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Perceived drivers and barriers in the governance of wastewater treatment and reuse in India: Insights from a two-round Delphi study

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ABSTRACT

Wastewater treatment and reuse practices are limited in India despite the known benefits of preventing water resources pollution and contributing to sustainable production and consumption systems. We identify the perceived key drivers and barriers to wastewater treatment and reuse governance in a two-round Delphi study, including literature and case study analyses and consultation with 75 panelists. Panelists indicated that the most significant driver for wastewater treatment and water reuse is persistent water scarcity that necessitates diversification to alternative water supplies. In contrast, the most significant barriers are the lack of enforcement of pollution monitoring and control, the lack of an umbrella directive for integrated water resources management, and insufficient collaboration between responsible governmental organizations, central and state water authorities. Given the absence of central guidelines, only a few Indian states such as Maharashtra, Gujarat or Punjab have adopted effective governance structures. These states showcase that defined reuse standards can create successful wastewater treatment and reuse practices but require target-based regulations which are enforced and regularly monitored and financing mechanisms for their long-term operation. The new effluent discharge standards by the National Green Tribunal, the government support programmes, and increasing water scarcity in many parts of India will supposedly drive innovative wastewater treatment and reuse structures. Panelists agreed that efforts are needed to develop technology guiding frameworks following the fit-for-purpose principle and that strengthening institutional and monitoring capacity is crucial to increase confidence in the quality of recovered water resources, create demand, and ultimately safeguard human health and the environment.

1. Introduction

Innovative wastewater treatment and reuse technologies play a key role in improving urban sanitation and enhancing water security as stipulated by the 2030 Agenda on Sustainable Development (UN Nations, 2015). Although the benefits of wastewater treatment and reuse technologies are well known and acknowledged, their implementation in the municipal wastewater management sector is still limited, especially in low- and middle-income countries, such as India (Otoo & Drechsel, 2018).

In India, the treatment of municipal wastewater ('sewage') is under state government responsibility. Only about a third of urban Indian households have access to piped sewer networks linked to state sewage treatment plants (STPs; 1,093 STPs in 2020, Indian Census, 2011; CPCB, 2021). Operational STPs treat only 37% of the 72,368 MLD of generated sewage (CPCB, 2021) and are poorly performing, with 35-50% not meeting the STP discharge standards (MOEFCC, 2017). The technologies used by most STPs are two-stage treatment processes, with capacities

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ranging from 0.2 - 800 MLD (CPCB, 2015a). Standard STP designs are primary settling, followed by sequential batch reactor (SBR), activated sludge process (ASP), up-flow anaerobic sludge blanket (UASB), and polishing ponds; or a series of waste stabilization ponds (WSP; CPCB, 2015a; CPCB, 2021). The STP technology designs and amounts of treated sewage differ between Indian states (Figure 1) due to resource and climate contexts, stakeholder preferences for technological options, and government support programmes in place (Breitenmoser et al., 2019). The Clean Ganga Programme (Namami Gange), for example, initiated by the Ministry of Jal Shakti (2014-2023) as integrated conservation and river protection mission, finances sewerage infrastructure projects (i.e. STPs and sewer systems) in the Ganga River Basin, particularly in those states with low treatment capacities (Figure 1), i.e. Uttarakhand (30.9% sewage treatment capacity installed in 2015), Uttar Pradesh (37.2%), Bihar (6.6%), Jharkhand (7.8%), and West Bengal (8.9%) (CPCB, 2015a; NMCG, 2021). A total of 152 sewerage infrastructure projects have been sanctioned to date, of which 50 projects are implemented or planned in Uttar Pradesh (UP), where the longest stretch of the Ganga River flows (1,000 km of 2,525 km) and major polluting activities are found (Press Information Bureau, 2020).

Next to sewage, India generates 13,468 MLD of industrial wastewater, out of which only 60% is treated. Treatment occurs in effluent treatment plants (ETPs) of single industries or common effluent treatment plants (CETPs) of industrial clusters from several small-or medium-scale industries (Kaur, 2012; Randade & Bhandari, 2014). Recent studies suggest that their compliance rate with industrial effluent standards (MOEFCC, 2016) is very low (< 35% for ETPs and < 10% for CETPs), attributed to inadequate planning at the stage of designing and commissioning of new plants and poor operation and maintenance (Kathuria & Turaga, 2014; IGEP, 2015, CPCB, 2018).

Centralized solutions for sewage treatment are the preferred ones by political actors and engineers (PwC, 2016; Never, 2016; Wankhade, 2015). Water reuse is limited to a few centralized schemes (CPHEEO, 2021). Formal water reuse schemes exist for agriculture and horticulture (WSP & IWMI, 2016), e.g. in Kanpur, Uttar Pradesh and some industries for cooling (PwC, 2016), e.g. in Nagpur, Maharashtra and Chennai, Tamil Nadu. The use of partially treated and untreated sewage for irrigation, such as e.g. in Hyderabad, Telangana, is widespread in India given the lack of a freshwater alternative and the fertilizing properties of sewage (Kaur et al., 2012; Kumar & Tortjada, 2020). Decentralized, smaller-scale STPs are less common and are perceived as solutions for underdeveloped areas (e.g. peri-urban and rural settings) by central and state authorities. The estimated 20,000 small-scale STPs (0.005 – 0.7 MLD) in India are constructed and operated by private entities for on-site wastewater treatment and reuse in residential and commercial complexes (Kuttuva et al., 2018, Klinger et al., 2020; Reymond et al., 2020). Also, for decentralized STPs, recent assessments show that most systems failed to treat wastewater up to the desired water reuse standards due to the lack of nutrient and microbial removal processes (Ulrich et al., 2018). Reuse of treated water is further hampered by a lack of demand in the vicinity (Klinger et al., 2020).

India's sewage and industrial wastewater treatment and reuse practices have caused severe negative impacts on surface water, groundwater and agricultural systems (e.g. Singh et al., 2004.; CPCB, 2013, Williams et al., 2019), human health (e.g. Singh et al., 2004.; Rakhecha, 2020), and the economy (WSP, 2011). Innovative, viable and safe wastewater treatment and reuse technologies and business models are imperative to meet the future water demand of fast-growing urban, agricultural and industrial sectors and combat the rapidly decreasing freshwater availabilities and qualities (WSP & IWMI, 2016). Recent experiences show that transitions towards advanced water reuse systems and practices are driven by governance structures, i.e. the political, legal and administrative systems that influence wastewater management and reuse (WWAP, 2017; IWA, 2018). Governance structures are very context-specific; they vary between and within countries (Lautze et al., 2014; Otoo & Drechsel, 2018). Only a few studies have comprehensively investigated the Indian governance structures related to wastewater treatment and reuse (e.g. WSP & IWMI, 2016., Alley et al., 2018, Kumar & Goyal, 2020; Kumar & Tortjada, 2020).

