Multi-criteria decision analysis (MCDA) and portfolio models to support regional wastewater management

Deliverable D2.3

Final version (public)

WP2 Water governance, stakeholder engagement and policy support

Task 2.2 *Co-creation workshops to identify with stakeholders the critical issues and strategies for wastewater treatment and management*

Task 2.3 *Multi criteria decision analysis and portfolio decision analysis modelling to assess the technologies and strategy portfolios based on their objective performance and their subjective desirability for regional water management*

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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
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SUMMARY

The aim of the Pavitra Ganga project is to "*define innovative, cost effective and energy efficient solutions for the treatment of (unregulated) drains in India*" (see webpage www.pavitra-ganga.eu). These are necessary to address the overexploitation of water resources and pollution in India, resulting in severe water stress. The project proposes to do so by focusing on technical improvements in terms of existing wastewater treatment installations and harnessing the opportunities of water reuse an resource recovery ('RRR') in urban and peri-urban settings. These are being piloted in two case study areas: the Barapullah drain in Delhi and the Jajmau area in Kanpur. The focal objective of the activities conducted in work package (WP) 2 on "Water governance, stakeholder engagement and policy support" – to which this deliverable pertains – is: *to create policy and social support for innovative technologies for wastewater treatment, reuse and resource recovery*. In this report, we present the stakeholder engagement approach and co-creation activities supporting this goal. This included a problem structuring phase, followed by a conceptual multi-criteria and portfolio decision analysis (hereafter 'MCDA' and 'PDA', respectively).

The COVID-19 pandemic seriously impacted the project, including the stakeholder engagement and related modelling activities foreseen in this work package. We had planned to conduct 5 full-day in-person co-creation workshops, 2 in each case study area and a joint workshop to identify the critical issues, solution strategies for wastewater treatment and management and respective evaluation criteria. These would then be used as input for model-based assessment of the anticipated performance outcomes and desirability of the technical solutions and regional portfolio combinations, supported by MCDA and PDA modelling. Given the circumstances, we switched to an online format with shorter workshops, interspersed by online or telephone interviews to collect additional stakeholder information and reflections. In sum, 7 online stakeholder workshops were held in addition to 30 stakeholder interviews. In the absence of performance results from the technology pilots, we relied on available literature and expert judgment by stakeholders both internal and external to the project consortium. Finally, a simplified MCDA and PDA analysis was conduced, using qualitative assessments for Delhi and basic quantitative assessments for Kanpur. Through the online engagements and co-creation workshops, rich insights on the situation, stakeholder goals and possible concerns regarding the technical solutions considered by local, state and national policy makers were obtained. As a side-effect of the pandemic, valuable experiences were gathered on conducting co-creation in an online context in India.

Our findings highlight the complexity of wastewater treatment and RRR in both case areas demanding for a holistic and systemic understanding of the problem and interventions across spatial, administrative, and time scales. This complexity is reflected in the sheer number of identified stakeholder organisations with a potential interest in, and leverage over, the system regarding wastewater management, reuse and resource recovery. The initial screening resulted in more than 60 organizations for each case area with overlaps at national-level. A reduced list with high-power/-interest organizations still included 30 stakeholders from local, state and national levels. Of these, 19 could be mobilized to participate in the project. The absence of local government representatives seems noteworthy given their crucial role as (co-)owners of both the local issues and possible

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solutions. During problem structuring and issues mapping, a great diversity of perspectives on the system behaviour and issues concerning wastewater management and RRR were identified. These related to different system boundary perceptions regarding the spatial scale and reach of the wastewater treatment technology and the environment it is embedded into, administrative scales relating to organizational and administrative responsibilities, as well as the scope of the political, social and economic consequences for different stakeholders.

The variety of issues and solutions explored in both cases indicate that the development of wastewater management and RRR solutions needs to go beyond identification and optimization of treatment technologies to fit the local conditions. Rather, the antecedent political, governance, regulatory, financial, capacity, and societal behaviour-releated preconditions and accompanying measures need to be created such that suitable technical solutions can be adopted and sustained over the longer term. With these conditions in place, the priority objectives that technical solutions need to achieve as per the perspectives of the participating stakeholders were identified. These relate to the improvement of the livelihoods of the local communities (in Kanpur focused on farmers, tanners and health of the general public; in Delhi with a focus on residents in formal and informal settlements), reducing impacts on natural and urban environments of wastewater and sludge, ensuring reliability of water treatment and transport (continuity and quality) and achieving coverage of life-cycle costs of the technical infrastructure (esp. ensuring operation and maintenance). We found that the technologies piloted in the project align well with the solutions identified by the stakeholders for their local context. Even so, based on the stakeholder and piloting information available at the time it was not possible to determine whether any of the solutions is clearly more desirable or better. What the results of the qualitative and quantiative assessments did show is that the individual technologies alone cannot satisfy the objectives and needs of the cases. Instead, combination into portfolios guided by the identified goals is needed for desirable solutions that can address the challenges. Taking into account the identified bottlenecks and critical enabling conditions can be used in planning for successive roll-out over time to ensure the adoption and sustained functioning of technical wastewater technology, reuse and resource recovery solutions.

As regards the co-creation process, participating stakeholders appreciated the inclusive discussion of diverse stakeholder perspectives and expertises as facilitated via the online co-creation process on the matter of issues and possible solutions that are marginalized in the current discourse. Moreover, our going beyond ‘sensitization’ towards better understanding of system-level issues and possibilities for joint action was positively noted. To move further, the participants see a need for further local engagement and bilateral discussions (including in-person discussions), especially including local government officials and regulatory agencies who were thus far missing, to develop implementable strategies. With a perspective on the scientific community, our work has shown that despite the challenges, it is possible to successfully implement co-creation processes with multiple stakeholders in India online. In the future, combining online and offline events in a hybrid manner has promise to facilitate deeper-discussions and negotiations across actors towards systemic solutions to address mounting global challenges.

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TABLE OF CONTENTS

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.

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LIST OF FIGURES

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

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 821051.

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LIST OF ABBREVIATIONS

WW	**Wastewater**
CETP	Common Effluent Treatment Plant
STP	Sewage Treatment Plant
WP	Work Package
MCDA	Multi-Criteria Decision Analysis
PDA	Portfolio Decision Analysis
TERI	The Energy Research Institute
MoU	Memorandum of Understanding
SODA	Systematic Options Development Analysis
UPJN	Uttar Pradesh Jal Nigam
MLD	Millions of Liter per Day
NMCG	National Mission for Clean Ganga
JTETA	Jajmau Tannery Effluent Treatment Association
LIWA	Leather Industries Welfare Association
CLRI	Central Leather Research Institute
BOD	Biochemical Oxygen Demand
DO	Dissolved Oxygen
DDA	Delhi Development Authority

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CHAPTER 1 INTRODUCTION

The objective of Work Package 2 “Water governance, stakeholder engagement and policy support” is to create policy and social support for innovative technologies and concepts through a co-creation process in which stakeholders are engaged in the framing of the problem and the creation of promising water management solutions as well as relevant criteria for their performance and desirability assessment in the two case areas. Problem-focused learning processes and decision support models will lead to targeted decision support to policy makers. The specific objectives are to:

- Analyse (successful and unsuccessful) water governance systems across India and internationally for delivering improved wastewater treatment, re-use and resource recovery solutions;
- Identify the critical water quality issues and related socio-economic problems for wastewater treatment, re-use and resource recovery in urban and peri-urban areas;
- Develop structured decision support processes and multi-criteria decision analysis models to support regional water management in the case study areas; and,
- Develop technology specific sanitation safety plans to assess, priorities' and mitigate exposure risks associated to wastewater treatment and reuse.

The second objective of WP2 defines Task 2.2 “Co-creation workshops to identify with stakeholders the critical issues and strategies for wastewater treatment and management”. In this task, we build on the first insights from the consultations held in the course of Task 2.1 to achieve a more comprehensive understanding of the complex and systemic issues pertaining to the wastewater treatment, reuse and resource recovery as perceived by local stakeholder. These insights serve as input for Task 2.3 “Multi criteria decision analysis and portfolio decision analysis modelling to assess the technologies and strategy portfolios based on their objective performance and their subjective desirability for regional water management”. Task 2.3 supports the third objective stated above. This would allow us to pinpoint promising options to pursue further, as well what accompanying measures might need to be considered to facilitate their uptake, implementation and sustainability over the longer term. In doing so, we are also taking into account the performance of the technological solutions for improving water quality (WP3 and WP5) that are developed and piloted within the Pavitra Ganga project (next to relevant insights from modelling in WP4). The insights on conducting structured decision support processed within the Indian context shall furthermore contribute to actionable knowledge on methodology and skills to further wastewater treatment, reuse and resource recovery in India.

The COVID-19 crisis has significantly affected our ability to mobilize stakeholders and to conduct fieldwork in both case areas. As a result, the stakeholder analysis could only be conducted in January 2021, followed by interviews and another interruption due to another COVID wave. Co-creation workshops and activities for WP2 could only be resumed from July 2021 onwards. Works in WP3, WP4, and WP5, which should provide

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inputs for the MCDA assessments be still under development. Hence, we had to adapt our approach for the co-creation activities and subsequent analyses as described in this preliminary D2.3 report.

The rest of the report is structured as follows. The next chapter discusses the stakeholder engagement approach, including Problem Structuring followed by conceptual multi-criteria decision analysis (MCDA) and Portfolio Decision Analysis (PDA) modelling, and finally a description of two case study areas. Chapter 3 elaborates on the results for Kanpur and Delhi; and Chapter 4 reports on the alternatives and portfolio discussion and desirability from the perspective of the stakeholders involved. Chapter 5 presents process and technology-based discussions of research findings using comparative analysis. Finally, the conclusion chapter elaborates on the key debates that have emerged and implications of the study.

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CHAPTER 2 APPROACH FOLLOWED IN THE CO-CREATION PROCESS

2.1. STAKEHOLDER ENGAGEMENT AND CO-CREATION APPROACH

In the following, the proposed approach, the challenges faced, and the adaptations made in light of these are presented. Multi-stakeholder partnerships and stakeholder engagement is a core component of this project, to enhance the acceptability and sustainability of identified interventions. A stakeholder engagement process was employed to understand the challenges related to wastewater management on the ground and discuss feasible solutions from stakeholders' perspectives.

Building onto activities in Task 2.1, an institutional mapping was conducted on central, state, district and community level agencies involved in different aspects of water management at the two case areas in Kanpur and Delhi. The focus of this activity was to understand the policies and programs of various agencies, their role in the decision-making process and inter-institutional synergies. Additionally, it also helped in identification of concerned departments and designation for the consultation process. Key policies and programs at Central and State level were analyzed to understand the overarching framework that governs water use in the two sites. Following the mapping process, key stakeholders were identified at a four-tier level: Central Government, State Government, District Authorities and Civil Society (comprising of Non-Governmental Organizations, Resident Welfare Associations, Community Associations, Corporate groups and Research/Academia) to undertake consultations on critical issues and strategies on wastewater treatment, water reuse and resource recovery. The stakeholder consultations were designed such as to understand the current wastewater management situation in Delhi and Kanpur, to discuss the key issues related to water quality, technology as well as social and economic aspects and devising wastewater management strategies for the two pilot sites through a co-creation process with the stakeholders. Scoping was conducted through in-person stakeholder consultation workshops in Delhi and Kanpur in February and March 2020 respectively to understand the opinions and views of diverse stakeholders on core challenges and opportunities of wastewater treatment and resource recovery in India.

After the initial scoping workshops in February 2020, the COVID-19 pandemic led to travel restrictions across the globe as well as various lockdown restrictions. During several months, we focused our efforts on testing the possibility to conduct our stakeholder engagement activities online. By summer 2020, we started the co-creation trajectory online as travel and in-person workshops were still not possible. Based on the experience of the internal test workshops, we judged that an online format would require shifting to a shorter meeting format instead of the planned half or full day sessions mentioned in the earlier proposal, in order to ensure active participation. Furthermore, ensuring an interactive co-creation format where everybody would have a voice required us to limit participation in the workshops to a smaller group of actors per case area. Additional inputs were collected from selected stakeholders through bilateral consultation on the workshop outcomes.

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However, a limited set of key stakeholders that would be sufficiently representative of the relevant actors and both willing and able to take part throughout the online co-creation trajectory needed to be identified and mobilized. In addition, the scope of the case study area in Delhi needed to be agreed with Pavitra Ganga partners to satisfy needs from perspective of both the location and the planned Pavitra Ganga activities. To remediate this situation, we conducted a stakeholder analysis internally with two senior experts of TERI and IRAP that was completed in December 2020. This led to identification of more than 30 relevant stakeholders in Kanpur and more than 40 in Delhi including participants from central government, state government, local authorities, civil society, private sector, educational institutes, and research and policy advocacy organizations. The list was narrowed down based on interest and power concerning the focus of the project as well as judgment on willingness and ability to take part in the full co-creation trajectory. Following consultations with senior members of the urban local bodies, the spatial boundaries and therewith administrative, environmental and spatial scope of the case study area in the Barapullah Drain in Delhi could be narrowed down by end of January 2021.

We started the co-creation process in Kanpur and Delhi in February 2021. Contact with participants was established via phone calls or the mobile messaging service WhatsApp to enquire about their willingness to participate in the co-creation trajectory and consult them for respective modalities. Mobilization of stakeholders progressed slowly, and various approvals needed to be obtained and MoUs be signed within respective stakeholder organizations following their decision-making procedures. The process was further halted because of the second COVID wave in India from March to June 2021. Adapting to the given circumstances, we designed a series of short, online co-creation workshops lasting between 1.5 and 3 hours each. Moreover, we needed to complement these by bilateral consultations and interviews with workshop participations or external experts in preparation of the workshops as well as for consolidation of outputs in between. These were to collect perspectives and concerns that would not be shared openly in a group setting and to understand points made in greater depth when the short workshop interactions would not allow us to dwell deeper on some aspects. The bilateral interviews and discussions would also allow us to establish a more direct rapport and a basis of trust.

