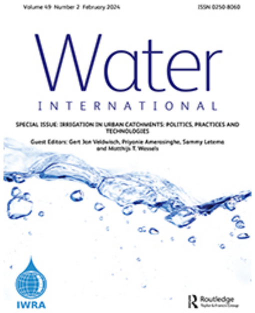

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Technological solutions for harnessing the urban water potential in the Bengal Delta – a scenario planning approach

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ABSTRACT

Given the future uncertainties regarding the availability of irrigation water in the Bengal Delta, planned water reuse in agriculture is a viable alternative. Using scenario planning, this paper depicted technological solutions to ensure the safe reuse of urban water in agriculture. A systematic literature review and expert interviews were conducted to identify the factors for appropriate technology selection. Results indicated that local conditions, resource recovery, energy consumption, initial investment and land availability are the notable factors for technology selection. Taking economic growth and demand for irrigation water, centralized (activated sludge) and decentralized technological (pond-based) solutions are envisioned to facilitate reuse.

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KEYWORDS
Treatment technology; scenario planning; water reuse; Bengal Delta

Introduction

Water with adequate quality and quantity is crucial for sustaining everyday life on the planet. The demand for clean water is increasing and wastewater management is a growing challenge in many developing countries. Recent studies indicate that around 48% of global wastewater, mostly from developing countries, is released into the environment without any treatment (Jones et al., 2021; Kookana et al., 2020). Efficient wastewater treatment systems are often found in developed countries (Global North), whereas developing countries (Global South) lack adequate wastewater treatment infrastructure, resulting in the discharge of untreated wastewater into the environment (Sato et al., 2013). Untreated wastewater discharge leads to environmental problems such as pollution by a variety of organic and inorganic substances and elements, resulting in an ecological imbalance in natural water bodies and health-related problems, including disease outbreaks (Akpor & Muchie, 2011; König et al., 2017; Singh et al., 2004; Williams et al., 2019). In addition to these man-made environmental problems, countries

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in the Global South are also struggling with the adverse impact of climate change, such as flash floods and droughts. Thus, proper wastewater management would lead to the improvement of the environmental condition as well as additional resources to combat water scarcity.

The Bengal Delta is the largest delta in the world and Bangladesh covers the major share of the Bengal Delta and is home to more than 180 million people (Akter et al., 2016; Steckler et al., 2010). Climate variability has been adversely impacting the availability of water resources; therefore, the delta area's agriculture, human health, and biodiversity are also severely impacted (Das et al., 2020; UNFCC, 2007). Coupled with intensified anthropogenic activities, the Bengal Delta is threatened by the availability of adequate quality water for drinking and food production. With the growing scarcity of quality freshwater resources, an adaptive strategy such as the safe reuse of domestic wastewater for food production could become an alternative in the delta areas (Haldar et al., 2022a; Haque & Jakariya, 2023). Historically, the use of urban water has been practiced worldwide, especially in water-scarce regions. In line with the Special Issue of Water International on The Practices and Politics of Irrigated Urban Agriculture, of which this paper is part, the term urban water is preferred over (urban) wastewater, as it gives a more positive impression of the practice, balancing against the dominant notion in many areas of the world that that such practices are 'dirty' (Veldwisch et al., 2024). Urban water is defined as a combination of greywater, surface water and surface runoff, as they are often collected through the same infrastructure. Despite the negative connotation, studies have asserted that urban water reuse can contribute to improved utilization of available water resources because wastewater can be recycled for multiple purposes through proper treatment before discharge into the natural streams (Haldar et al., 2022a, 2020). The reuse of urban water would positively contribute to the growing water demand for food production to sustain a quality of life in the Bengal Delta.

To safely reuse urban water in agriculture, the demand in terms of water quantities, qualities and socioeconomic, planning and legal constraints need to be assessed before designing a suitable collection and treatment infrastructure. The first step has already been discussed in previous publications, whereas this paper focuses on the second step, taking Khulna City, Bangladesh, as an example. Previous studies indicated that there is enough urban water available (8 million m^3) in the study area to meet the annual irrigation demand (7 million m^3); however, the water, in terms of chemical–physical and microbial quality, needs significant improvement to meet the international guidelines set by the Food and Agriculture Organization (FAO) and the World Health Organization (WHO) (Haldar et al., 2020, 2022a, 2022b). Millions of cubic metres of urban water generated in Khulna city due to domestic activities are collected via drains and finally discharged into the natural streams without any treatment and the diluted urban water is used for irrigation purposes. A similar practice is common in other areas of the Bengal Delta due to a lack of wastewater treatment infrastructure and farmers lacking alternative irrigation sources for agricultural activities are forced to use contaminated surface water as shallow groundwater use for irrigation is also restricted due to salinity invasion into the aquifers. Under these circumstances, urban water generated from fresh drinking water would positively address the growing challenge of securing irrigation water for agriculture if quality improvement is ensured through technological interventions. Given the strategic importance of the Bengal Delta and the growing concern over irrigation water availability, the reuse of urban water has great potential, given that technological solutions can easily be adapted considering the local socio-economic, environmental and technical (SET) factors. This paper aims to explore the influence of SET factors using a mixed-method approach utilizing a systematic literature review, expert interviews, and scenario planning. It is envisaged that this approach will help understanding of how water reuse interacts with the existing urban water system and impacts its stakeholders, especially in relation to agriculture.