Hence, in this paper, we pursue the following research questions: What are the key drivers and barriers of the current governance structures that influence the long-term operation and up-scaling of wastewater treatment and reuse systems and practices in India? What are in particular: i) the key laws, policies and government programmes at

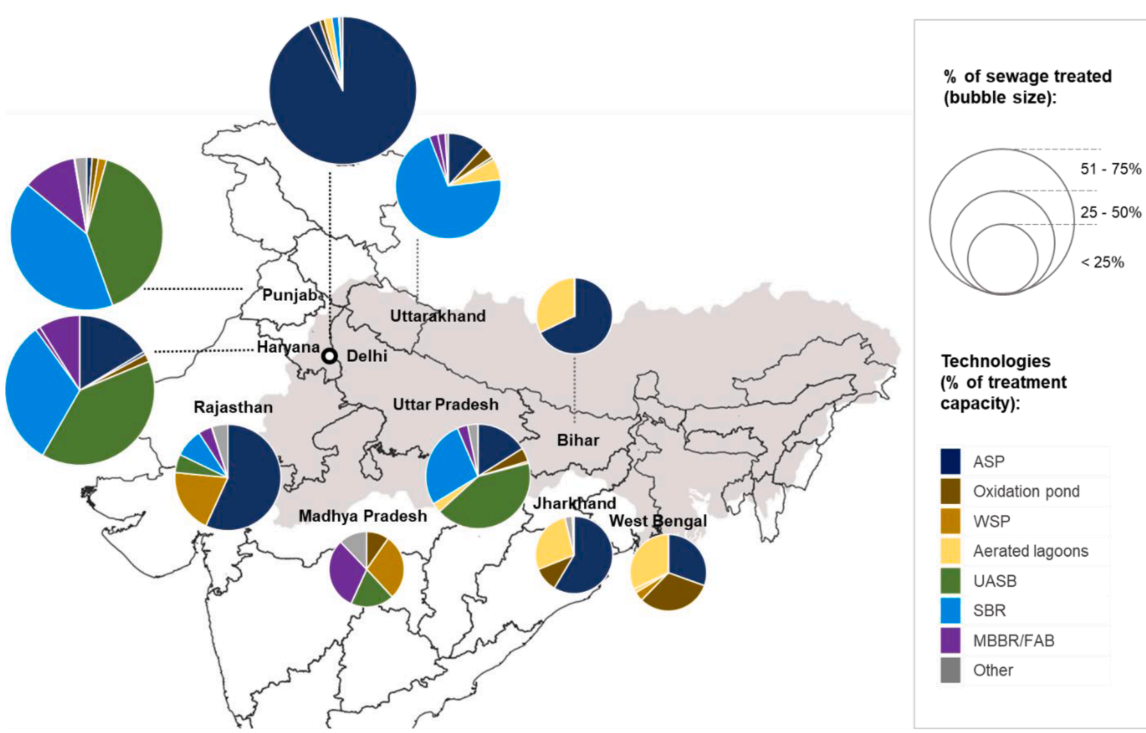

Fig. 1. STP technologies and total treatment capacity installed (or planned) in selected states of the Ganga river basin (Based on data from CPCB, 2015a)

different administrative levels, i.e. at the central government level and in four case studies (at the state level), and ii) the governance structures that impact on wastewater treatment and reuse practices? In contrast to previous studies on the topic, our analyses capitalize not only on existing peer-reviewed and grey literature but also on stakeholder practices, experiences, knowledge and perceptions gathered in a two-round Delphi study. We conclude with recommendations for a governance framework to support the phasing-in of innovative wastewater treatment and reuse models in India.

2. Material and Methods

2.1. Governance analysis framework

We used an adapted policy and planning framework (WHO, 2019; Figure 2) to define and analyze key elements in the wastewater treatment and reuse governance structures at the Central and State government levels (pertaining to four selected Indian case studies). We used peer-reviewed published and grey literature, such as government reports, to investigate the impacts of governance structures on wastewater treatment and reuse practices.

2.2. Case studies

The case studies presented in this paper include:

- Case 1) agricultural water reuse in Kanpur, Uttar Pradesh;
- Case 2) agricultural water reuse in Hyderabad, Telangana;
- Case 3) industrial water reuse in Nagpur, Maharashtra; and
- Case 4) industrial water reuse in Chennai, Tamil Nadu.

Based on previous studies (e.g. Amerasinghe et al., 2013; Keremane, 2017; IWA, 2018; Kumar & Tortjada, 2020), these case studies are symbolic for their water endowments, intra-state governance arrangements, and their scales and types of wastewater treatment and reuse. The city of Kanpur is one of the major industrial cities (tanneries) in Northern India. It has been distributing a mix of treated wastewater from STPs and CETPs in an irrigation channel to nearby agricultural fields (166 MLD on 2,500 ha) since 1986 due to the Ganga Action Plan. In Hyderabad, around 1,200 MLD untreated and partly treated sewage flowing in the Musi River is diverted informally by farmers into irrigation channels at several points to irrigate approximately 10,000 – 12,000 ha of agricultural land. The city of Nagpur supplies 330 MLD of treated sewage to nearby thermal power plants based on private-public partnership (PPP) initiatives. Several water reuse practices are on-going in the city of Chennai. 8% of treated sewage (58 MLD) is reused by petrol and fertilizer industries for boiling and cooling towers. 40% of the urban water demand (290 MLD) is further secured from in-house wastewater treatment and reuse in new buildings.

2.3. Two-round Delphi study

We investigated perceptions of key drivers and barriers in governance structures for wastewater treatment and reuse in India in a two-round Delphi study. The Delphi method uses a structured group communication process to collectively address and explore areas where controversy, debate, or a lack of clarity exists (Iqbal & Pipon-Young, 2009; Mukherjee et al., 2015). The main characteristics of Delphi studies are the consultation with a group of experts ('panelists') to gather their opinions in a series of two or more sequential questionnaires ('rounds') (Grime & Wright, 2016).