Based on the initial participant engagements, the co-creation trajectory was adapted as follows. For Kanpur Jajmau area, the situation allowed for joint discussion and agreement on main outputs in a group setting. There was sufficient buy-in and common focus concerning the shared wastewater management issues. In contrast, for the Delhi Barapullah Drain, participation was more erratic, also due to the more high-level engagements our participants would be involved in. This made it more difficult to identify sufficiently long time slots during which the whole group would be available and often this would change at the last minute. Moreover, participants' views on the scale and scope of wastewater treatment reuse and resource recovery issues varied widely. Therefore, we endorsed a 'co-creation light' approach, where we still aimed to collect and use the inputs as shared by the participants but engage in much more preparation and mediation in terms of content focus and discussion content. As in Kanpur, these engagements were supported by bilateral discussions to collect, structure and synthesize individual inputs provided, which

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were presented, discussed and validated during the group workshops. **Error! Reference source not found.** and

Figure 2: Schematic overview of stakeholder engagement activities over time in Delhi

shows the co-creation trajectory that has been successfully completed in both the locations. A total of four local workshops for Kanpur (where the first workshop was split into two, resulting in four workshops overall) and three for Delhi have been held. Moreover, we conducted about 35 bilateral interviews to date (see Appendix A1-1 for an overview).

Figure 1: Schematic overview of stakeholder engagement activities over time in Kanpur

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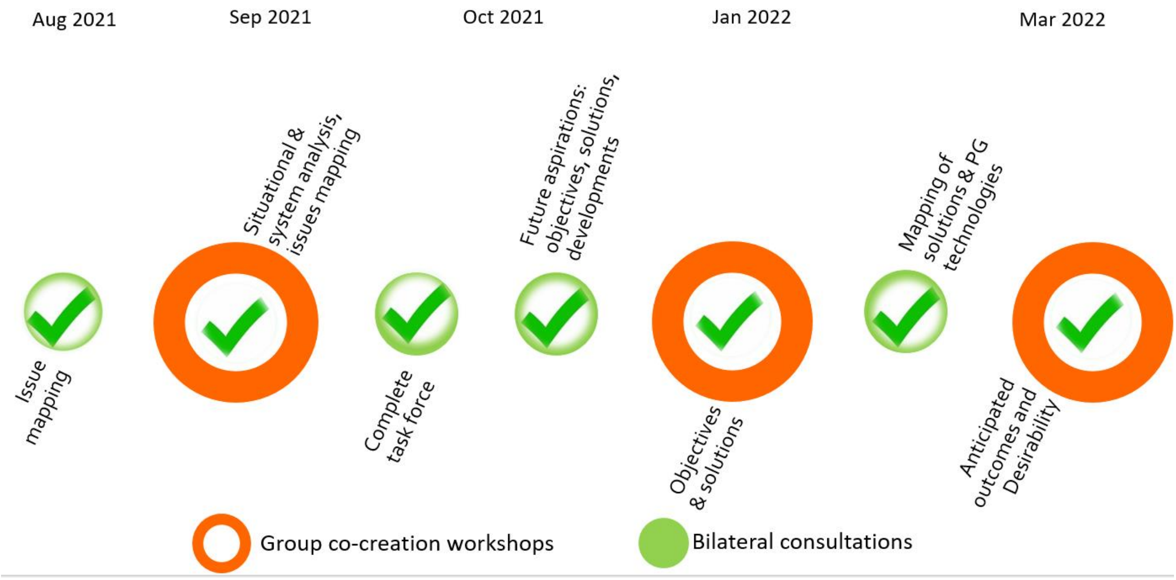

Figure 2: Schematic overview of stakeholder engagement activities over time in Delhi

Table 1: Overview of stakeholder co-creation workshops in Kanpur and New Delhi

No.	Workshop	Date	Duration	Topic
Kanpur				
1	Kanpur Co-creation Workshop I	07-09-2021, 08-09-2021	2 hrs: 2 hrs	Introducing project and process, System and issues exploration
2	Kanpur Co-creation Workshop II	06-10-2021	3 hrs	Cognitive map finalization and alternative solution generation.
3	Kanpur Co-creation Workshop III	14-12-2021	2 hrs	Assessment criteria, alternative solution consolidation
4	Kanpur Co-creation Workshop IV	25-03- 2022	2-3 hrs	Explore outcomes and desirability of portfolio alternatives, discuss Pavitra Ganga roadmap
Delhi				
1	Delhi Co-creation Workshop I	14-09-2021, 15-09-2021	2 hrs, 2 hrs	Introducing project and process, System and issues exploration
2	Delhi Co-creation Workshop II	19-01-2022	1.5 hrs	Assessment criteria, alternative solution consolidation
3	Delhi Co-creation Workshop III	14-03- 2022	2 hrs	Explore outcomes and desirability of portfolio alternatives

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Joint final workshop (Kanpur and Delhi)				
1	Final dissemination event	? (depends on progress in other work packages)	≈ ½ day	Final results presentation, lessons learnt and implications for scaling

In combination, the process shown in **Error! Reference source not found.** and

Figure 2: Schematic overview of stakeholder engagement activities over time in Delhi

along with the workshops and content summarized in Table 1, covered the use of problem structuring methods and conceptual modelling for Multi-Criteria Decision Analysis (MCDA), followed by qualitative and quantitative MCDA and portfolio decision analysis. These are described in the following section.

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2.2. Problem Structuring, Multi-Criteria Decision Analysis (MCDA) and Portfolio Decision Analysis (PDA) Approach

2.2.1. Problem Structuring

As summarized in the overview (Table 1), the first workshops focused on problem structuring with the stakeholders. This was to ensure a common framing and comprehensive understanding of the key issues pertaining to (waste)water quality, technology as well as governance, social and economic aspects. Group cognitive mapping from SODA (Systematic Options Development Analysis) methodology (Ackermann & Eden, 2011) was used and facilitated online via MS Teams and using Miro Boards[1] and Decision Explorer software[2]. In the workshop follow-up meetings, the perceived causal links between these issues were explored in-depth to create a more comprehensive issues map and identify intervention levers. Bilateral interviews were held to identify ongoing or envisaged alternative water management solutions (incl. those that are currently in place, the piloted technologies and promising alternatives) as well as objectives that the participants aspire for these alternatives to achieve, reflecting important personal and social values. Means-ends networks were built to reflect on these discussions. From the issue's maps and the means-ends networks, a hierarchy of objectives was derived and a list of candidate alternatives was developed for each case study area. We furthermore determined measurable performance indicators as a basis for strategy evaluation and comparison.

Following the workshops, documentation was submitted for review by the participants involved. Apart from the external stakeholders, an internal review and refinement of the alternatives was done with Pavitra Ganga project technical experts. This additional step was necessary as (1) tasks in the other work packages were much delayed and hence it was not possible to obtain performance data from the pilot field testing and (2) the alternative solutions envisaged by our key stakeholders reached beyond specific treatment or monitoring technology, complicating assessment with available resources. During this review, we aimed to identify key interactions and contingencies between alternatives in order to build comparable alternatives and suitable portfolios as per the wishes of the workshop participants and taking into consideration Pavitra Ganga technologies for the two case areas.

2.2.2. Multi-criteria Decision and Portfolio Decision Analysis

Attribute quantification

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[1] Miro is a visual online collaboration platform that enables remote meetings and workshop without the constraint of physical location. For more details, please see - https://miro.com

[2] Decision Explorer® is a tool for facilitating discussions and organising information for complex or uncertain situations by capturing the different issues and establishing links between them in real-time, therefore building new understanding and insights. For more details, see - https://banxia.com/

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During the discussion of the objectives hierarchy, the assessment criteria for the attributes were presented to the participants in workshops held in both Delhi and Kanpur. In the case of Delhi, the assessment of the alternatives and the portfolios has been limited to qualitative analysis; therefore, the quantification was not done for the identified attributes. However, the alternative solutions were presented to and discussed with the Pavitra Ganga consortium members to ensure they made sense both from the perspective of the considered technology combinations and the local context. This was done through multilateral meetings and one presentation held online with Pavitra Ganga team colleagues of Work Packages 3, 4, 5 and 7.

In contrast, in the case of Kanpur, a series of steps were undertaken for a quantification of the criteria based on the objectives hierarchy agreed with the research participants. First, for the rough assessment of the alternatives and portfolios in Kanpur, a few attributes that seemed to be double counting were removed. For example, low air pollution was removed from the objectives hierarchy with an assumption that contribution of wastewater treatment, reuse and resource recovery to national air quality parameters is limited. It can, however, be a nuisance in terms of stench / smell and emanating gases can have a corrosive effect in the immediate vicinity of the irrigation channel. Similarly, increase in crop productivity correlates strongly with farmer household income, so the latter was removed to avoid double-counting. Second, the attributes were further expanded and defined based on the existing literature. The literature references aided in estimations of performances of the final alternatives on the different attributes identified. Thereafter, these estimates were discussed onlinewith the Pavitra Ganga colleagues who hold relevant knowledge of the Pavitra Ganga technologies through 4 bilateral meetings. Additionally, 2 bilateral discussions were held with external experts about the case study areas and the various relevant aspects identified in the workshops for quantification were also conducted. The minimum and maximum ranges of possible outcomes across alternatives were double-checked for realism with research participants during preference elicitation. However, the quantification exercise could not be done robustly within the limited remaining time for data collection. Given the paucity of real-world data for the envisaged solutions in the two pilot locations at this time, we largely relied on literature values, lab testing results, and expert judgment to assess the anticipated impact of these portfolios on the stakeholder goals. It was unfortunately not possible to wait until the results from the piloting and modelling in other work packages became available as the funding for staff employed on this project for Tasks 2.2 and 2.3 ended by 31-03-2022. Once quantification was completed, we assessed the anticipated performance of the alternative portfolios on the identified criteria with a (portfolio) multi-criteria decision analysis model.

Preference elicitation

In line with differences in attribute quantification, preference elicitation for Delhi and Kanpur was accordingly adapted. In Delhi, the approach was based on asking workshop participants to rank alternatives with regard to their perceived performance and preference concerning the main objectives. This was done in a facilitated group discussion.

In Kanpur, where a quantitative MCDA analysis was conducted, preference elicitation focused on identifying importance ranks for the assessment criteria as well as weights to reflect trade-offs between them. Preference elicitation meetings were conducted bilaterally with five of the Kanpur research participants in an online setting, using Miro Board to facilitate discussion. One of the participants was reluctant to provide

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the requested preference information during the meeting. It was agreed to fill in the elicitation form in his own time and to share it with us, yet no version was finally shared. The meetings were structured in 3 parts. First, the criteria for the rough assessment of the alternatives were discussed with the stakeholder involved. Following this, the best and worst outcome levels for each of the criteria were presented and discussed. Finally, desirability of outcomes of the participant was mapped using the SWING weight elicitation method (Eisenführ, Weber, & Langer, 2010). Thus, a weight preference set of four participants was collected. Given the time research participants were available and the limited time-line, it was not possible to elicit subjective risk preferences and (portfolio) value functions as aspired. Instead, assumptions were made for exploratory MCDA modelling and analysis.

Analysis of alternatives and portfolios

The alternative and portfolio exploration workshops were held in March 2022 (workshop 2 as per the original project proposal, now workshop 3 and 4 respectively for Delhi and Kanpur as per amended design, see Table 1). These workshops were dedicated to presenting and discussing the results of the assessment of the wastewater management, reuse and resource recovery alternatives and portfolios with regard to the objectives.

In Delhi, the alternative solutions were discussed in relation to the four objectives, asking participants about the anticipated outcomes of the solutions on the main objectives and how these would rank relative to each other. This was followed by discussion about combinations of alternatives in order to being able to address the complexity at hand (where single alternatives in isolation would not be able to overcome the current situation).

In Kanpur, an exploratory Multi-Criteria Decision Analysis (MCDA) was done to analyse the performance of alternatives against the objectives identified by the participants. We used a linear-additive multi-attribute value theory model, which assumes linearly increasing marginal value over the performance criteria and full compensation between criteria (Dyer & Sarin, 1979; Eisenführ et al., 2010). Several limitations for data collection resulted in high levels of uncertainties in the quantified criteria. Also, there are many potential uncertainties in the preferences that could have been further explored, see e.g. Scholten, Reichert, Schuwirth, and Lienert (2015). The analysis was conducted using R in the R Studio development environment (R Core Team, 2019; RStudio-Team, 2020), making use of the following R packages: *utility* (Reichert, Schuwirth, & Langhans, 2013), *reshape2* (Wickham, 2007), *ggplot2 (Wickham, 2009)*. Uncertainties were not considered in the MCDA results that were presented to the workshop participants (see Fig 10) as the limited reliability of the performance estimates only allowed to aim for an exploratory discussion based on an illustration of the results that could be obtained from an MCDA after more reliable information on their performance has been obtained. Including the very broad uncertainty ranges would have distracted from the purpose of the in-workshop interaction. Furthermore, the impact of quantitative portfolio interactions was explored in an MSc thesis, with an intermediate version of goals and criteria for the Kanpur case (Meerman, 2022).

The insights from the workshops were used to refine the alternatives and portfolios and formulate lessons learned about content and process. These shall be used as inputs for other work packages (especially WP3, 4, 6, and 8) and presented at the final joint event for Kanpur and Delhi. At this time, it is hard to foresee when

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exactly the final event can be conducted, as it would be concluding various project activities some of which have advanced faster than others.

2.3. Overview of the case study areas

2.3.1. Kanpur – Jajmau area

The Jajmau drainage area in Kanpur is located in the State of Uttar Pradesh. Kanpur city is the 10th most populous city in India with nearly 2.76 million people (Census of India, 2011) and an important industrial centre along the Ganges. It is also one of the largest hubs of leather industries in the country. The Jajmau cluster of tanneries in Kanpur consists of 400 industrial units (Gupta et al., 2018). However, poor adherence to environmental protection norms by the leather tanneries marks a major threat to the ecology of the area as well as the livelihoods of the people involved (Bassi, Babu, & Kumar, 2019). While our participants reported it to be mandatory for tanneries to have an effluent treatment plant within their premises, they are often not used.

Presently, there are three operational sewage treatment plants (STP) located in the Jajmau area. Additionally, in 1994, Uttar Pradesh Jal Nigam (UPJN) installed a 36 MLD common effluent treatment plant (CETP) to treat the effluent from tanneries (with its high loads of chromium and salt) along with sanitary wastewater to make it more amenable for biological treatment. The designed blending ratio of 1:3 (tannery effluent to sewage) in the CETP is not maintained, making the treatment plant non-complying (CPCB, 2019; 2020; 2021). Moreover, the tannery effluent received at the CETP is measured as 11-19 MLD, which is significantly higher than its design capacity of 9 MLD, therefore resulting in reduced performance (CPCB, 2021). However, an installation of a new 20 MLD CETP to treat separately collected tannery wastewater from Jajmau area which is to be diluted with treated effluent from the other STPs before discharge is under way. This new CETP is being installed with funding by National Mission for Clean Ganga (NMCG) and shall be managed by the Jajmau Tannery Effluent Treatment Association (JTETA), based on fees collected from its (tannery) members. For an overview of where the plants are located, see Figure 3. More detailed information about the technical infrastructure and the hydrology at the location can be found in project deliverable D4.1.

