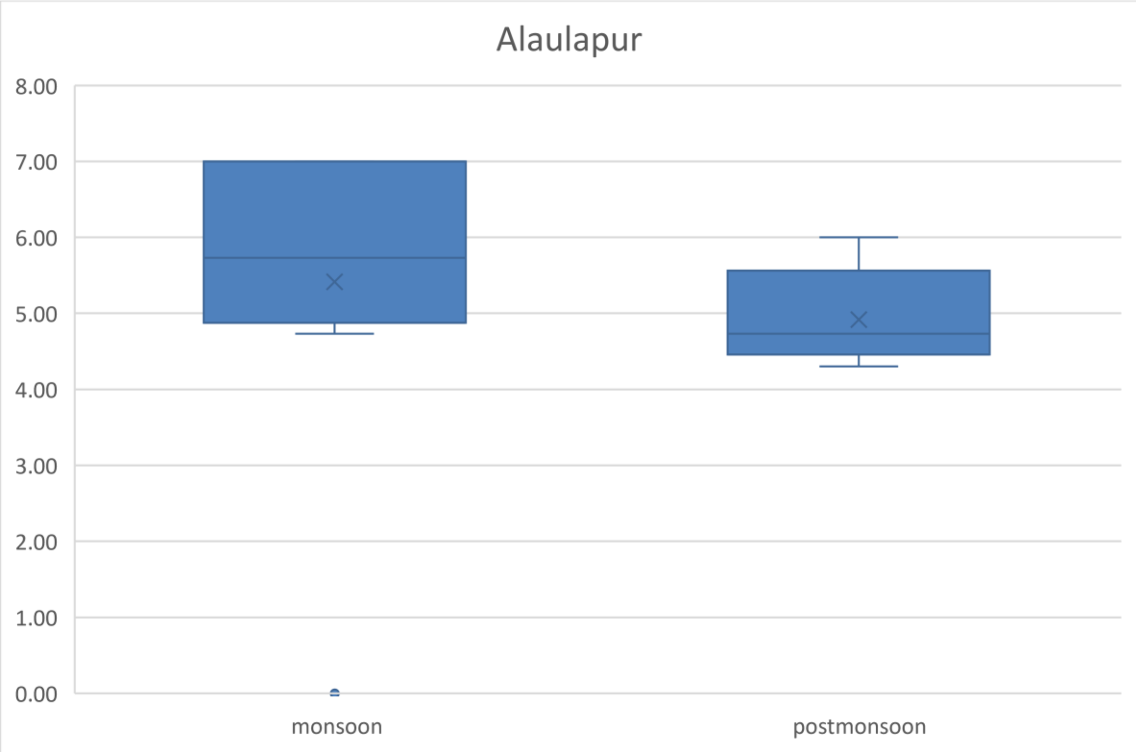
Low risk score
Medium risk score
High risk score

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 821051.
This project has been co-funded by Department of Biotechnology (DBT), Government of India.





This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 821051.
This project has been co-funded by Department of Biotechnology (DBT), Government of India.



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 821051.
This project has been co-funded by Department of Biotechnology (DBT), Government of India.