Our two-round Delphi study aimed to determine the diversity of opinions among 75 selected panelists which were shortlisted purposively given their expertise within the wider Horizon 2020 Pavitra Ganga Project network (https://pavitra-ganga.eu/en). The panel

Table 1
Panelist profiles and number of panelists in two-round Delphi study

Panelists' professional backgrounds	Total Pavitra Ganga Expert panel	Number of panelists Round 1: Consultation workshops/Telephone interviews	Round 2: Online survey
Government/ Water authority	26	21	3
Research	20	16	6
Non-governmental organization	13	8	5
Consultant	5	3	3
Technology provider	4	4	
Industry	4	1	2
Engineer	2		
Wastewater treatment utility	1		1
Total	**75**	**53**	**20**

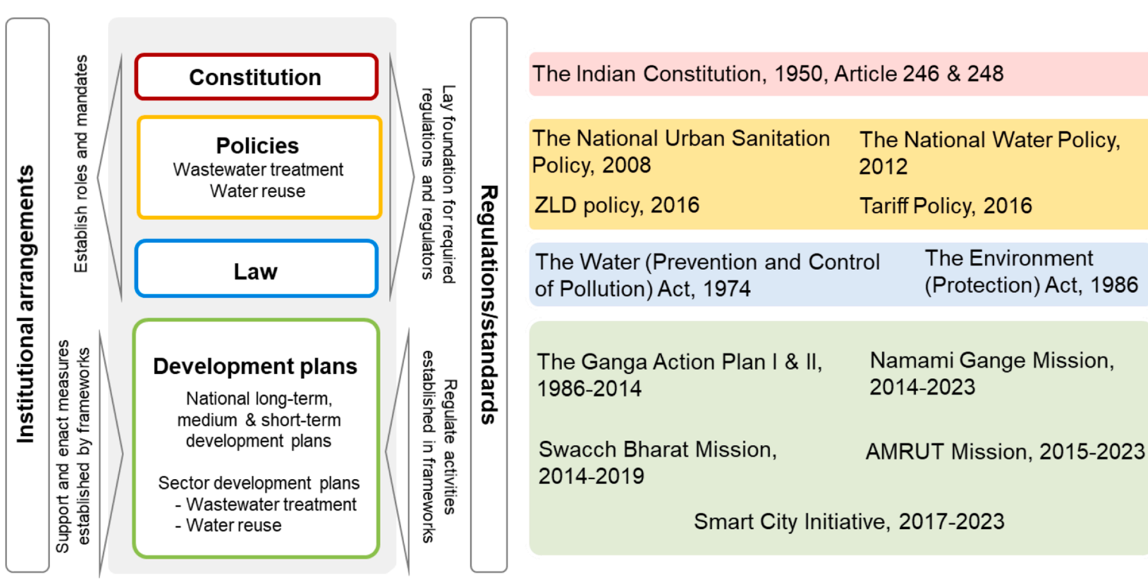

Fig. 2. Elements of the wastewater treatment and water reuse governance framework of the Central Government in India (adapted from WHO, 2019)

included experts with different professional backgrounds and roles in India's wastewater treatment and reuse management (Table 1).

During *Round 1* of the Delphi study, stakeholder consultation workshops were held in March 2020 (n=41 participants) and expert-based telephone interviews were conducted in November 2020 (n=12 participants). The participation rate in Round 1 was 70%; with 30% female and 70% male participants and a majority of participants from government authorities (39%), research (30%), and non-governmental organizations (NGOs; 15%). We used open-ended questions (see supplementary material A.1) to explore a wide range of perceived key drivers and barriers in the governance structures and the long-term operation and uptake of innovative wastewater treatment and reuse systems.

For *Round 2,* we synthesized the findings from literature reviews and Round 1 using a qualitative content analysis method (Forman & Damschroder, 2007) to construct an online follow-up survey. The online survey included 40 selected thematic statements on key drivers and barriers in wastewater treatment and reuse governance in India. 45 panelists from the expert panel were asked to provide their individual perceptions on these statements using a 6-point-Likert type agreement scale (+++ *highly agree,* ++ *agree,* + *rather agree,* - *rather disagree,* – *disagree,* — *highly disagree*; see supplementary material, A.2). After distributing the online survey via SurveyMonkey® in mid-March 2021, non-responders have been followed-up twice. The online survey terminated end of April 2021 with a 44% response rate (n= 20 fully completed questionnaires; n= 2 partially completed questionnaires; 25% female and 75% male participants). The smaller expert panel and response rate in round 2 resulted from the worsening COVID-19 situation in India during the online survey. Participants of round 2 are involved in research or NGOs (30% and 25% respectively) or work for government or consultancies (each 15%). 14 participants had practical experience with wastewater treatment and reuse schemes, while 6 participants answered to have research knowledge of the topic.

We designed, piloted, and conducted the Delphi study following guidelines for telephone interviews (Block & Erskine, 2012) and online questionnaire surveys (Regmi et al., 2016) to avoid unclear, repetitive or inaccurate statements. The panelists provided informed consent before participating in Round 1 and Round 2 of the Delphi study.

For data analysis, Round 2 statements were coded and the 6-point Likert type agreement scale was transformed to a numeric scale (1 - 6; *1 = highly disagree; 6 = highly agree*). We calculated mean values m showing the level of agreement/disagreement to the respective statements and percentiles to demonstrate the degree of consensus/dissensus within the expert panel.

3. Results & Discussion

We analyzed policies, laws, development plans, regulatory and institutional arrangements for wastewater treatment and reuse at the Central government (Figure 2) and case study level.

We identified and reflected on the perceived key drivers and barriers of these governance structures in sections 3.1 and 3.2. We provided the mean m and used percentiles to identify the level of agreement and degree of consensus among panelists towards a respective statement:

- $m = 1.00$ - 3.49 is interpreted as disagreement to a statement; $m =$ 3.50 - 6.00 is interpreted as agreement to a statement. The lower or higher the mean values, the higher the level of disagreement or agreement, respectively.
- Percentiles show the degree of consensus/dissensus towards a statement within the expert panel. A consensus is observed if ≥ 75% of the experts agree/ disagree with a statement. In case of an agreement with the statement ($m \geq 3.50$), a consensus among the experts is achieved if the 25th percentile is $Q1 \geq 3.50$, which signifies that ≥ 75% of the experts rather agree with the statement. In case of disagreement with the statement ($m < 3.50$), a consensus is achieved if the 75th percentile is $Q3 < 3.50$.

Statement ratings of Round 2 are used to categorize weak, strong and very strong governance drivers and barriers. Statements with high agreement or disagreement levels ($m \geq 5$ or $m \leq 2$) and consensus among the experts (≥ 75% of the experts agreeing/disagreeing) are interpreted and discussed as key drivers and barriers in section 3.3 (*cf.* supplementary materials Tables A.2.1 – A.2.5 showing boxplots with means and percentiles of all statements).