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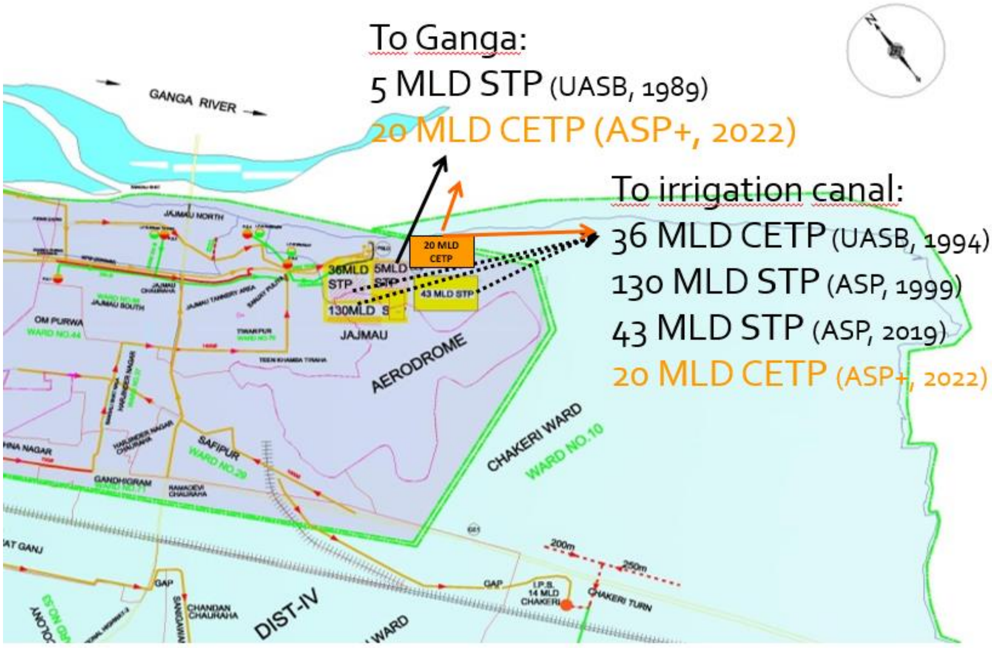

Sources: from Kanpur Jal Nigam: Pavitra Ganga Project Deliverable D3.1

Figure 3: Layout of STPs and CETP in Jajmau area in Kanpur

Jajmau treatment cluster including the tanneries located in Jajmau area of Kanpur along with the farmers down-stream formed the system boundaries for the problem structuring and analysis. Stakeholder analysis (Enserink, et al., 2010) in the Kanpur area shows interrelated resources and independencies of government, civil society organisations, research and policy advocacy organisations, private companies, educational institutes and international development agencies for wastewater governance and management in the Jajmau area of Kanpur. Furthermore, government at local, state and national levels serve a direct and critical role as decision-makers (see Figure 44). Among them, Kanpur Nagar Nigam, National Mission of Clean Ganga, Uttar Pradesh Jal Nigam and Uttar Pradesh Pollution Control Board are the most prominent ones. Kanpur Nagar Nigam is directly responsible for collecting sewage tax form the tanneries and residents in the city. Uttar Pradesh Jal Nigam overlooks the day-to-day operation and maintenance of the sewage system in Kanpur. Uttar Pradesh Pollution Control Board is the regulatory authority responsible for prevention, control and abatement of water pollution in the city. National Mission of Clean Ganga (NMCG) aims to ensure effective abatement of pollution and rejuvenation of the river Ganga. NMCG has commissioned the new 20 MLD CETP which is contracted to Jajmau Tannery Effluent Treatment Association (JTETA). JTETA aims to undertake the implementation, operation and maintenance of CETP at Jajmau, Kanpur. Non-governmental organisations such as Solidaridad, Ecofriends, World Wildlife Funds, and Leather Industries Welfare Association (LIWA) have social resources because of their direct relations and access to the communities including the farmers working down-stream as well as tanneries operating in the Jajmau cluster. Research and educational institutes such as Central Leather Research Institute (CLRI), Indian Institute of Toxicology Research, Indian Institute of Technology Kanpur, and Chandra Shekhar Azad University of Agriculture &

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Technology possess the knowledge and expertise regarding livelihoods, environmental protection and pollution reduction in Kanpur. Because of the overlapping roles and responsibilities of these different actors involved in the decision-making process, it was not possible to define a singular problem owner in the Jajmau treatment cluster.

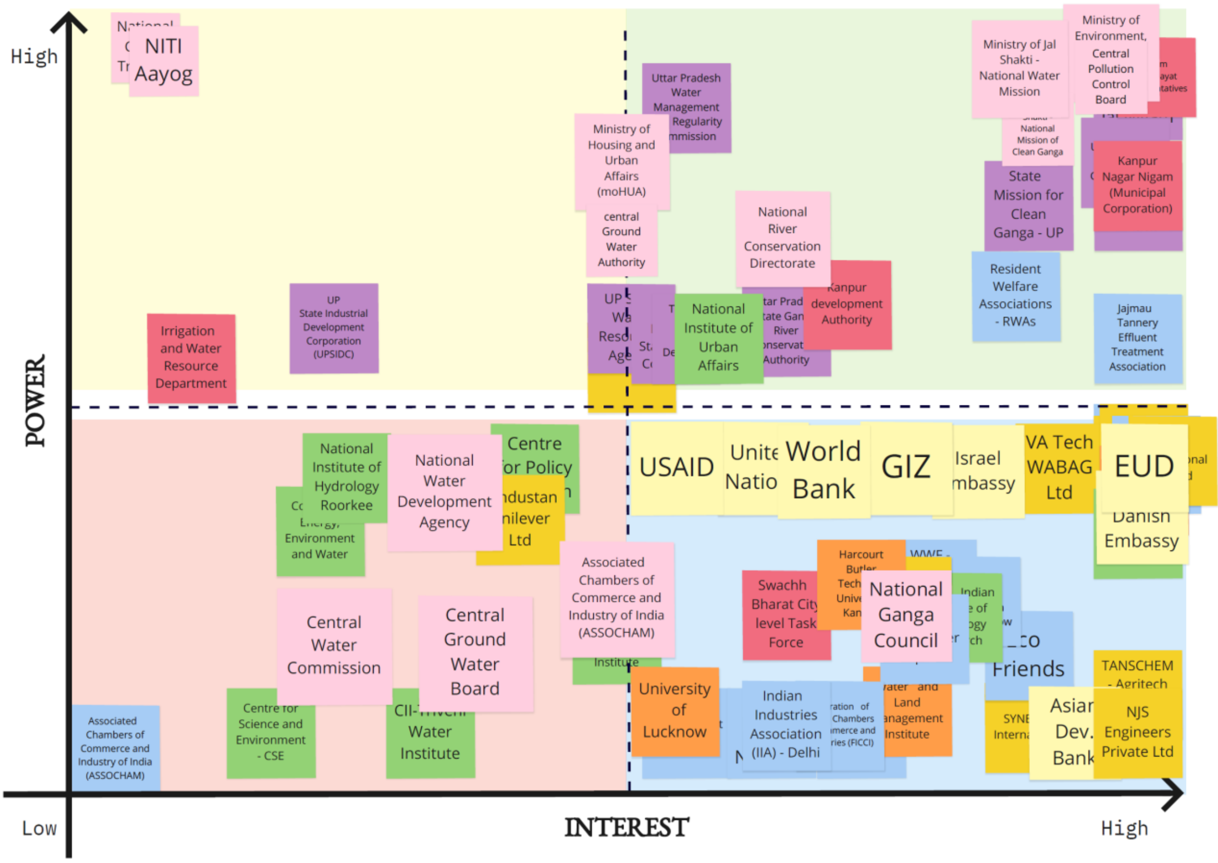

Figure 4: Screenshot of the power-Interest matrix of actors developed during stakeholder analysis on wastewater management in Kanpur

2.3.2. Delhi – Barapullah Drain

The Barapullah Drain catchment is situated on the western bank of the river Yamuna and completely urbanized, spreading across 5 sub-districts of Delhi. The catchment area is approximately 16 km long, spanning an area of approximately 372 km^2, inhabited by an estimated 3.5 million people. The Barapullah drain (also referred to as Nizammuddin darya) was once a major stormwater drain. Due to limitations in sewage transport and treatment infrastructure, the Barapullah Drain carries sewage along with stormwater.

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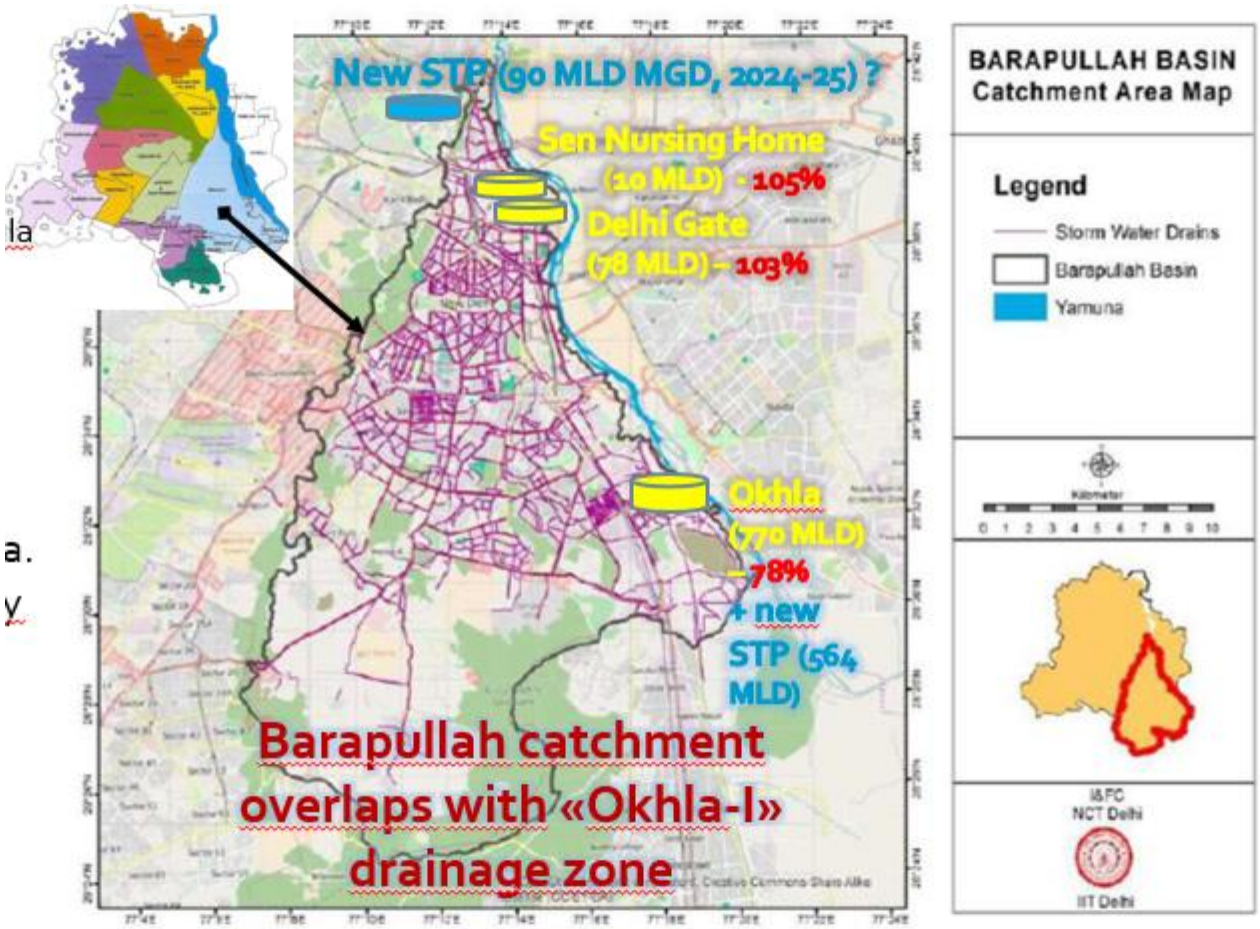
It currently discharges approximately 330 MGD into the Yamuna river, accounting for 80% of the stormwater that is transported to the Yamuna from the region. Moreover, it is estimated that domestic sources account for about 85% of pollution to the Yamuna river, originating from both the formal and informal settlements along the drain. Next to sewage, this also includes illictily dumped industrial and solid waste. The water in the drain thus does not meet recommended biochemical oxygen demand (BOD) and dissolved oxygen (DO) levels. Construction of a 90 MLD Sewage Treatment Plant is planned at the mouth of Barapullah drain before outfall into the Yamuna and 20 acre land for the same has been allocated by Delhi Development Authority (DPCC, 2022). However, the cost of land is high, therefore other techo-economical alternatives are currently under consideration (ibid). More details about the technical infrastructure and hydrology of the catchment are provided in the Pavitra Ganga project Deliverable D4.1.



Sources: CPCB (2021) National Inventory of STPs, NCT Government (2020), Delhi Jal Board Sewerage Master Plan (2014)

Figure 5: Overview of the Barapullah Drain catchment in New Delhi and its main wastewater treatment works

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The spatial boundary of the case study area was difficult to define because of the 16 km extent of the Barapullah drain and therefore the system boundary for issues related to wastewater treatment, reuse and resource recovery remained ambiguous. Because of its strategic location, several actors at national, state and local levels play a critical role in the wastewater governance in Delhi (see also **Error! Not a valid bookmark self-reference.** below). Concerning wastewater management, Delhi Jal Board (DJB) is the implementing agency for matters related to water supply, sewage disposal and drainage; whereas the South Delhi Municipal Corporation is managing, the stormwater drains. National Green Tribunal, Central Pollution Control Board and Delhi Pollution Control Committee serve as regulatory authorities overlooking aspects of pollution and environment in the city. There is a mismatch between the multiple actors involved in the wastewater treatment and their respective administrative boundaries and sector role vis-à-vis the spatial extent of the Barapullah, which is intended to be a stormwater drain, but effectively serving as an open, combined sewer. This made it challenging to define and agree on a common problem boundary as well as to identify clear problem owners for the Delhi case study.