3.1. Wastewater treatment and reuse governance structure at the Central Government

3.1.1. The Indian Constitution, 1950, Article 246 & 248

The Indian Constitution, in its Article 246, places water resources (i.e. water supply and wastewater treatment, irrigation and canal management, drainage and embankments, water storage and water power) under the legislative jurisdiction of the State Governments. The regulation and development of inter-state rivers remain under the Central Government's jurisdiction as well as the ability to legislate on environmental matters (*cf.* Article 248 of the Indian Constitution; Government of India, 1974a). Delegating the jurisdiction over water resources to the State Governments and the jurisdiction over environmental matters to the Central Government allows for dual Central and State Government water and wastewater regulations. As a result, the governance system sees many duplicative functions and institutions by the Central and State Governments, which is perceived as an important institutional barrier by the expert panel of this study: *The different central and state governmental organizations tend to work in silos* (*Inst1* (statement code); $n = 20$ (number of expert ratings for the statement); $m = 5.0$ (mean value on the agreement scale); $Q1 = 4.25$ (25th percentile); Table A.2.1); and *their lack of collaboration present significant challenges for the implementation and long-term operation of wastewater treatment and reuse systems* (*Inst2;* $n = 19$; $m = 5.00$; $Q1 = 4.00$; Table A.2.1).

3.1.2. Central government policies fostering wastewater treatment and reuse

Wastewater treatment and reuse to foster water conservation and to enhance alternative water supplies are promoted in the National Urban Sanitation Policy (MoUD, 2008) and the National Water Policy (MoJS 1987; 2012). However, there are no clear central water reuse standards or rules in India which specify reuse applications (Schellenberg et al., 2020), nor does an integrated framework for integrated water resources management (IWRM) exist in India (*Reg6;* $n = 20$; $m = 5.10$; $Q1 = 5.00$, Table A.2.1). An umbrella directive for IWRM as well as water reuse standards are perceived *to foster wastewater treatment and reuse systems in India* (*Reg7;* n=19; m=5.00; $Q1 = 5.00$ and *Reg8;* $n = 19$; $m = 4.74$; $Q1 =$ 5.00; Table A.2.1), as experienced in several Indian states (Schellenberg et al., 2020, Reymond et al., 2020) such as Karnataka, Gujarat, Jharkhand, Haryana and Punjab (*Reg9;* $n = 16$; $m = 4.44$; $Q1 = 4.00$; Table A.2.1). Similarly, newer policies, such as the zero-liquid discharge (ZLD) policy 2015 (CPCB, 2015b) or the Tariff Policy 2016 (MOP, 2016), are also supposed to increase on-site water reuse by industries and thermal power plants within 50 km radius of STPs (*Pol1;* $n = 16$; $m =$ 4.56; $Q1 = 4.00$; Table A.2.2). Even though political priorities seem to influence whether investments in wastewater treatment and reuse are made (*Pol4;* $n = 19$; $m = 4.84$; $Q1$ =4.00, Table A.2.2), the lack of clear action plans to operationalize the policies, weak enforcement (*Reg3*), lacking monitoring mechanisms (*Reg4*), and unclear responsibilities, as well as inter-sectoral conflicts among water-related ministries (Inst2), hinder any significant impact on improving India's water management practices (Pandit and Biswas, 2019; Jain, 2019). The expert panel further highlighted that a future central legislation on water reuse should include quality targets for different water reuse purposes (*Reg10;* $n = 19$; $m = 5.47$; $Q1 = 5.00$; Table A.2.1) and should provide better guidance on legislative, regulatory and financial measures for state governments to implement them *(Reg11;* $n = 20$; $m = 5.45$; $Q1 = 5.00$; Table A.2.1).

3.1.3. The Water (Prevention and Control of Pollution) Act 1974 and The Environment (Protection) Act 1986

The Water (Prevention and Control of Pollution) Act, 1947 (amended 1988; Government of India, 1974b) laid the foundation for establishing Central and State Pollution Control Boards (the CPCB and SPCBs). Their mandate is to advise, monitor, and enforce sewage and industrial effluents' treatment and disposal regulations to prevent and control water pollution. Discharge standards for STPs and CETPs are regulated under the Environment (Protection) Act of 1986, which prescribes maximum limits of various pollutants to be discharged to different environmental compartments (land, surface water bodies, marine coastal areas, etc.). The STP discharge standards were amended in 2017 (MoEFCC, 2017) and in 2019 by the National Green Tribunal (NGT). The NGT Order makes the STP standards more stringent and is perceived as a rather *good development to reduce environmental pollution to water bodies* (*Reg2;* $n = 20$; $m = 4.65$; $Q1 = 4.00$; Table A.2.1). However, major problems are attributed to the enforcement of the STP and CETP standards, as *STPs and CETPs are not sufficiently monitored due to a lack of expertise, capacity and infrastructure* (*Reg4;* $n = 22$; $m = 5.27$; $Q1 = 5.00$: Table A.2.1) and *there are hardly any penalties for non-compliance* (*Reg3;* $n = 21$; $m = 5.00$; $Q1 = 5.00$; Table A.2.1).

3.1.4. National development plans to clean River Ganga and recent sector development plans to improve wastewater treatment and management

The key flagship national programmes launched by the Government of India to clean the River Ganga have been the Ganga Action Plan (GAP) launched in 1985 and the current Namami Gange programme launched in 2014. The Government of India has recently also initiated or renewed several sectoral programmes to improve un-sewered and sewered sanitation, such as the Swachh Bharat (Clean India) Mission 2014-2019, the AMRUT Mission 2015-2023 and the Smart City initiative 2017-2023 (Cuadrado-Quesada et al., 2020). Under these national and sectoral programmes, municipal and private-sector applicants are offered grants, subsidies, and loans for investments. Despite creating considerable STP or sanitation infrastructure, these financial instruments hardly achieve their overall objectives due to multiple factors. Perceived barriers are i) unclear responsibilities between central, state, and local government bodies to implement schemes (cf. statements *Inst 1 & Inst 2*), ii) inadequate technological designs, *which do not adequately consider long-term development plans of the areas and which hamper treatment efficacy* (*Tech3;* $n = 18$; $m = 4.78$; $Q1 = 4.00$; Table A.2.4), iii) significant delays in project execution, iv) weak monitoring of STP compliance (cf. statement *Reg4;* Table A.2.1) and v) lack of adequate financing strategies for cost-recovering wastewater treatment services. The expert panel emphasized the latter aspect, as *cost-recovery for the operation and maintenance (OPEX) of wastewater treatment is very low* in India (*Fin5;* $n = 17$; $m = 4.82$; $Q1 = 5.0$; Table A.2.3). While there is some agreement among the experts that the national and sector programmes provide sufficient funds to enhance wastewater treatment infrastructure (*Fin1;* $n = 19$; $m = 4.26$; $Q1 = 4.00$; Table A.2.3), the experts rather disagreed that *central and state governments provide sufficient budget to operate and maintain wastewater treatment infrastructure* (*Fin3*; $n = 18$; $m = 3.06$; $Q3 = 5.00$; Table A.2.3). Despite the dissensus in the expert panel, which could be explained by state-specific financing strategies for wastewater treatment, barriers for adequate financing are, e.g. attributed to the *low cost-recovery due to low wastewater treatment tariffs* (*Fin6;* $n = 16$; $m = 4.56$; $Q1 = 4.25$; Table A.2.3) and *low willingness to pay for municipal wastewater treatment services* (*Fin7;* $n = 17$; $m = 3.94$; $Q1 = 3.50$; Table A.2.3).