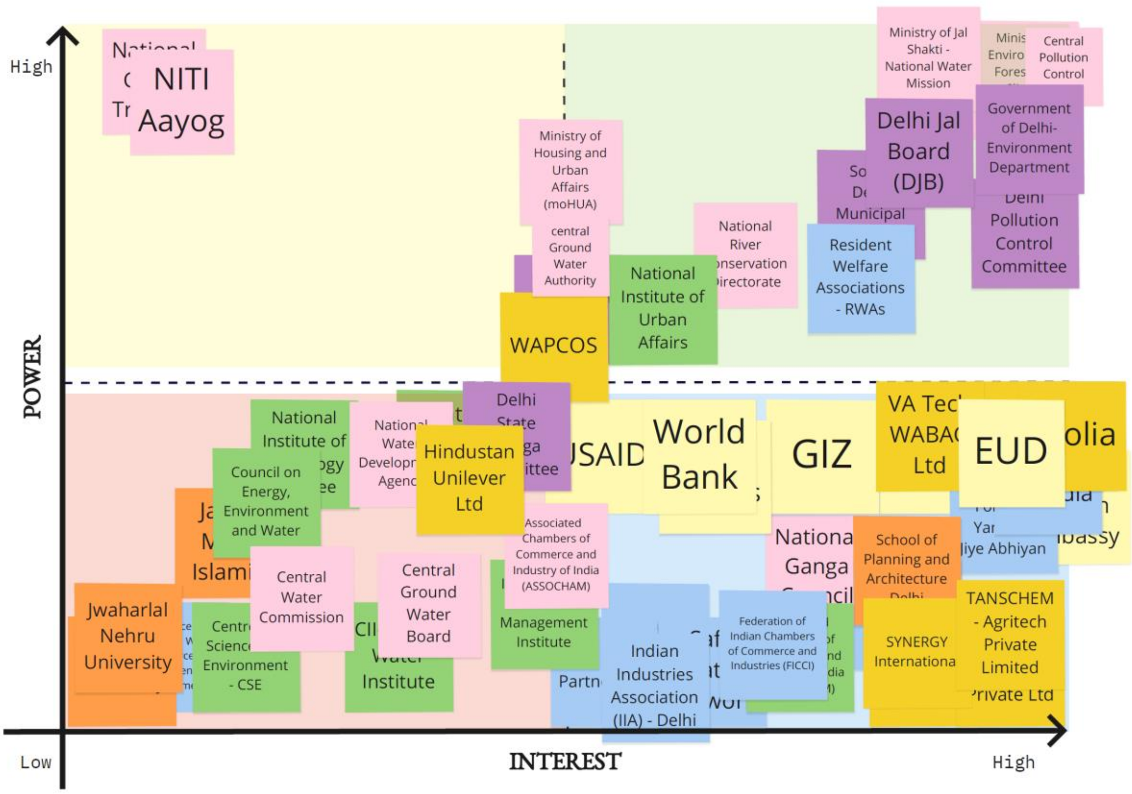

Figure 6: Screenshot of the power-interest matrix of actors developed during stakeholder analysis on wastewater management in Delhi

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CHAPTER 3 RESULTS ON PROBLEM STRUCTURING

3.1. STAKEHOLDERS IDENTIFICATION AND MOBILIZATION FOR ENGAGEMENT

The key stakeholders for the co-creation process were identified based on the stakeholder analysis conducted internally with the Pavitra Ganga project partners. The main goal was to consult them on critical issues and strategies on wastewater treatment, water reuse and resource recovery. The stakeholder analysis included organizations at four tier levels (Central Government, State Government, District Authorities and Civil Society – comprising of Non-Governmental Organizations, Resident Welfare Associations, Community Associations, Corporate groups and Research/Academia), see Table 2

Table 2: Institutional mapping of agencies involved in water management at Central, State, District, and Community level for the two case study areas

Tier 1 (Central)	Tier 2 (State)		Tier 3 (District)		Tier 4 (Academia / Civil Society/ Corporate)
	Delhi	Kanpur	Delhi	Kanpur	
Ministry of Jal Shakti	Delhi Development Authority	Uttar Pradesh Pollution Control Board	Delhi Jal Board	Kanpur Nagar Nigam	Non-Governmental Organizations
National Mission for Clean Ganga	Delhi Pollution Control Committee	Ground Water Department, UP	South Delhi Municipal Corporatio n		Resident Welfare Associations
Central Water Commission	Government of Delhi-Environment Department	UP Jal Nigam			Community Associations (Farmers, Community)
National Water Mission		State Mission for Clean Ganga			Technology Providers
Central Pollution Control Board		U.P State Industrial Development Corporation			Research and Academia
Ministry of Housing and Urban Affairs		State Water & Sanitation Mission, UP			Tanners Association (Jajmau Tannery Effluent Treatment Association)

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Tier 1 (Central)	Tier 2 (State)		Tier 3 (District)		Tier 4 (Academia / Civil Society/ Corporate)
	Delhi	Kanpur	Delhi	Kanpur	
Central Ground Water Board		Uttar Pradesh State Ganga River Conservation Authority			
NITI Aayog					
Ministry of Environment, Forest & Climate Change					
National River Conservation Directorate					
National Water Development Agency					

Whereas we planned for full participation of stakeholder organizations representing the identified key actors on wastewater treatment, reuse and resource recovery, it was not possible to mobilize all of them. Therefore, a shortlisted set of governance actors including the government (local, state and central), civil society, private sector and research and policy advocacy organizations were invited to participate in the workshops for both Delhi and Kanpur. Buy-in from the local government actors for a continued participation was challenging to obtain in both the case-study areas for several reasons. First, the time when the participants were contacted was not ideal and we could not delay further initiation of the co-creation process. When we started contacting the stakeholders in July and August 2021, many of them also had to resume their responsibilities at work and found it difficult to prioritize their participation over other work needs in that period. Second, several government actors who would otherwise join the session were reluctant to do so online using the new medium of communication. Limited access to reliable internet connection and computer infrastructure to support group video conferencing also contributed to their lack of participation. Additionally, not being able to visit stakeholders physically at their place of work or getting introduced by others in a social setting put extra constraints on access to key stakeholders. There was also the perception that political concerns may contribute to government officials shying away from participation. This issue was much more pronounced in Delhi where there was no immediately apparent shared wastewater treatment, reuse and resource recovery problem at the scale of the Barapullah Drain itself. Instead, the identified and interested experts operated at different spatial scales reaching beyond the Barapullah Drain, such as the whole city or state of Delhi or even across the country and internationally. Finally, both in Delhi and Kanpur, it was agreed to continue with the stakeholders who were available, motivated and saw value in being a part of the co-creation process. An overview of participating organizations is provided below in Table 3 and

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Table 4.

Table 3: Number of participants per stakeholder in co-creation workshops for the Jajmau area in Kanpur

No.	Type of stakeholder	Workshop I	Workshop II	Workshop III	Workshop IV
1	Toxicology research organization	1	1	1	1
2	International Non-Governmental Organization working on sustainable agricultural and tannery production in the area - Tanneries expert	0	1	1	1
3	International Non-Governmental Organization working on sustainable agricultural and tannery production in the area – Farming expert	2	1	1	1
4	National Government entity for improvement of river Ganga	1	1	1	1
5	Tannery Industry Association	1	0	1	0
6	State Government entity for pollution abatement	1	0	0	0
7	Research and Policy Advocacy organization (consortium member)	2	2	2	3
8	Technological research organization (consortium member)	1	1	1	1
9	Technical University (consortium member)	2	2	2	2
10	Public company specialized in wastewater treatment (consortium member)	0	0	0	1

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Table 4: Number of participants per stakeholder in co-creation workshops for the Barapullah Drain area in New Delhi

No.	Stakeholder	Workshop I	Workshop II	Workshop III
1	State government agency responsible for water and sanitation	1	1	0
2	Delhi-based Educational Institute focusing on sustainable development	1	1	1
3	Delhi-based research, policy and practice-based organization for urban development and management	1	1	1
4	Multi-national private company working for water management	1	0	0
5	State government entity responsible for planning and urban development	1	0	0
6	Central government entity working for pollution abatement	1	0	0
7	Research and policy advocacy organization (consortium member)	2	2	3
8	Technological research organization (consortium member)	1	1	1
9	Technical University (consortium member)	2	2	2

Throughout the process, rapport building through bilateral interactions and leveraging existing social network connections was critical to mobilizing participants. A total of 35 bilateral meetings were conducted online out of which 23 were with stakeholders from Kanpur and 12 from Delhi. These bilateral meetings were done prior to and in-between co-creation workshops with the goal of incorporating reflections from the subjective point of view of the stakeholders involved. In addition, these continuous bilateral engagements aided in making participants feel at ease and ask any questions or share any comments they would be reluctant to share in a group setting. In that case, we could use our inside-outsider role to facilitate sharing of tacit information. We also used the information to adapt the workshop design toward the resulting content and process goals.

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3.2. System exploration and issue mapping

3.2.1. Jajmau Area in Kanpur

Several challenges with regard to wastewater treatment, reuse and resource recovery in the Jajmau cluster have been identified from the perspectives of farmers, tanneries and governance actors. While the farmers are currently using partially treated wastewater treatment plant (WWTP) effluent that was discharged upstream into the irrigation channel and they would like to continue receiving irrigation water, they are not willing to pay for its use. Moreover, resource recovery is not currently practiced. The health effects of using the partially treated wastewater on farmers and their livestock is a key concern. Root-causes of these issues expressed by the participants are the limited awareness of systemic long-term effects of inadequately treated wastewater for irrigation, lack of alternative water sources, high levels of toxic metals in the delivered WW effluent, varying effluent quality discharged into the drainage channel, and the history of the area that led to free use of partially treated WWTP effluent.

From the perspective of the tanneries, some of the key challenges that emerged from the co-creation work were the increased discharge from tanneries to be treated at CETP, limited use of primary effluent treatment plants (PETPs), low adoption of green technologies for leather production within tanneries, insufficient skills for PETP operation, and no remedy for the disposal of salts used in the tanneries or hazardous slurries. The underlying causes for these issues are the non-compliance with criteria set by the authorities, [low] capacity building, increasing cost of operation, lack of market and profitability of the tannery business, and lack of solidarity between private actors in capacity building.

The main issues from governance perspective included that discharge from Jajmau to current CETP (of 1994) exceeds the design capacity of 9 MLD by at least 6-8 MLD, the varying effluent quality that is discharged into the drainage channel (not only from CETP but also from other Jajmau STPs), not meeting the standards for irrigation, limited operation and maintenance resources, the situation where the municipal corporation and tanneries do not pay on time for effluent treatment, and the limited space for – as well as low adoption of – WWT+RRR in the public space.

The Kanpur city is divided into 4 sewage districts. The wastewater in Jajmau treatment cluster primarily comes from residential and commercial areas as well as tanneries units located in the Sewage District 1 that comprises of 34 wards. In terms of wastewater reuse, there is indirect river flow augmentation from the treated effluent that is discharged into river Ganga and direct flow of (partially) treated wastewater into the irrigation channel that transports it to the nearby fields located in 10 villages with nearly 1800 hectare area (Gupta, Srivastava, Sardar, & Kanaujia, 2018). These agricultural fields are used to grow seasonal vegetables, such as mustard and fodder crops for dairy and livestock farming by the downstream communities. For 3 months, starting from the last weeks of December until beginning of March, tannery operations are restricted due to temporary closing notices given by the regulatory authorities. This period marks the religious festivities in the Hindu calendar wherein many people visit the banks of Ganges for the holy dip.

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3.2.2. Barapullah Drain area in Delhi

Several challenges with regard to wastewater treatment, reuse and resource recovery in the Barapullah Drain area have been identified. The key challenges are- 1) mixing between storm water and wastewater, which causes 2) varying characteristics of wastewater and increase in discharge of Barapullah Drain. Both authorized and unauthorized colonies contribute towards these challenges. Root-causes of these issues expressed by the participants are the limited political willingness, illegal activities of existing industries, improper collection of the entire sewage stream of individual households, poor maintenance in existing sewers and ageing sewage system. For the reuse aspects, some of the key challenges that emerged were the limited market for reuse of treated wastewater, underutilization of treated effluent, public reluctance to reuse treated wastewater and limited infrastructure for reuse and resource recovery. The underlying causes for these issues are innovative solutions are being turned down, there is stigma around direct reuse, limited role of civil society (e.g. represented through residence welfare organizations) in governance, limited citizen participation, absence of business models and government schemes, difficulties of Delhi Jal Board to get industries to reuse treated wastewater, and limited funds to set-up a conveyance network for treated effluents. The main challenge with resource recovery is the heavy metal loading that makes it difficult to dispose of the sludge as it makes it unattractive for farmers to accept/use along with lack of research or policy.

Several challenges with regard to wastewater treatment, reuse and resource recovery in Barapullah Drain area are overlapping in nature. For instance, varying characteristics of wastewater lead to limited market for reuse of treated wastewater, which is caused by limited political support for reusing treated wastewater or extending its use. This limited political support results in a lack of research or policy for resource recovery in the Barapullah Drain area of Delhi. Not all participants were able to reach an agreement about the sources of water pollution in the Barapullah drain area. Disagreements were often shared in bilateral discussions that preceded or followed the co-creation workshops. Some questioned the existence of industrial effluent entering the drain, as no visible sign of industries have been identified in the vicinity of the Barapullah drain area. Similarly, some pointed fingers at the authorized colonies for the existing pollution as the unauthorized settlements often had limited access to water supply, therefore generated considerably less wastewater in comparison to the planned colonies. Additionally, there were difficulties of scope and scale within the case study area as the Barapullah drain was originally designed as a stormwater drain and does not fall within sanitary wastewater management, though at present it is an 'open drain carrying sewage' (Hindu, 2016). This resulted in two-fold challenges. First, the problem structuring with the participants was less concerted due to the large scale of the drain and difficulties in aligning storm-water and wastewater management concerns. Second, the scope and scale of interventions needed for the drain vis-à-vis that of technologies piloted in the project were misaligned.