The Namami Gange programme 2014 – 2023 is an on-going programme with a broader scope of effective abatement of pollution, conservation and rejuvenation of the National River Ganga. To account for the barriers related to financing strategies under GAP, central and state governments support public-private partnership models (PPP) to increase financial viability e.g. through DBOT (design, build, operate and transfer), Hybrid Annuity Model or Viability Gap Funds. PPP models are perceived as rather promising solutions to *promote cost-effective long-term O&M of wastewater treatment and water reuse infrastructure* (*Fin4;* $n = 17$; $m = 4.47$; $Q1 = 3.50$; Table A.2.3), mostly for *industrial water reuse schemes, where willingness to pay for treated wastewater exists* (*Fin9;* $n = 17$; $m = 4.41$; $Q1 = 3.00$; Table A.2.3). The moderate level of agreement among experts on the relevance of PPP models could be attributed to rather general phrasing of the statements, i.e. PPP models can promote cost-effective long-term wastewater treatment and water reuse infrastructure, if single or few large industrial players are the end-users (cf. case study Nagpur, chapter 3.2.3). If multiple end-users such as small- and medium enterprises (SMEs) are involved or water is reused for low-revenue applications such as agriculture, the development of cost-covering projects is more challenging, e.g. due to l*ow financial capacities of SMEs and farmers* (PwC, 2016, *Fin8;* $n = 18$; $m = 4.33$; $Q1 = 4.00$; Table A.2.3), as seen in case studies of Kanpur, Hyderabad and Chennai (chapters 3.2.1, 3.2.2 and 3.2.4).

3.2. Wastewater treatment and reuse governance in four case studies

3.2.1. Agricultural water reuse in Kanpur, Uttar Pradesh

Kanpur is the largest city of Uttar Pradesh (UP) state, with over 3 million inhabitants (United Nations, 2018). The city produces about 340 MLD of sewage and 26 MLD of wastewater is produced from its tannery cluster (Bassi et al., 2019). Installed wastewater treatment capacity is less than 50% (Bassi et al., 2019). There is no formal regulation or policy to incentivize the reuse of wastewater in UP.

Under the Ganga Action Plan – Phase I (GAP- I) in 1986 (cf. Chapter 3.1.3), three wastewater treatment plants were commissioned at Jajmau: a 130 MLD STP based on ASP; a 36 MLD CETP based on UASB and a 5 MLD pilot plant based on UASB. The treated sewage from ASP is mixed with tannery effluent from the UASB (166 MLD) and conveyed in a 4 km concrete irrigation channel to about 2,500 ha of peri-urban farmland (Australian Aid, 2013).

GAP- I was introduced to improve water quality through interception, diversion and treatment of domestic sewage and industrial wastes. However, the technological design of the CETP in Kanpur was unable to treat the increased volume of tannery effluent (from 9 MLD in 1993 to 36 MLD in 2015) nor specific contaminants of tanneries (heavy metals, salts). Furthermore, the plants were poorly operated and subjected to frequent electricity breakdowns (Singh, 2006). The mixing of treated STP and CETP wastewater produced low-quality irrigation water exceeding standards for, e.g. suspended solids, BOD, COD, and heavy metals such as chromium (CPCB, 2016; Ahmad & Chaurasia, 2019). These practices led to severe soil and water contamination (e.g. Kumar et al., 2020; Singh et al., 2020) and a decrease in milk and crop productivity (e.g. Amerasinghe et al., 2013, Gupta et al., 2018) as well as health issues (e.g. Sharma et al., 2012; Maurya et al., 2019) in the peri-urban farmland. The involvement of multiple organizations in wastewater management in Kanpur, such as Uttar Pradesh Pollution Control Board, Uttar Pradesh Jal Nigam, Jajmau Tannery Effluent Treatment Association, Small Tanners Associations and farmers, resulted in inter-institutional conflicts e.g. on the accountability of the leather industry to reduce pollution on-site (Singh, 2006) and refusal to pay for treated wastewater among farmers (Amerasinghe et al., 2013).

Several interventions have been recently initiated under the Namami Gange Programme. These comprise the implementation of an additional 43 MLD STP based on ASP and an additional 20 MLD CETP to treat tannery effluent, which comprises a tertiary treatment step based on ultrafiltration and includes a ZLD system that is tested on-site (Van Ermen et al., 2020). However, desalination to lower the salinity of the treated effluent is not (yet) included but needs to be addressed if the water is to be reused for agricultural purposes.

3.2.2. Agricultural water reuse in Hyderabad, Telangana

As of 2020, the population in the Greater Hyderabad area is estimated to be about 10 million (United Nations, 2018). The twin cities Hyderabad and Secunderabad have a semi-arid climate. They need to source freshwater (2,350 MLD) for domestic purposes from several reservoirs located at 10 km to 270 km from the city. About 1,800 MLD of wastewater, a mix of sewage and industrial effluents, is generated, whereas capacity exists to treat only 43% of this quantity (TSPCB, 2020). There are two centralized large-scale plants (Amberpet 339 MLD and Nagole 172 MLD) and some smaller decentralized STPs. In 2020, out of 23 STPs in the Greater Hyderabad area, nine were not fully operational, two were under maintenance and three did not comply with the discharge norms (CPCB, 2021). Most of the treated and untreated wastewater is discharged into the river Musi, a perennial tributary of river Krishna that consists only of wastewater during non-monsoon months. Water is diverted into irrigation channels from the Musi river at several points downstream to irrigate 10,000 – 12,000 ha of farmland (Kumar and Tortajada, 2020). It is estimated that about 90% of the wastewater generated (1,200 MLD) in Hyderabad is used in agriculture downstream (van Rooijen et al., 2010). As there is no alternative (fresh) water source available, irrigation with partly treated wastewater (which is free of costs) enables farmers to harvest para grass throughout the year or to produce rice crops twice per year (Buechler and Devi, 2003; Amerasinghe et al., 2013).