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3.3. Objectives hierarchy and assessment criteria

3.3.1. Jajmau area in Kanpur

The overall objective for wastewater treatment, reuse and resource recovery was identified as – 'a sustainable wastewater management in Jajmau area' of Kanpur. This central objective would be achieved through four sub-objectives – 1) low impact on environment, 2) improve livelihoods, 3) affordable cost and 4) high reliability. Aspects within each of the four sub-objectives were discussed and the participants were asked whether the objective hierarchy reflected the most relevant objectives as their perspective, or if anything was missing? All the participants agreed that the objective hierarchy was clear, acceptable and covered their priorities. The only suggestion made was to rephrase the 'low cost' objective in terms of affordability from the tannery perspective. Following this, the participants were asked to role-play about other key actors or parties that were not present in the workshop to identify objectives that might be relevant but missing. Participants suggested contacting actors in regulatory authorities as well as private organizations involved in solid waste management in the Jajmau area. The new policy of the central government - "one city, one operator" and the privatization of operation and maintenance of the STPs in Kanpur was highlighted by the participants. The discussion was concluded with an elaboration on the assessment criteria identified to assess the objective hierarchy.

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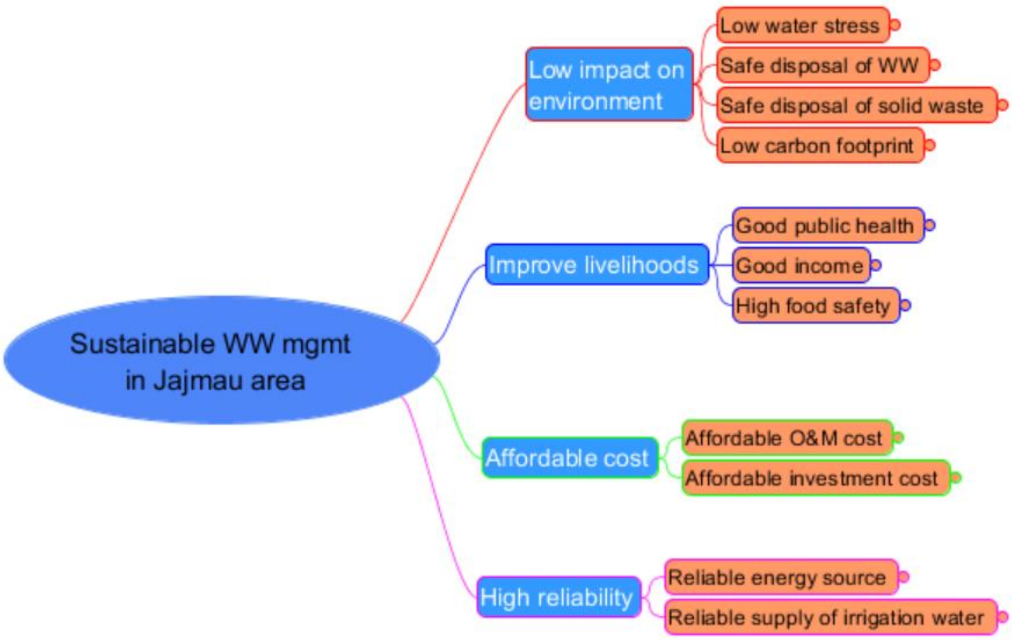

Figure 7: Objectives hierarchy for Jajmau, Kanpur

3.3.2. Barapullah Drain area in Delhi

The overall objective was identified as – 'Healthy Barapullah Drain'. This main objective consisted of four sub-objectives – 1) improve the environment, 2) increase livability of the residents, 3) low life-cycle costs and 4) good wastewater infrastructures. Aspects within each of the four sub-objectives were discussed and the participants were asked whether the objective hierarchy reflected the most relevant objectives from their perspectives, or if anything was missing? For the sub-objective of 'increase livability of the residents', reducing the emissions of H_2S and other gases emanating from the drain and subsequently resulting in gas corrosion of nearby buildings and metals parts was proposed. Similarly, for the sub-objective of 'good wastewater infrastructure', planning and investment on treated wastewater conveyance infrastructure was suggested. Another suggestion was made regarding behavioral aspects related to nudging civic behavior through awareness building, encouraging water conservation and other such related measures.

The discussion on objectives hierarchy was revisited during the last part of the workshop. Within the increase livability of the residents' sub-objective, it was suggested to include 'increased awareness' as a third aspect within the goal. For the rest, all the participants agreed that the objective hierarchy was clear, acceptable and covered their priorities.

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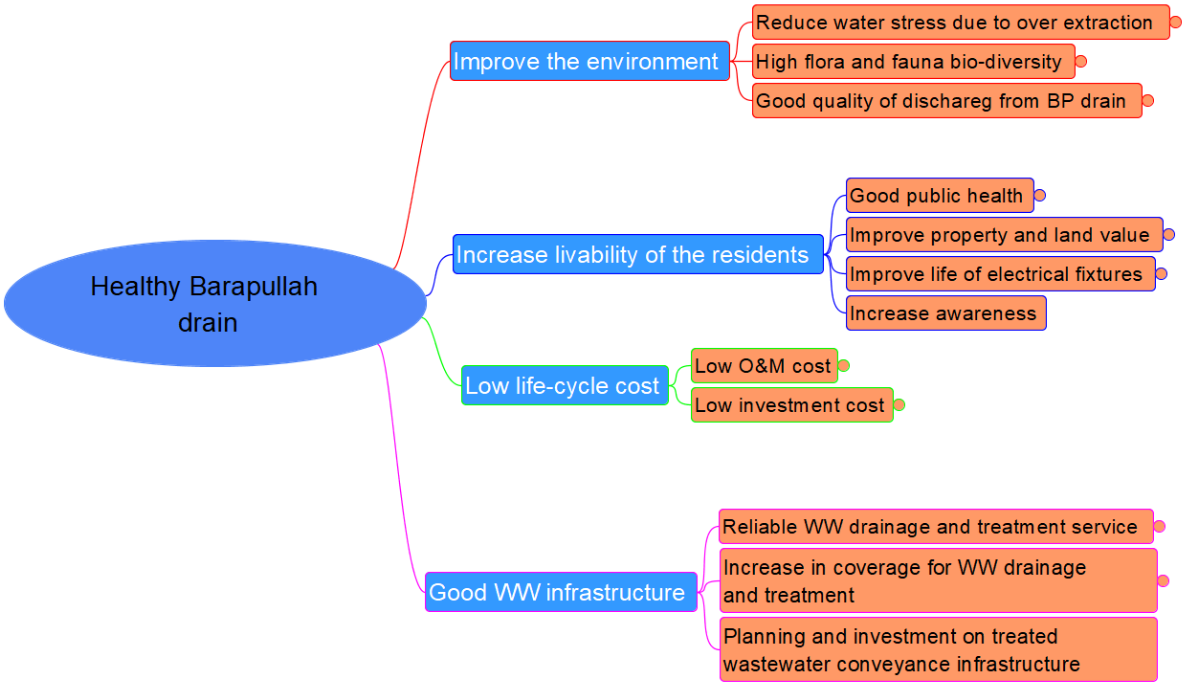

Figure 8: Objectives hierarchy for the Barapullah Drain in Delhi

3.4. ALTERNATIVES FOR PORTFOLIO CONSTRUCTION

3.4.1. JAJMAU AREA IN KANPUR

A preliminary list of 11 alternatives were generated from means or solutions mentioned during bilateral discussions with the stakeholders (see Table 5). This initial set of alternatives was then presented and discussed in a group workshop setting with all the participants present. Overall, the participants were satisfied with the alternatives that were presented to them. The ensuing discussions were centred on alternative 1 and 11. Regarding alternative 1, 'eco-friendly leather production to reduce emissions', it was agreed to include 'green label as an incentivisation strategy' as a sub-alternative 1A. For alternative 11 which is 'increase of general infrastructure tax to cover operation and maintenance for wastewater treatment plant', it was flagged that the solution of increasing tax might not be of help because the issue with poor operation and maintenance is not primarily because of lack of funds but rather the revenue flow between different state and local agencies. However, no remarks were made for the revisions related to the alternative. Following the workshops, two additional alternatives were added to the list that had been mentioned during earlier problem structuring activities with the participants (see Table 5).

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Table 5: List of preliminary alternatives for Kanpur

	Alternatives
Technological and physical measures	**Alternative 0: Status quo at present**
	Alternative 0A: New 20 MLD CETP + existing STPs
	Alternative 1: Eco-friendly leather production to reduce emissions **Alternative 1A**: Green label as an incentivisation strategy
	Alternative 2: Green technology to reduce pollution load @WWTPs and tanneries and agricultural land.
	Alternative 3: Separate dedicated conveyance system for WW transportation
	Alternative 4: Soil remediation of farmland
	Alternative 5: Relocation of tanneries
Long term sustainability and adoption measures	**Alternative 6:** Public campaigns to increase awareness for using treated WW
	Alternative 7: Tannery knowledge exchange platform
	Alternative 8: Clear and implementable laws and regulations for the environmental protection
	Alternative 9: Cost recovery of treated WW used by farmers, tanneries and public
Enabling measures	**Alternative 10:** No GST tax for eco-friendly chemicals for treating leather
	Alternative 11: Increase general infrastructure tax to cover O&M for WWTPs

All 11 alternatives were sorted into three different categories (see Table 5): (1) technological and physical infrastructural interventions (Alternatives 1, 2, 3, 4, and 5), (2) long-term sustainability and adoption measures (alternatives 6, 7, 8 and 9) as precondition for some of the physical interventions, and (3) enabling measures (alternatives 6, 7, 8 and 9). Only the five direct technological or physical interventions (1st category) were taken up for further specification of alternatives and subsequent quantitative analysis. In order to ensure consistency, coherence, comparability and distinctiveness of alternatives (Gregory, et al., 2012), the alternatives of the 2nd and 3rd categories were not taken forward. They are significant to ensuring adoption and implementation of physical or technological interventions as well as to fostering their sustainability over the longer term, yet they are incommensurate in the context of the prescribed technical intervention focus of the project and generated objectives for their assessment. Hence, their effects cannot be directly compared in a consistent and coherent manner with regard to the identified goals of the stakeholders.

In the following, the shortlisted alternatives related to technological and physical infrastructural solutions were specified in detail to ensure consistency, coherence, comparability and distinctiveness (Gregory, et al., 2012). For this, a strategy generation table was created (Howard, 1988) including the spatial focus of the intervention in connection to key actors (tanneries - upstream, local government - intermediary, farmers - downstream), as well as detailed characteristics including the means of water supply, usage for, effluent storage, treatment, effluent receiver, conveyance to the receiver, effluent monitoring, ownership of

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measures taken, operation and maintenance responsibility. For specification of the alternatives, specific matching technologies were included which were either proposed by the stakeholders during the workshops, during bilateral interactions or are being piloted within the Pavitra Ganga research project, as per the suitability. The resulting alternatives 1, 2A, and 2B are technological solutions for sustainable agriculture and leather production. Alternatives 3A and 3B focus on the infrastructural grid of Jajmau in Kanpur. Alternatives 4A, 4B, 4C and 4D are related to other additions for the centralised wastewater treatment plants. The specifications of each factor for each of the 13 decision alternatives and 2 status-quo situations that were created in the stakeholder workshop are summarized in the Strategy Generation Table (see Annex). A list of the final set of alternatives is provided in Table 6.

Table 6: List of final alternatives for Kanpur

Alternative	Description of the alternatives
Alternative 0A	Status quo at present
Alternative 0B	New 20 MLD CETP + existing STPs
Alternative 1	Eco-friendly leather production to reduce emissions using enzymes in vegetable tanning
Alternative 2A	Green technology for improving agriculture through soil remediation of farmland
Alternative 2B	Green technology for improving agriculture through pre-treatment of irrigation water by using CW plus
Alternative 3A	Separate conveyance system for treated WW to transport it to reuse point within Jajmau for non-potable purposes
Alternative 3B	Semi-centralized treatment of household and small-scale tannery wastewater - self-forming dynamic MBR (ca. 5000-10'000 PE each)
Alternative 4A	Advanced chromium removal at STPs using structured sorbents
Alternative 4B	Green technology to reduce pollution load @WWTPs- CW plus to post-treat STP effluent
Alternative 4C	Energy recovery and sludge reduction - anaerobic co-digestion of sewage with organic waste (Andicos TM)
Alternative 4D	Biomass power plants to reduce fossil fuel use - co-palletization of secondary sludge and agricultural residue + Recovery of P-fertilizer
Alternative 5	Relocation of tanneries to mega leather cluster

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3.4.2. Barapullah Drain area in Delhi

During the Delhi co-creation workshop, 11 alternatives to achieving the goal of "Healthy Barapullah Drain" were presented and discussed with the participants (see Table 7). Limitations and constraints for operationalization of the alternatives surfaced during the discussion. For example, someone suggested that it might not be acceptable to use sludge from fecal origin for farming. Also, agricultural land is shrinking in Delhi and the presence of heavy metals in the sludge was another issue mentioned. So social norms, change in land use and heavy metal contamination served as a constraint for alternative 11 which is distribution of sludge to the farmers for free in and around Delhi. Additionally, participants also contributed to fine-tuning the alternatives by specifying several key aspects that were not evident. For instance, it was suggested to expand the focus of alternative 10, which is related to reuse of treated wastewater in agricultural areas in the outskirts of Delhi to other venues located within the city such as large railway yards, parks, gardens, bus and metro depots.