The city is administered by the Greater Hyderabad Municipal Corporation (GHMC). The planning, design, construction, operation, and maintenance of infrastructure related to water supply, sewerage, and sewage treatment works is with the Hyderabad Metropolitan Water Supply and Sewerage Board (HMWSSB). The Telangana State Pollution Control Board (TSPCB) monitors the effluents from the STPs and ensures that they meet the prescribed standards for the discharge of treated wastewater. The state government implemented the Hyderabad Metropolitan Water Supply and Sewerage Act in 1989, which follows the Central government laws (mainly Environment Protection Act, 1986, cf. chapter 3.1.2) and associated rules when it comes to the quality of the effluents from the treatment plants that can be discharged over land or in water. Although one of the sections of the Act mentions that no sewage shall be released to any water-course without treatment following the prescribed standards, the untreated wastewater continues to be discharged into river Musi. A sewerage master plan was prepared for the Greater Hyderabad area in 2019. There is a provision to set up 65 new STPs, doubling the existing treatment capacity by 2021 and reaching 3,000 MLD by 2051 (TSPCB, 2020). The master plan is supported with 3,000 crores INR (400 million USD) from the National River Conservation Directorate and intends to run the STPs under PPP models.

As of now, there is no legislation or specific policy to promote treated wastewater reuse in Telangana and no provisions to monitor the quality of wastewater being used by farmers downstream for irrigation. A small part of the treated wastewater (45 MLD) is sold from the STPs by HMWSSB for different urban uses. However, conveyance (transferability) to end-consumers via tankers is complex and costly, resulting in low demand for treated wastewater. Also, the HMWSSB or GHMC do not provide facilities to transport treated water to the farmers' fields. As a result, only those farmers who are close to the STPs or require a small volume of water for high-value crops will find it viable to transport treated water by tanker to their fields (Kumar and Tortajada, 2020). Further, the absence of institutional capacity to implement and monitor rules (such as those related to discharge of wastewater), the poor freshwater supply and sewage pricing system, and insufficient attention to environmental issues (river pollution) are the other factors identified behind the gap between formal use of treated (supplied by the HMWSSB) and informal use of partly treated wastewater by farmers in the Greater Hyderabad area (Devi and Samad, 2008; Saldías et al., 2015).

3.2.3. Industrial water reuse in Nagpur, Maharashtra

Nagpur, with almost 3 million inhabitants, is one of the largest cities in the state of Maharashtra (United Nations, 2018). Nagpur was selected as one of 63 mission cities under the Jawaharlal Nehru National Urban Renewal Mission (JnNURM) in 2006. Under the programme, water and wastewater treatment infrastructure were developed to tackle the severe water shortage in Nagpur city. About 550 MLD of sewage is generated in the city, which, if untreated, is discharged into the nearby Nag and Pili rivers. Two large STPs with the capacities of 130 MLD and 200 MLD (60% treatment capacity) were commissioned in the city in 2016 and 2018, respectively and are operated by the Nagpur Municipal Corporation (NMC). A Memorandum of Understanding was signed in 2008 between NMC and Maharashtra Generation Company Limited (MahaGenCo) for supplying of 110 MLD treated sewage from Bhandewadi STP (SBR and multi-media filter, 130 MLD) (Ade et al., 2018) to be used in the cooling towers of the thermal power plant in Koradi. Mahagenco and Vishvaraj Infrastructure Ltd made further commitments to buy an additional 200 MLD from the second NMC STP for the Koradi and Khaparkheda thermal power stations following the same PPP contract (build-operate-transfer model). The National Power Corporation recently committed to buy 150 MLD of a newly planned STP in Nagpur.

The PPP model provoked other thermal power stations situated near the city to opt for treated wastewater as a reliable water source. In 2017, the State of Maharashtra adopted the wastewater reuse policy for the reuse of treated municipal wastewater for cooling in thermal power plants and in industrial estates for non-potable purposes. The policy stated that permission for the extraction of freshwater from reservoirs for industrial areas and power plants located within 50 km of municipal corporations, for non-potable purposes, would be withdrawn once the treated wastewater was made available (Ashar, 2017).

The highly acceptable quality of tertiary treated wastewater from Bhandewadi STP was the primary driver for the industrial reuse of the treated wastewater. Further, the wastewater reuse project for Bhandewadi STP was jointly developed by the NMC and MahaGenCo. MahaGenCo pays INR 15 crores (2 million USD) per year for 110 MLD treated sewage and INR 2.3 (0.03 USD) per m^3 of additionally treated sewage exceeding 110 MLD. This has clear economic advantages for MahaGenCo, as sourcing freshwater from irrigation or municipal projects is more expensive in water-scarce Nagpur (about INR 9.6/ 0.13 USD per m^3). On the other hand, the PPP contract and revenues from MahaGenCo helped NMC cover the operation and maintenance of their wastewater treatment plants (World Bank Group, 2019). The strong contractual agreements backed by government policies ensured a regular and reliable wastewater supply to the industry with regular monitoring. It also established project ownership and management as MahaGenCo is the only end-user of the treated wastewater (World Bank Group, 2019). Thus, the Nagpur case is recognized as a successful business model for industrial reuse.

3.2.4. Industrial water reuse in Chennai, Tamil Nadu

As of 2020, Chennai urban agglomeration has an estimated population of about 10.9 million (United Nations, 2018). The city, located on the coast, has a dry climate. Lakes, reservoirs, and bore wells are the major sources of domestic water supply. The Chennai Metropolitan Water Supply & Sewerage Board (CMWSSB), a statutory body established in 1978, is responsible for providing water supply and sewerage services. As of March 2018, about 99% and 82% of the Chennai Metropolitan Area (CMA), comprising Chennai city and its contiguous urban and rural areas, is covered by water supply and sewerage services, respectively (CMWSSB, 2018). However, the city is known for acute water shortage with existing water supply sources unable to provide water to meet the demands of the growing population (Kumar, 2018). The total wastewater generation in the CMA is estimated to be 1,100 MLD, and the installed capacity for its treatment is around 70% (based on data presented in IWA, 2018). The 12 STPs established by CMWSSB undertake secondary treatment of wastewater (cumulative capacity 727

MLD) and sell it to large industries in Chennai (Natarajan, 2020). The industries further treat the water to tertiary standards before using it. Overall, 49% of the treated wastewater is reused, which can meet 15% of the CMA's water demand. Industries reuse about 8% of the treated wastewater (IWA, 2018). A total of 33 MLD of secondary treated wastewater is supplied to industries, including tanneries, fertiliser, and petro chemical units (Natarajan, 2020). By 2030, CMWSSB aims to treat, recycle and reuse all the wastewater generated from the CMA (IWA, 2018). For the monitoring of effluents from the STPs, Tamil Nadu Pollution Control Board is the responsible agency.