Table 7: List of Preliminary Alternatives for Delhi

	Alternatives
Technological and physical measures	**Alternative 0:** Status quo at present
	Alternative 0A: New 90 MLD STP
	Alternative 1: Fully-sewered Barapullah drain catchment to treat all WW to an acceptable quality
	Alternative 2: Decentralized STPs for unauthorized settlements, e.g. (A) Septic tanks, (B) Hybrid-DEWATs
	Alternative 3: Decentralized STP for authorized neighborhoods e.g. (A) in-situ systems, (B) constructed wetlands
	Alternative 4: Centralized STP: stabilization pond for organics removal
Long term sustainability and adoption measures	**Alternative 5:** Build green corridor along the BP drain and treat the waterbody as a resource (creating a carbon sink)
	Alternative 6: Managed aquifer recharge using the treated WW [thereby replenishing aquifers and flood plains]
	Alternative 7: Reusing treated WW in public buildings to reduce water demand
Enabling measures	**Alternative 8:** Strict monitoring of existing regulations related to WWT RRR
	Alternative 9: Awareness-building for wastewater treatment, reuse, resource recovery, e.g. (b) integrate RWAs in water governance
	Alternative 10: Building a grid for conveyance of treated wastewater to agricultural areas in the outskirts of Delhi
	Alternative 11: Distribution of sludge to the farmers for free in and around Delhi
	Alternative 12: Nudging civic behavior
	Alternative 13: Rational pricing of water and WW for a viable business model using treated WW

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Again, the alternatives were organized and color coded into three categories – a) physical measures focusing on transport and treatment options for wastewater in the Barapullah Drain, b) long term sustainability and adoption measures regarding recharging the flood plain or reusing wastewater in public buildings, and c) preconditions for wastewater treatment reuse and resource recovery, such as regulation, grid for transport for wastewater, etc.

During the workshop, two new alternatives were added to the enabling measures i.e., alternative 12: nudging civic behavior and alternative 13: rational pricing of water and wastewater for a viable business model using treated wastewater. As explained in the case of Kanpur, alternatives related to technological and physical measures were taken forward for specification. Solutions pertaining to adoption and those enabling long-term sustainability were not specified and analysed further to ensure consistency, coherence, comparability and distinctiveness of alternatives (Gregory, et al., 2012). A list of the final set of alternatives is provided in Table 8.

Table 8: List of final alternatives for Delhi

Alternative	Description
Alternative 0A	Status quo
Alternative 0B	New 90 MLD STP at end of Barapullah drain
Alternative 1	Fully-sewered Barapullah drain catchment
Alternative 2A	Decentralised STPs for unauthorized settlements - Septic tanks and Andicos TM
Alternative 2B	Decentralised STPs for unauthorized settlements – hybrid-DEWATs
Alternative 3	Decentralised STP for authorized neighbourhoods – Packaged plants and constructed wetlands plus
Alternative 4	Photo-activated sludge and Cleanblocks for organics removal
Alternative 5	Mechanical in-situ filtration systems for interception of solid waste
Alternative 6A	Aerobic membrane bioreactors and advanced oxidation
Alternative 6B	Self-Forming Dynamic Membrane BioReactor (SFD-MBR) and advanced oxidation

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CHAPTER 4 RESULTS ON MCDA, PORTFOLIO DISCUSSION AND DESIRABILITY OF ALTERNATIVE SOLUTIONS

4.1. ROUGH ASSESSMENT OF ALTERNATIVES AND PORTFOLIOS

The attributes for the Jajmau area in Kanpur and Barapullah drain in Delhi were presented to the participants in the co-creation workshops held for the two case-study areas (Table 9 and Table 10) - for detailed assessment of the alternatives, see Appendix A-2.

Table 9: Overview of attributes and attribute ranges in Kanpur.

Sub-objective	Attribute (short name)	Unit	Worst	Best
Low water stress	Percentage of produced WW that is reused (env_watstr)	%	0	100
Safe disposal of wastewater	Percentage of WW discharged at or better than standard (env_disp.ww)	%	0	100
Safe disposal of solid waste	Percentage of hazardous sludge that is safely disposed of (env_disp.slg)	%	0	100
Low carbon footprint	Wh of fossil energy used per m3 of treated WW (env_co2.footpr)	Wh/m3	15	0
Good public health	Days per year when irrigation water meets reuse standards (live_health)	days/year	0	365
Good income tanners	Profits from hides processing (live_income.tann)	INR/ft2	-10	30
Good income farmers	Crop productivity of farmland (live_income.farm)	%	0	100
High food safety	Chromium concentration in soil (live_safe.food)	mg/g	1000	0
Low investment cost	Investment cost- percentage of average household income per year (afford_capex)	%/household income	15	0
Low maintenance cost	O&M cost- percentage of average household income per year (afford_opex)	%/household income	10	0
High cost-coverage	percentage of O&M costs covered by general infrastructure or sewer tax (afford_cover)	%	0	100
High energy supply reliability	Days per year without electricity interruptions (reliab_energy)	days/year	353	365
High irrigation water reliability	Days per year when irrigation water demand is met (reliab_irri.wat)	days/year	0	365

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In both the cases, the attributes focused on aspects related to environment, life-cycle costs of the treatment infrastructure and reliability issues related to it. Environmental attributes in Kanpur included –reuse of wastewater that is produced, wastewater discharge quality, safe disposal of treatment and tannery sludge, and use of fossil fuel. For Delhi, the environmental attributes were defined by the fresh water extracted or demanded, wastewater discharge quality, and fertilizer in wastewater and bio-diversity index. The life cycle cost in both Delhi and Kanpur were related to annualized investment as well as operation and maintenance costs. Similarly, time without electricity interruptions served as a measure for reliability. Also, meeting irrigation water demand in Kanpur and increasing number of households with improved sanitation in Delhi were other attributes for reliability aspects. Additionally, in Kanpur, emphasis was around livelihood aspects related to tanneries and the farmer communities; in Delhi, the focus was on the liveability of the residents. Livelihoods measures in Kanpur were profits from hides processing, crop productivity and Chromium concentration in soil. Similarly, the liveability attributes in Delhi were – drain water meeting reuse standards, flooding impacts on land, reducing smell of methane and green areas in the vicinity of Barapullah drain.

Because of the rough quantification of the attributes discussed above due to factors discussed in the methodology chapter, there is lower levels of confidence in the assessment of the alternatives that has resulted into high levels of uncertainty in the multi-criteria decision analysis. This also calls for a need to update the analysis when the results from piloting the technologies are available to achieve due diligence and improvement in the robustness of the findings of this study.

Table 10: List of attributes in Delhi

Attribute list in Delhi
1. Amount of fresh water extracted or demanded
2. Time WW discharged better or equal to discharge standards
3. Amount of fertilizer replaced by nutrients from wastewater
4. Bio-diversity index reflecting richness, abundance and types of species of the Barapullah drain ecosystem
5. Time when drain water meets reuse standards
6. Flooding impacts on land and soil-pollution amount of solid waste and potentially toxic elements (PTEs)
7. Reducing smell of methane and sulphur dioxide emanating from the drain
8. Percentage of green areas in the vicinity of Barapullah drain
9. Annualized investment cost
10. Annualized operation and maintenance cost
11. Time without electricity interruptions
12. Percentage of households with improved sanitation solution or sewage connection in the Barapullah drain catchment area

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4.2. Expert discussion and preference elicitation in Kanpur

Two of the five participants in Kanpur would not share their subjective preferences. Whereas one of them still ended up providing ranking and relative SWING weighting scores, these were hardly different across criteria in order to reflect that "all criteria are important". The other said he would share his scores after the meeting, yet did not do so. It was apparent from the bilateral engagement that thinking about individual subjective preferences, let alone stating them and informing others, was not something participants were used to or comfortable with. That aside, with some encouragement to reduce concerns, SWING weights from four stakeholders were obtained. These are displayed in Figures 9 and 10.

Among the objectives, all four participating stakeholders indicated highest importance to improve livelihoods, followed by high reliability, low impact on environment and high affordability.

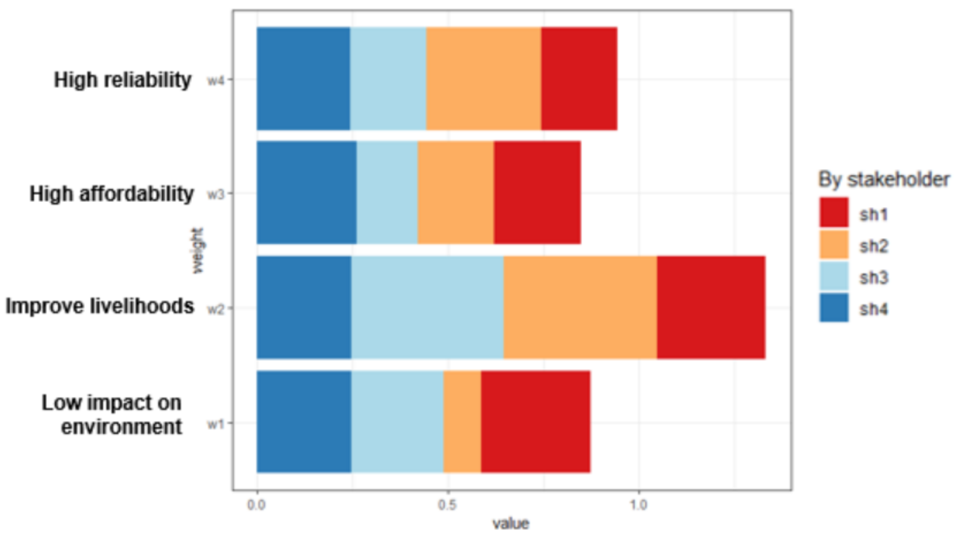

Figure 9: Relative importance weights of the four main objectives in Kanpur. The weights are normalised so that the total of the four weights per individual sum to one. Individual stakeholder weights are stacked to indicate importance at group level.

Furthermore, stakeholders also provided their preferences for the different sub-objectives. For the improve livelihoods objective, good income for farmers and tanners was considered the most important, followed by good public health and high food safety. Both high reliability of irrigation water supply as well as energy supply was reported equally important. Within low impact on environment objective, low carbon footprint got most weightage and low water stress was indicated as the least importance. Finally, for the high affordability objective, most weightage was indicated for low operation and maintenance cost, followed by high cost coverage and finally, low investment cost.

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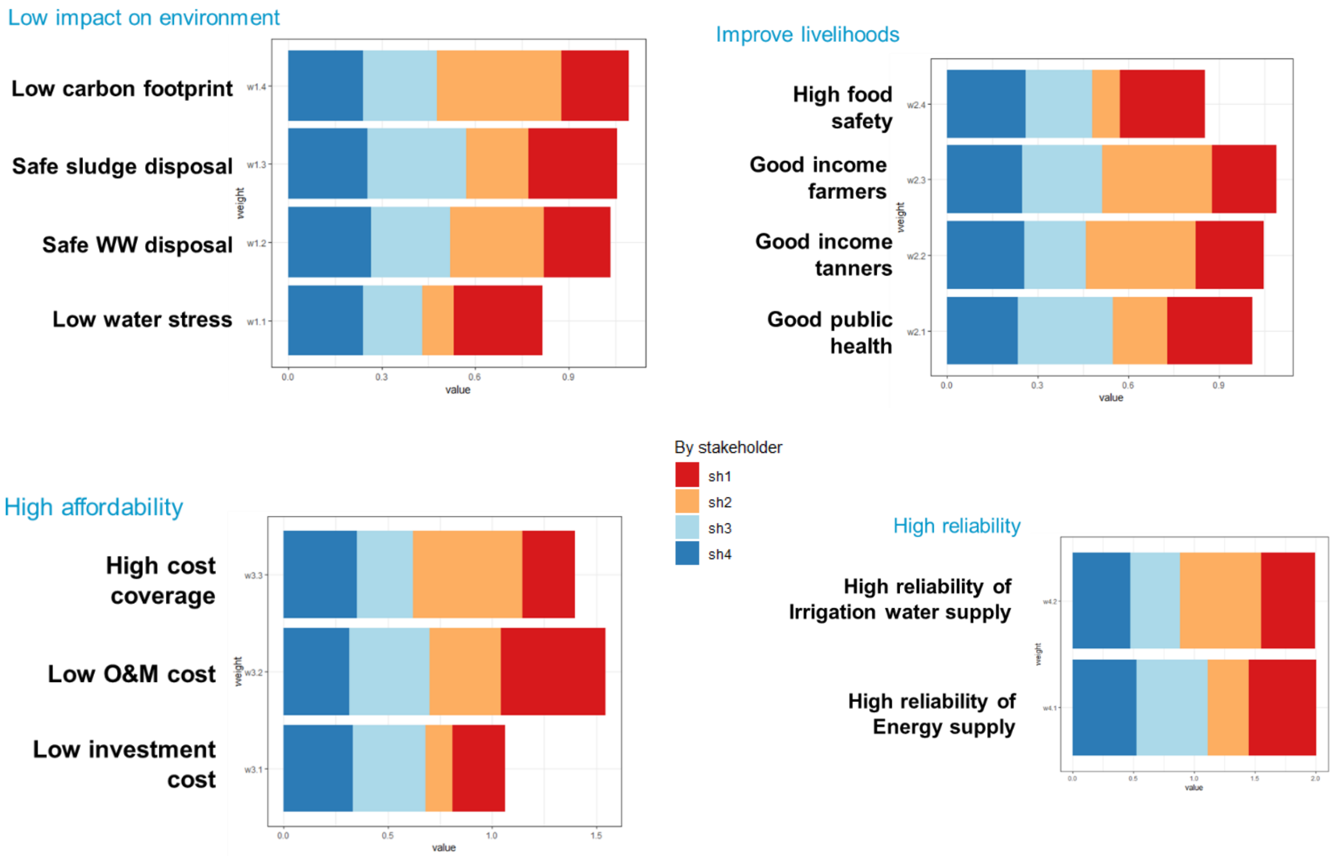

Figure 10: Relative importance weights of the respective sub-objectives of the four main objectives in Kanpur. The weights are normalised so that the the sub-objectives per individual sum to one for each main objective. Individual stakeholder weights are stacked to indicate importance at group level.

4.3. Exploratory MCDA analysis of Alternatives in Kanpur

The overall multi-criteria values of the alternatives in Kanpur are shown in Figure 12. They result from the mathematical combination of their predicted performance on the criteria and the subjective preferences concerning the weights (contingent on the assumption of a linear-additive value aggregation model, see 2.2.2). The observation that the curves of the alternatives in Figure 12 hardly ever cross suggest high agreement between the four stakeholders as regards the valuation of the alternatives. Both **Alternative 4C**: Energy recovery and sludge reduction - anaerobic co-digestion of sewage with organic waste (Andicos TM) and **Alternative 1**: Eco-friendly leather production to reduce emissions using enzymes in vegetable tanning would come up as most preferred solutions. They perform best on the criteria that were given the highest weight, which is reflected in higher overall value. Additionally, **Alternative 0B:** New 20 MLD CETP + existing STPs also performed among the better alternatives, which is an alternative that is currently being

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implemented. **Alternative 4A:** Structured sorbents for Cr removal also received an overall value of 0.5 or above, making this Pavitra Ganga technology a desirable one as per the analysis conducted.

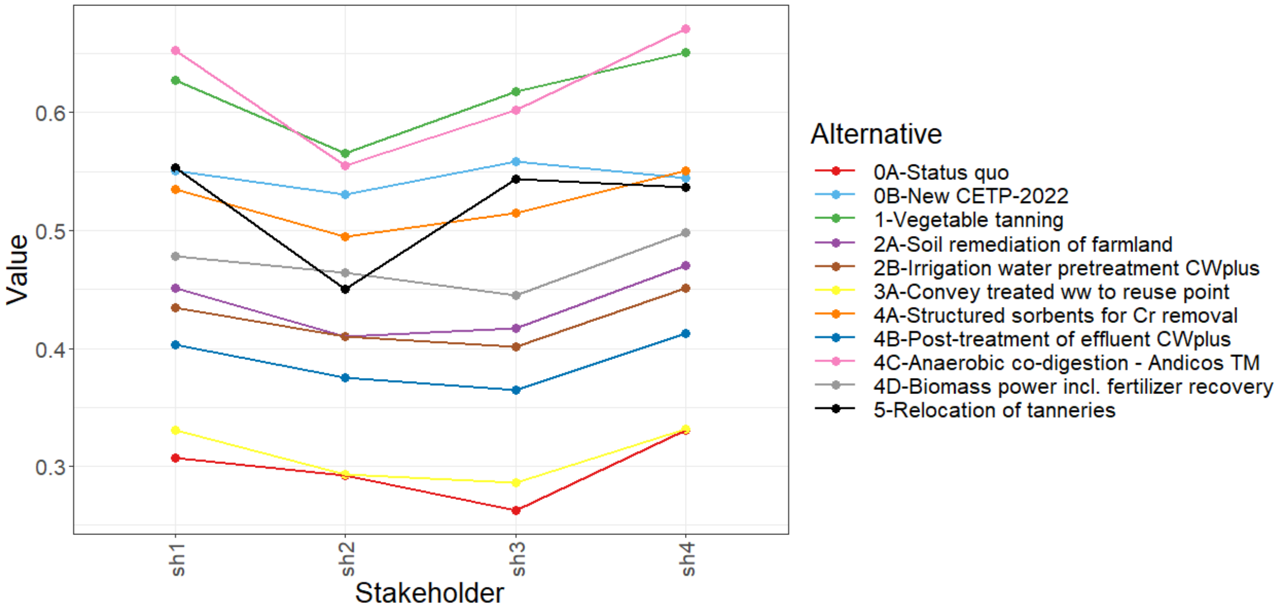

Figure 11: Overall multi-criteria value of the alternatives resulting from the exploratory MCDA analysis for Kanpur. Uncertainty bounds are not displayed.

A significant difference in resulting multi-criteria value score was observed for **Alternative A5:** Relocation of tanneries, which is an action the governing authorities can take to curb pollution. For 2 stakeholders it would be among the top four, whereas the preferences of 2 stakeholders would suggest preference for other solutions. This is an interesting observation, as the in-workshop discussion suggested this alternative was unthinkable – on the merit of other criteria not taken into account on the MCDA analysis (concerning preserving businesses and livelihoods in the area). The current status quo at the Jajmau cluster performed the worst for the priorities of the stakeholders. In sum, this would suggest that the most preferred alternatives lie outside of the scope of the solutions currently being researched within Pavitra Ganga, except for the application of anaerobic co-digestion with Andicos TM and structured sorbents for Cr removal. The overall performance of the alternatives is low to moderate, considering that 9 out of 11 alternatives achieve an overall value of less than 0.6 for all stakeholders (the maximum value would be 1). Even the 2 highest-scoring alternatives would only score between 0.55 and 0.67 across stakeholders. However, it is important to remember that these scores result based on the rough attribute assessment lined out above, which needs consolidation and thorough uncertainty and sensitivity analysis after the piloting phase has been completed for more reliable results, next to assumption of a relatively simple preference model. Conducting a sensitivity audit (Saltelli *et al.*, 2013) is recommended. **In short: the presented results at this stage do not allow for any normative conclusions about which alternatives are 'better' to be drawn.**

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4.4. PERCEIVED PERFORMANCE AND DESIRABILITY OF SOLUTIONS

4.4.1. JAJMAU AREA IN KANPUR

Discussions in Kanpur exploring the desirability of the different alternatives as portfolio options were initiated by asking the participants to choose three or more alternatives that they would implement first. They were also asked why would they choose to do so. This portfolio discussion and desirability in the Jajmau area in Kanpur surfaced a range of options. The first portfolio discussion highlighted technological solutions focusing on sustainability including **Alternative 1**: Eco-friendly leather production to reduce emissions using enzymes in vegetable tanning; **Alternative 2A**: Green technology for improving agriculture through soil remediation of farmland; and **Alternative 2B**: Green technology for improving agriculture through pre-treatment of irrigation water by using CW plus were desired. The second discussion for the portfolio was around issues that impact the down-stream farmers and desirability was indicated for **Alternative 2B** and **Alternative 4B**: Green technology to reduce pollution load at the WWTPs - CW plus to post-treat STP effluent. Another portfolio proposed was a combination of **Alternative 2A** with **Alternative 2B** as the former focuses on pre-treatment and the latter on soil-remediation. Finally, **Alternative 4B**: Green technology to reduce pollution load at the WWTPs - CW plus to post-treat STP effluent and **Alternative 4C**: Energy recovery and sludge reduction - anaerobic co-digestion of sewage with organic waste (Andicos TM) were also combined in a portfolio.

Apart from discussion on the portfolio combination of the alternatives, there were also several deliberations on independent alternatives. **Alternative 5**: Relocation of tanneries to mega leather cluster was indicated to be 'out of question' by some as it would lead to removal of businesses and people who are living in the Jajmau area for generations. **Alternative 4C**: Energy recovery and sludge reduction - anaerobic co-digestion of sewage with organic waste (Andicos TM) was highlighted as a beneficial alternative not only in terms of treatment but also cost recovery in the form of energy generation. Similarly, **Alternative 3A**: Separate conveyance system for treated WW to transport it to reuse point within Jajmau for non-potable purposes - was also indicated as an important solution as it fosters scaling-up of treated wastewater transportation towards the point of use. It was not possible to discuss the explore the differences between the MCDA assessment results and the stated preferences about alternatives in the group, workshop setting to leave sufficient workshop time for presentation of the roadmap (for work package 7 of the project).

Concerning the earlier identified accompanying measures (cf. section 3.4), it is important to highlight also the enthusiastic discussions that were had with and between the stakeholders about the alternatives that were not related to technological and physical measures, see section 3.4. These 'accompanying measures' concern alternatives that focus on long term sustainability and adoption as well as enabling measures. The long-term sustainability concerns were reflected in solutions such as building public campaigns to increase awareness for using treated wastewater, creating tannery knowledge exchange platform, creating clear and implementable laws and regulations for the environmental protection and ensuring cost recovery of treated WW used by farmers, tanneries and public. Similarly, enabling measures were discussed through removing GST tax for eco-friendly chemicals for treating leather and by increasing general infrastructure tax to cover

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O&M for WWTPs. While, these solutions are considered absolutely crucial to achieve the goal of sustainable wastewater management in Jajmau area of Kanpur identified by the research participants, they could not be included in the MCDA assessment because these address a different decision problem (such as 'how to increase uptake of reuse and resource recovery technology?' or 'how to ensure sufficient financial resources for operation and maintenance?'), next to methodological concerns about commensurability of the alternatives.

4.4.2. Barapullah Drain area in New Delhi

In the case of Delhi, the desirability of the alternative solutions was discussed in relation to the four objectives earlier identified by the participants. With regard to improving the environment, **Alternative 1**: Fully sewered Barapullah drain catchment was the most desired, followed by centralized and decentralized solutions (Alternatives 2 till 4). The choices reflected the spatial scope and scale of the solutions in relation to the entire stretch of the drain. For the livability of residents in the vicinity of Barapullah drain, decentralized alternatives were most preferred, followed by the sewer network and centralized solutions. Within the low life-cycle costs objective, decentralized solutions were most preferred and sewer network as well as centralized solutions were ranked second and at par with each other. Finally, for the good wastewater infrastructure objective, both fully sewered and centralized solutions were most desired alternatives followed with decentralized solutions.

While discussing the desirability of the different alternatives, though centralised solutions such as the proposed 90 MLD STP was considered most important, the limitation of its location was highlighted. This was done by explaining that the new STP is planned at the mouth of Barapullah drain, which would result in retaining the pollution in the entire stretch of the drain despite the implementation of the alternative. Similarly, coverage of sewer system in the Barapullah drain area was also indicated as the best option for several objectives. Additionally, it was highlighted that all the solutions in isolation are insufficient, but their amalgamation into portfolios would be able to address the complex problem at hand.

Similarly, also in Delhi several 'accompanying alternatives' focusing on long term sustainability and adoption issues as well as enabling measures for the Barapullah drain were discussed by the participants. The long-term sustainability concerns were reflected in solutions such as building a green corridor along the drain and treating the waterbody as a resource, creating a carbon sink, managing aquifer recharge using the treated wastewater, and reusing treated WW in public buildings to reduce water demand. Similarly, enabling measures were discussed through strict monitoring of existing regulations, building awareness for wastewater treatment, reuse, resource recovery by integrate RWAs in water governance, building a grid for conveyance of treated wastewater to agricultural areas in the outskirts of Delhi, distributing sludge to the farmers for free, nudging civic behavior and using treated wastewater for a viable business model. These solutions are crucial to achieve the goal of healthy Barapullah drain as identified by the research participants, yet they could not be included in the assessment because of their different scope as compared to the decision problem in relation to the Pavitra Ganga project, next to commensurability concerns as in the Kanpur case.

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CHAPTER 5 DISCUSSION AND CONCLUSIONS

The challenges concerning wastewater treatment, reuse and resource recovery both in the Jajmau cluster in Kanpur and the Barapullah drain in Delhi were closely interrelated and overlapping in nature. Also, they were noticed most prominently in the implementation frameworks, economic, regulatory and socio-technical constraints. However, there are key differences in both the contexts. The first difference was related to the complexity of the two contexts. Both the sites had high levels of complexity and dealt with persistent challenges related to issues focusing on wastewater treatment, reuse and resource recovery. However, the complexity was characterized in different ways. First, in Kanpur, the strategies were defined based on the perspectives of farmers, tanneries and the government and related spatial scales. In Delhi, the main stakeholders included authorised colonies, unauthorised colonies, industry and the urban local body. Second, in Delhi challenges of stormwater management were intertwined with wastewater treatment in the Barapullah drain area. In contrast, the Jajmau case presented complex yet well-defined challenges related to wastewater treatment and reuse in and around Kanpur.

This work has highlighted different opportunities and constraints faced by the Pavitra Ganga technologies in the context of stakeholders' priorities in both Delhi and Kanpur. The technologies piloted within the Pavitra Ganga project align well with the alternatives identified by the stakeholders in the two case study areas during the co-creation process. Furthermore, the integration of Pavitra Ganga technologies with the alternatives identified in the co-creation process reveals novel ways in which the technologies could be applied, beyond what has been proposed within the project. This establishes the relevance of Pavitra Ganga technologies within the local context. Two key constraints emerged for the technological solutions proposed within the Pavitra Ganga project. First, most of the technologies do not perform very well on the objectives as shown in the MCDA analysis (see Figure 12 and discussion thereof in section 4.3). However, when combined in portfolios, the different technologies within the Pavitra Ganga project are much more preferred as indicated in the section on portfolio discussion and desirability (section 4.4). Second, the technological innovations within the Pavitra Ganga project are limited to physical interventions and do not relate to enabling solutions which were considered critically important in both the case study areas. Moreover, the commensurability of the different technologies and related alternatives was challenging because some represented short-term interventions while others included long-term measures. In this study, though descriptive preferences are subjective and subject to change, the combination of performance assessment and subjective preferences can be used to identify the perceived 'value for money' of the alternatives as well as the most relevant advantages and disadvantages. This information is often overlooked in technical assessments but is key to determining the available room for compromise or conflict between actors and accompanying measures that may be needed to enable discussion, further study and ultimately adoption of superior solutions.

At the beginning of the co-creation process, considerable efforts were made for aligning the shared purpose that is valued by the participants. Conducting the workshops and bilateral discussions online limited the

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possibility for social interaction and network building that is likely to happen when such events are conducted on location. However, in the case of Kanpur, several participants reached out to one another to share updates as well as to provide clarifications during the workshop discussions. In some instances, participants also joined each other in another event based on their interactions during the workshops. The diversity among the facilitators of the co-creation process and the research participants were taken into consideration in designing the workshops. Participants' communication style, age, professional status, experience, and education were taken into account during all times in the co-creation process. Additionally, festivals and holidays were taken into account so that it does not impact attendance and participation. Furthermore, the participants were always consulted to finalise the workshop dates. During the workshop ground rules were made clear to ensure an inclusive environment where everyone feels safe to address their comments. The participants were encouraged to express their views freely by openly addressing the confidentiality concerns and maintaining anonymity to the points discussed during bilateral meetings as well as group workshops.

The research participants in both Delhi and Kanpur reflected on the co-creation process that they were a part of. The participants expressed appreciation for 1) providing a platform to the marginalised communities such as down-stream farmers in the Kanpur region who are directly impacted by the issues addressed, 2) bringing in different experts and stakeholders together for addressing the challenges 3) developing a good grasp of the local problem, 4) providing effective take-home message, 5) inclusive approach that provided time to all the participants to bring their points on the table, 6) amount of research and exhaustive work done during the co-creation process, 7) conducting bilateral meetings in addition to group discussions during the workshops, 8) including a systemic point of view and not limiting the workshops as a forum for 'sensitization', and 9) dynamic design characteristic based on feedback and feedforward loops. Additionally, participants also mentioned the need for – 1) conducting on-location workshops and bilateral discussions and 2) inclusion of local government officials and regulatory agencies, and 3) 'from here to where?' - way forward for making the discussed alternatives implementable strategies.