The Greater Chennai Corporation, a civic body that governs Chennai city, has adopted a by-law that sets the rules for mandatory wastewater recycling (IWA, 2018). As per the rules framed under the by-law, permits for all the new developments in the CMA will only be awarded to those that plan for wastewater recycling and reuse for non-potable purposes in their design. Further, industries and manufacturers must achieve ZLD in their operations and reuse all the wastewater that is generated through their operations after treatment (IWA, 2018). Also, as a long-term measure to promote the reuse of treated wastewater in industries, the Government of Tamil Nadu is contemplating the formation of a 'reuse grid' for supplying treated wastewater from the STPs to industries all over the state (Natarajan, 2020).

However, there are concerns about the quality of effluents released after treatment from the STPs. The presence of several trace organic compounds (such as acesulfame, atenolol, caffeine, iohexol, and sucralose) was reported in the effluents of some of the STPs that are supplying treated wastewater in the CMA (Anumol et al., 2016). This will further increase the treatment cost of wastewater supplied to the industries. Further, although the price at which treated wastewater is supplied to industries is very low (INR 18.4 (0.25 USD) per m^3) in comparison to the price to be paid for obtaining freshwater supply (INR 73 - 145 (0.99 – 1.97 USD) per m^3), depending on the daily water demand), it may still be not of economic interest to small scale industries, such as auto ancillary, textiles, and dyeing units, as a substantial capital investment will be required to further treat the supplied wastewater to that of acceptable norms for industrial use.

3.3. Key drivers and barriers of governance for technology uptake and long-term operation of wastewater treatment and reuse systems

Our study illustrates that important steps have been taken by the Indian Central Government and State Governments to create an enabling environment for tackling the issues of water pollution and water scarcity through wastewater treatment and reuse. However, the lack of an overarching and clearly defined policy or law from the Central Government is a key limiting factor to enhancing wastewater treatment and reuse in India (Table 3). This barrier is evident from the fact that most State Governments lack a wastewater management and reuse policy and/or law. Some States in India (e.g. Maharashtra, Gujarat, Punjab) have formulated policies/laws to improve wastewater treatment and encourage reuse practices, yet, their enforcement is challenged by inappropriate pollution control measures and a lack of clear market incentive/disincentive mechanisms. While Nagpur has benefitted from a strong contractual PPP agreement, government policies and tertiary treatment technologies and was able to create successful business models for industrial water reuse, only a few other cities in Maharashtra have so far implemented the state governments 2017 policy for water reuse in cooling towers of thermal power plants. The low uptake of this business model can partly be attributed to the opposition of freshwater suppliers who fear revenue losses if industrial customers switch to treated wastewater as an alternative. Economic interests of multiple stakeholders thus need to be considered and steered with appropriate market mechanisms to render treated wastewater a cost-competitive alternative to freshwater for industrial end-users.

In Nagpur and Chennai, water scarcity has been a key driver for taking up recycling and reuse practices of treated wastewater (Table 2 and 3). The effective use of strategies such as 'ZLD', 'building permits', 'PPP models' and cost-competitive prices for treated wastewater in Chennai also enabled greater cooperation between CMWSSB and the stakeholders concerning the intended reuse of treated wastewater. However, the quality of secondary effluents from STPs requires additional treatment before industrial reuse, which is too expensive for many SMEs in India. For agricultural purposes, farmers commonly accept

Table 2
Comparative analysis of drivers (+) and barriers (-) in four case studies on the governance of wastewater treatment and reuse practices in India

	Kanpur, Uttar Pradesh	Hyderabad, Telangana	Nagpur, Maharashtra	Chennai, Tamil Nadu
Resource	Treated sewage	Partly treated sewage	Treated sewage	Treated sewage
End-use	Agriculture	Agriculture	Industry (cooling)	Industries
End-users	Farmers (2,500 ha irrigated farmland; ca. 2,500 farmer households)	Farmers (10,000-12,000 ha irrigated farmland; ca, 10,000 -12,000 farmer households)	Maharashtra Generation Company Limited (MahaGenCo) thermal power plant	Chennai Petroleum Corporation Ltd, Madras Fertilizer Ltd, Manali Petro Chemicals
Sewage treatment plants (capacity)	Jajmau STP (130 MLD + 5 MLD, secondary treatment) and CETP (36 MLD, secondary treatment)	20 different STPs (cumulative capacity: 686 MLD, secondary treatment)	2 STPs (130 MLD and 200 MLD, tertiary treatment),	16 different STPs (cumulative capacity: 727 MLD, secondary treatment)
% of sewage treated	46%	43%	60%	66%
% of treated sewage reused	100%*	90%**	90%	49%
Successful long-term operation	No	yes (informal reuse)/no (formal reuse)	yes	yes
Governance drivers and barriers	(+) GAP-I (−) multiple organizations, inter-institutional conflicts (−) lack of UP water reuse regulation	(−) lack of institutional capacity to monitor STP effluent standards (−) lack of state water reuse regulation	(+) JnNURM (+) state policy on water reuse in thermal power plants (+) PPP contract, single industrial end-user	(+) by-law for mandatory wastewater recycling, zero-liquid discharge for industries
Other key drivers/barriers	(−) Inadequate technology design (not considering resource context)	(+/−) poor freshwater supply fosters informal reuse of partly treated sewage with high health and environmental risks involved (-) poor sewage pricing system (−) conveyance of treated wastewater (with tankers) is expensive (−) low demand for treated wastewater	(+) water scarcity, high freshwater prices (+) tertiary technology design, providing fit-for-purpose water to industrial requirements	(+) water scarcity, high and fluctuating freshwater prices (−) secondary technology design, additional treatment required, which comes with high investments costs

*mix of treated sewage and industrial wastewater, ** 90% of total wastewater generated (treated and untreated) is reused

Table 3
Drivers (+) and barriers (-) for agricultural and industrial water reuse in India