Conducting research based on the co-creation process during COVID19 presented several constraints. There were serious limitations to mobilising the participants for the online event and for obtaining buy-in, especially from the local government actors for continued participation. Additionally, data collection did not commence as planned and was halted a couple of times because of the pandemic. Finally, the delays within other work packages also limited what could be achieved within the co-creation process. Despite, these challenges, many newfound opportunities were identified during the process. The study has shown the possibility of successful implementation of the co-creation process with multiple stakeholders online. This has implications for future research that can explore the hybrid nature of interactions by including online events in addition to on-location events focusing on stakeholder engagement and co-creation processes. The co-creation trajectory was different in the two case study areas. There were significant challenges in the Delhi case study mainly because of the lack of well-defined problem boundaries and the involvement of high-level stakeholders who weren't as readily available as was the case for stakeholders in Kanpur. This shows that a successful trajectory of the online co-creation process is contingent on the characteristics of the case study area and the selection of participants.

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This research has surfaced the complexity of wastewater treatment, reuse and resource recovery in both Delhi and Kanpur, demanding a holistic and systemic understanding of the problem and interventions at different spatial scales. Furthermore, this study has shown that to address these inter-related, complex and overlapping challenges, technological solutions though important in themselves are inadequate. Therefore, these technological innovations are required to be coupled with governance, regulatory and behavioural measures that can bring in the required holistic change needed to address the challenge.

5.1. Main recommendations

- Acknowledge the inherent systemic nature of water scarcity and pollution problems beyond technical aspects. Innovative technical wastewater treatment, reuse and resource recovery solutions are unlikely succeed if they are not designed to fit the socio-environmental-technical context.
- Couple technological innovations of the Pavitra Ganga project (and beyond) with governance, regulatory, financial and behavioural measures for more holistic solutions that can weather the present socio-environmental-technical challenges.
- Portfolios of solutions that cover wastewater collection, treatment, distribution, solid waste management and resource recovery are considered more suitable to meet the goals identified through the co-creation process than individual technologies. Smart planning would consider their adoption over space and time.
- Whereas many challenges are broad-reaching, the local needs, capacity and interests with regard to possible solutions differ. It is crucial to develop solutions that fit the local context for success and which the local stakeholders are able and willing to implement.
- To ensure this, giving voice and consideration for local perspectives, and ensuring situations in which it is desirable and safe for local stakeholders to participate in understanding and addressing local problems is key.
- The inherently political nature of problem recognition and solving implies a need for careful design and close moderation of co-creation processes to ensure psychological safety and productive dialogue. The problem structuring methods along with multicriteria and portfolio analysis were deemed suitable to support such processes.
- Interlacing of group engagements with bilateral engagements on specific topics or similar formats is advisable to tackle sensitive topics. Sufficient trust in the process and facilitator(s) is a prerequisite, which requires attention, time and effort to build.
- To tackle the issues identified in the Delhi and Kanpur case areas, we recommend to continue and scale the co-creation processes conducted thus far to share and integrate divergent perspectives of stakeholders about the system driving perceived problems, possible solutions and the desired goals beyong the participants thus far.
- Engage local government actors in these processes. Possibly, there are barriers or disincentives to their participation that may need to be overcome, which we couldn't at the time.

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APPENDICES

A-1. Overview of stakeholder interviews conducted

A-2.1. Online interviews conducted in Kanpur

No.	Interviewed actor	Date	Duration [in minutes]	Topic
1	Toxicology research organisation	16-04-2021	56	Issue surfacing
2		28-09-2021	50	Clarifications for issues and links
3		02-11-2021	32	Objectives and solutions
4	International Non-Governmental Organization working on sustainable agricultural and tannery production in the area – Farming expert	25-02-2021	58	Establishing contact and introducing PG project
5		16-07-2021	50	Issue surfacing
6		29-09-2021	16	Clarifications for issues and links
7		02-11-2021	32	Objectives and solutions
8	International Non-Governmental Organization working on sustainable agricultural and tannery production in the area - Tanneries expert	13-07-2021	57	Issue surfacing
9		29-09-2021	20	Clarifications for issues and links
10		15-11-2021	37	Objectives and solutions
11	National Government entity for improvement of river Ganga	21-07-2021	50	Issue surfacing
12		03-10-2021	45	Clarifications for issues and links
13		23-11-2021	39	Objectives and solutions
14	Tannery Industry Association	09-08-2021	53	Issue surfacing
15	State Government Water Authority	01-09-2021	23	Issue surfacing
16	State Government entity for pollution abatement	01-09-2021	35	Issue surfacing
17	Private leather company	10-08-2021	33	Issue surfacing
18	Technical University (consortium member)	26-02-2021	35	Issue surfacing

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A-2.2. Online interviews conducted in New Delhi

No.	Interviewed actor	Date	Duration [in minutes]	Topic
1	Multi-national private company working on (waste)water management and treatment	19-07-2021	52	Issue surfacing
2		25 -11- 2021	40	Objectives and solutions
3	Delhi-based research, policy and practice-based organization for urban development and management	04-08-2021	41	Issue surfacing
4		11-11-2021	46	Objectives and solutions
5	Delhi-based educational institute focusing on sustainable development (associated with consortium member organization)	24-08-2021	53	Issue surfacing
6		09-11-2021	19	Objectives and solutions
7	State government agency responsible for water and sanitation	02-09-2021	45	Issue surfacing
8		19-11-2021	35	Clarifications for issues and links
9		23-11-2021	42	Objectives and solutions
10	Resident Welfare Association in Delhi	02-08-2021	35	Issue surfacing
11	Central Government entity working for water management and river development	13-09-2021	33	Issue surfacing
12	Central Government entity working for pollution abatement	11-11-2021	34	Objectives and solutions

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A-2. Assessment of Alternatives for Exploratory MCDA in Kanpur

Table A3.1 Attribute levels for the alternatives. Legend: 'estim' – best estimate, 'min' – minimum value, 'max'-maximum value, 'range' – minimum and/or maximum value equal minimum or maximum of attribute range, 'dist' – probability density distribution used, 'par1' – first parameter of distribution, 'par2' – second parameter of distribution

#	Type	env_watstr	env_disp.ww	env_disp.sldg	env_co2.footpr	live_health	live_income.tann	live_income.farm
0A	prediction	41	0	0	mid	0	5	0
0A	min	range	range	range	range	range	range	range
0A	max	range	range	range	range	range	range	range
0A	dist	uniform	uniform	uniform	uniform	uniform	uniform	uniform
0A	par1	range	range	range	range	range	range	range
0A	par2	range	range	range	range	range	range	range
0B	prediction	60	86.30	mid	mid	275	mid	mid
0B	min	range	Range	range	range	range	range	range
0B	max	range	Range	range	range	range	range	range
0B	dist	uniform	uniform	uniform	uniform	uniform	uniform	uniform
0B	par1	range	Range	range	range	range	range	range
0B	par2	range	Range	range	range	range	range	range
1	prediction	50	82.19	37.5	mid	250	5	7
1	min	range	Range	range	range	range	range	range
1	max	range	range	range	range	range	range	range
1	dist	uniform	uniform	uniform	uniform	uniform	uniform	uniform
1	par1	range	range	range	range	range	range	range
1	par2	range	range	range	range	range	range	range
2A	prediction	41	0	0	0	0	0	10
2A	min	range	range	range	range	range	range	range
2A	max	range	range	range	range	range	range	range
2A	dist	uniform	uniform	uniform	uniform	uniform	uniform	uniform
2A	par1	range	range	range	range	range	range	range
2A	par2	range	range	range	range	range	range	range
2B	prediction	41	16.44	0	0.55	50	0	8
2B	min	range	range	range	range	range	range	range
2B	max	range	range	range	range	range	range	range
2B	dist	uniform	uniform	uniform	uniform	uniform	uniform	uniform
2B	par1	range	range	range	range	range	range	range
2B	par2	range	range	range	range	range	range	range
3A	prediction	41	0	25	0	40	0	0

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#	Type	env_watstr	env_disp.ww	env_disp.sldg	env_co2.footpr	live_health	live_income.tann	live_income.farm
3A	min	range	range	range	range	range	range	range
3A	max	range	range	range	range	range	range	range
3A	dist	uniform	uniform	uniform	uniform	uniform	uniform	uniform
3A	par1	range	range	range	range	range	range	range
3A	par2	range	range	range	range	range	range	range
3B	prediction	80	82.19	mid	0.45	250	0	0
3B	min	range	range	range	range	range	range	range
3B	max	range	range	range	range	range	range	range
3B	dist	uniform	uniform	uniform	uniform	uniform	uniform	uniform
3B	par1	range	range	range	range	range	range	range
3B	par2	range	range	range	range	range	range	range
4A	prediction	50	54.80	25	mid	150	0	10
4A	min	range	range	range	range	range	range	range
4A	max	range	range	range	range	range	range	range
4A	dist	uniform	uniform	uniform	uniform	uniform	uniform	uniform
4A	par1	range	range	range	range	range	range	range
4A	par2	range	range	range	range	range	range	range
4B	prediction	50	16.44	0	0.55	50	0	6
4B	min	range	range	range	range	range	range	range
4B	max	range	range	range	range	range	range	range
4B	dist	uniform	uniform	uniform	uniform	uniform	uniform	uniform
4B	par1	range	range	range	range	range	range	range
4B	par2	range	range	range	range	range	range	range
4C	prediction	50	54.80	40	0	250	0	0
4C	min	range	range	range	range	range	range	range
4C	max	range	range	range	range	range	range	range
4C	dist	uniform	uniform	uniform	uniform	uniform	uniform	uniform
4C	par1	range	range	range	range	range	range	range
4C	par2	range	range	range	range	range	range	range
4D	prediction	41	0	40	0.1	0	mid	15
4D	min	range	range	range	range	range	range	range
4D	max	range	range	range	range	range	range	range
4D	dist	uniform	uniform	uniform	uniform	uniform	uniform	uniform
4D	par1	range	range	range	range	range	range	range
4D	par2	range	range	range	range	range	range	range
5	prediction	mid	82.19	72.5	mid	300	0	5

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#	Type	env_watstr	env_disp.ww	env_disp.sldg	env_co2.footpr	live_health	live_income.tann	live_income.farm
5	min	range	range	range	range	range	range	range
5	max	range	range	range	range	range	range	range
5	dist	uniform	uniform	uniform	uniform	uniform	uniform	uniform
5	par1	range	range	range	range	range	range	range
5	par2	range	range	range	range	range	range	range

Table A3.2 Attribute levels for the alternatives (continued). Legend see Table A3.1.

#	Type	live_safe.food	afford_capex	afford_opex	afford_cover	reliab_energy	reliab_irri.wat
0A	prediction	505.9	0	mid	mid	353	150
0A	min	252.4	range	range	range	range	range
0A	max	941.7	range	range	range	range	range
0A	dist	uniform	uniform	uniform	uniform	uniform	uniform
0A	par1	252.4	range	range	range	range	range
0A	par2	941.7	range	range	range	range	range
0B	prediction	mid	mid	mid	mid	mid	mid
0B	min	range	range	range	range	range	range
0B	max	range	range	range	range	range	range
0B	dist	uniform	uniform	uniform	uniform	uniform	uniform
0B	par1	range	range	range	range	range	range
0B	par2	range	range	range	range	range	range
1	prediction	110	0	mid	mid	365	270
1	min	55	range	range	range	range	range
1	max	205	range	range	range	range	range
1	dist	uniform	uniform	uniform	uniform	uniform	uniform
1	par1	54.9	range	range	range	range	range
1	par2	204.8	range	range	range	range	range
2A	prediction	100	mid	mid	mid	365	150
2A	min	50	range	range	range	range	range
2A	max	175	range	range	range	range	range
2A	dist	uniform	uniform	uniform	uniform	uniform	uniform
2A	par1	50	range	range	range	range	range
2A	par2	175	range	range	range	range	range
2B	prediction	220	mid	mid	mid	361	200
2B	min	110	range	range	range	range	range
2B	max	410	range	range	range	range	range

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#	Type	live_safe.food	afford_capex	afford_opex	afford_cover	reliab_energy	reliab_irri.wat
2B	dist	uniform	uniform	uniform	uniform	uniform	uniform
2B	par1	109.8	range	range	range	range	range
2B	par2	409.5	range	range	range	range	range
3A	prediction	505.9	mid	mid	mid	353	150
3A	min	252.4	range	range	range	range	range
3A	max	941.7	range	range	range	range	range
3A	dist	uniform	uniform	uniform	uniform	uniform	uniform
3A	par1	252.4	range	range	range	range	range
3A	par2	941.7	range	range	range	range	range
3B	prediction	505.9	0.02	mid	mid	362	150
3B	min	252.4	range	range	range	range	range
3B	max	941.7	range	range	range	range	range
3B	dist	uniform	uniform	uniform	uniform	uniform	uniform
3B	par1	252.4	range	range	range	range	range
3B	par2	941.7	range	range	range	range	range
4A	prediction	150	mid	mid	mid	365	250
4A	min	75	range	range	range	range	range
4A	max	279	range	range	range	range	range
4A	dist	uniform	uniform	uniform	uniform	uniform	uniform
4A	par1	74.8	range	range	range	range	range
4A	par2	279.2	range	range	range	range	range
4B	prediction	220	mid	mid	mid	357	200
4B	min	110	range	range	range	range	range
4B	max	410	range	range	range	range	range
4B	dist	uniform	uniform	uniform	uniform	uniform	uniform
4B	par1	109.8	range	range	range	range	range
4B	par2	409.5	range	range	range	range	range
4C	prediction	500.9	0.74	0	100	365	150
4C	min	252.4	range	range	range	range	range
4C	max	941.7	range	range	range	range	range
4C	dist	uniform	uniform	uniform	uniform	uniform	uniform
4C	par1	252.4	range	range	range	range	range
4C	par2	941.7	range	range	range	range	range
4D	prediction	505.9	mid	mid	mid	365	mid
4D	min	252.4	range	range	range	range	range
4D	max	941.7	range	range	range	range	range
4D	dist	uniform	uniform	uniform	uniform	uniform	uniform

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#	Type	live_safe.food	afford_capex	afford_opex	afford_cover	reliab_energy	reliab_irri.wat
4D	par1	252.4	range	range	range	range	range
4D	par2	941.7	range	range	range	range	range
5	prediction	100	mid	mid	mid	mid	mid
5	min	50	range	range	range	range	range
5	max	186	range	range	range	range	range
5	dist	uniform	uniform	uniform	uniform	uniform	uniform
5	par1	49.9	range	range	range	range	range
5	par2	186.2	range	range	range	range	range

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