Driver /Barrier*	Agricultural and/or industrial water reuse
Regulations & Legislation	(++) important central regulations/standards in place, e.g., CPCB standards for STP and CETP effluents with stricter norms coming under NGT (*Reg2*), but (—) lack of enforcement of pollution monitoring and control (*Reg3, Reg4*) (—) lack of umbrella directive for integrated water resources management (*Reg6*) (–) no India-wide regulation or norms on water reuse quality parameters (*Reg8*) which includes quality targets for different water reuse purposes (*Reg10*) and provide details on legislative, regulatory, and financial measures to implement them on the state level (*Reg11*) (+) State legislation on water reuse (e.g. Maharashtra, Gujarat, Punjab; *Reg9)*
Policies & government support	*Specific for industrial water reuse:* (++) ZLD 2015 Policy, Tariff Policy 2016 can foster industrial reuse (*Pol1*), but (-) ZLD is technologically and financially challenging for India's SME industry (*Pol2, Pol3*)
Institutional arrangements	(—) insufficient collaboration between responsible governmental organizations, central and state water authorities (*Inst 1, Inst2*)
Financing/Cost recovery	(+) National river protection plans provide funds for wastewater treatment infrastructure (*Fin1*), but **(-)** in some states, funding for long-term O&M of wastewater treatment infrastructure is not adequately considered *(Fin3)* **(–)** cost recovery for O&M is generally very low (*Fin5*) due to **(–)** no rational pricing for wastewater treatment services (*Fin6*), and **(-)** households' unwillingness to pay for wastewater treatment (F*in7*) *Specific for industrial water reuse:* (+) PPP for industrial water reuse schemes (large-scale industries) can promote cost recovery of O&M (*Fin4*), if economic incentives of freshwater supply prevail and there is ownership *Specific for agricultural water reuse:* **(-)** cost recovery is difficult for low revenue applications such as agricultural irrigation due to farmers' inability/unwillingness to pay for treated wastewater (*Fin 8*)
Technology options	**(–)** wastewater treatment technologies rely on a limited array of technological designs (*Tech1*) do not adequately consider the long-term development plans of the area, resulting in under-/overload of the systems and hampered treatment efficacy (*Tech3*) **(-)** lacking plant operator's skills and capacities to operate and maintain wastewater treatment plants (*Res3*)
Resource context	**(+++)** water scarcity drives diversification to alternative water supplies, more local supply / semi-closed water cycles (*Res1)* and triggers alternative solutions to conventional wastewater technology designs (*Res4*)

* Drivers and barriers are categorized as weak, strong and very strong drivers (+, ++, +++) and barriers (-, –, —) respectively, based on the statement ratings in round 2 of the Delphi study (cf. supplementary tables A.2.1-A.2.5). Only statements where consensus was achieved are considered. The categorization is as follows: m = 3.50-4.40 (weak driver/barrier), m = 4.41 - 4.99 (strong driver/barrier) and m ≥ 5.0 (very strong driver/barrier).

secondary effluents, as seen in Hyderabad, where the lack of an alternative freshwater source drives the informal reuse of partly treated wastewater on farmland (*Res1, n* = 19, *m* = 5.21, *Q1* = 5.00; Table A.2.5). Despite high health and environmental risks, the farmers accept the low quality but free-of-cost irrigation water as it enables them to sustain their livelihoods. On the contrary, the formal reuse of treated wastewater among farmers and urban end-users is impacted by the complexity and costs of the existing tanker distribution system.

The choice of technology to treat and recycle/reuse municipal wastewater has to be guided by the physical constraints as well as the intended use of the treated wastewater (fit-for-purpose treatment). The case of Kanpur shows that governance interventions can lead to the construction of STPs, but the *technologies implemented rely on a limited array of technological designs* (*Tech1, n* = 19, *m* = 4.53, *Q1* = 4.00; Table A.2.3), which often *do not adequately consider the long-term development plans of the area resulting in reduced treatment efficacy* (*Tech3, n*= 18, *m*= 4.78, *Q1*= 4.00; Table A.2.3). The importance of technology choice is perceived as an essential driver for sustainable long-term operation of wastewater treatment and reuse systems in the expert panel and *should be guided by the resource context, i.e. availability of land, electricity and local capacities* (*Tech7, n* = 19, *m* = 4.89, *Q1* = 4.00; Table A.2.3) and *follow the fit-for-purpose treatment principle* (*Tech6, n* = 20, *m* = 5.35, *Q1* = 5.00; Table A.2.3). Nevertheless, moving towards water reuse requires a multi-barrier approach, as promoted e.g. by the World Health Organization, to safeguard environmental and public health, to increase confidence in the quality of recovered water resources and ultimately to create market demand.

4. Conclusions and recommendations

The two-round Delphi study indicates that the most significant driver for wastewater treatment and water reuse is persistent water scarcity that necessitates diversification to alternative water supplies. In contrast, the most significant barriers are the lack of enforcement of pollution monitoring and control, the lack of an umbrella directive for integrated water resources management, and insufficient collaboration between responsible governmental organizations, central and state water authorities.

Though there are certain policies, laws and programmes by the Central Government and State Governments that endorse wastewater treatment and reuse, the availability of clear guidelines and specific standards with a defined implementation framework for wastewater treatment and reuse is lacking. There is the need to dovetail existing water and wastewater policies and programmes into a National Water Framework as an umbrella of general principles governing water issues by the Central Government, the State Governments and the local governing bodies. This should lead the way for essential legislation on wastewater governance in the entire country.

Most utilities cannot recover the costs of treatment from the farming sector re-using wastewater for irrigation unless high-value cash crops are cultivated or there is enough government price support. An effective water pricing mechanism is required, together with a circular economy approach to wastewater, to help reduce and/or recover treatment costs. Besides these, clear target-based regulations, defined national standards of reuse water quality, as well as wastewater safety planning and risk mitigation are imperative interventions for stepping up the water reuse in India. Core drivers to increase the reuse of wastewater are the increasing unavailability of conventional water sources and the better quality of reclaimed water as a result of compliance with more stringent wastewater standards. Several industries and bulk water users will need to look towards wastewater as an economically viable option to meet their water requirements. Hence, treated wastewater should be cost-competitive compared to alternative options available to industries.

Our study showed that policy and regulatory interventions and government support programmes to increase wastewater treatment infrastructure can create successful business models for wastewater treatment and reuse but need effective monitoring, enforcement and follow-up at all governance levels (central, national and local governing bodies). We conclude with the following recommendations for future governance of wastewater treatment and reuse in India: i) Target-based regulations, defined national reuse standards for treated sewage and effective enforcement strategies need to be developed. ii) Policy and guiding frameworks need to establish detailed guidance on sewage treatment and reuse technologies (fit-for-purpose treatment). iii) Effective financing mechanisms (funds, taxes, tariffs) that permit sufficient cost-recovery for long-term operation and maintenance of sewage treatment infrastructure should be established, and iv) Institutional and monitoring capacity needs to be strengthened and engagement and collaboration of key stakeholders tackled to increase acceptance of waste-recycled products.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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