Methodology

Research approach and study area

A mixed-method approach consisting of systematic literature review, expert interviews and scenario planning has been selected for this study. This approach is deployed in the selected study area of Khulna City, Bangladesh. Khulna, a coastal city located in the tidally active area of the lower Bengal Delta, is vulnerable to climate change impacts due to its proximity to the Bay of Bengal (Datta et al., 2020; Khan & Martin, 2016). Being an administrative and economic hub of the region, the city provides necessary services to millions of people from the surrounding areas. The city is located in an active tidal delta area, resulting in salinity invasion and intrusion in surface and groundwater, limiting the availability of freshwater resources. Similar to other cities in Asia, the core urban area has built-up areas and agricultural activities dominate peri-urban areas as a form of paddy fields (Figure 1). After selecting the study area, systematic literature review was used to

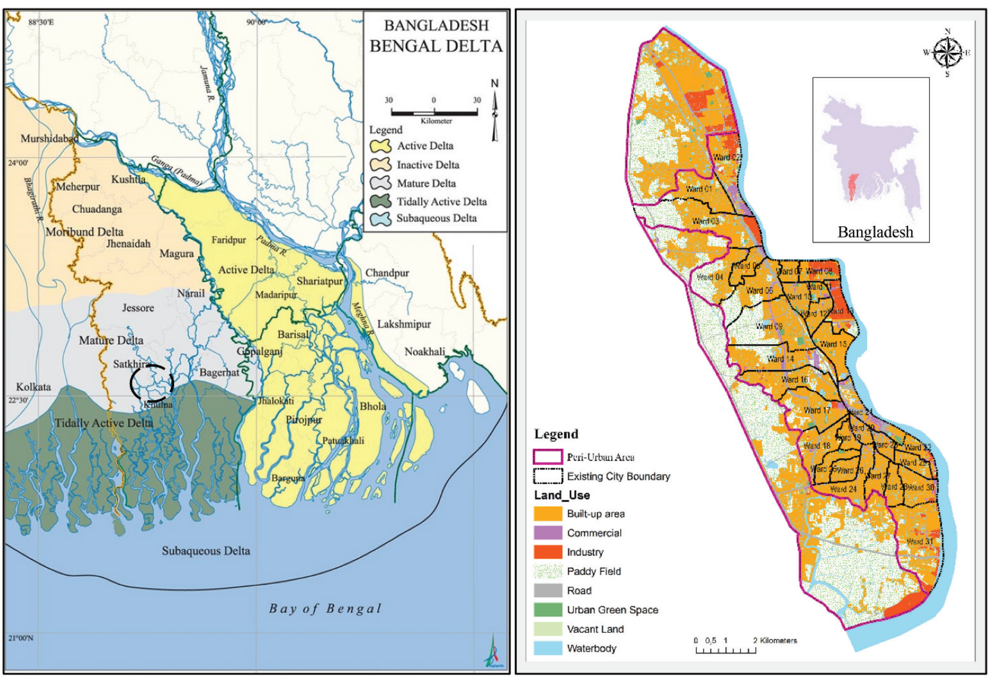

Figure 1. Map of Bengal Delta (left) (Source: Banglapedia, 2021) and the study area in the context of Bangladesh (right) (Source: own production).

gather the knowledge from the existing studies, which is then further validated through expert interviews. After that, the outputs provide a solid basis for scenario planning, which is explained in the following sections.

Systematic literature review

Systematic literature review is a widely used, efficient and reliable tool to map the existing scientific knowledge on a specific topic while diminishing bias (Eftim et al., 2017; Kakwani & Kalbar, 2020; Tiedeken et al., 2017; Tranfield et al., 2003). Systematic literature review comprises different steps: identification, screening, eligibility assessment and qualitative synthesis (Pati & Lorusso, 2018). It has been used to identify the socio-economic, environmental, and technical factors mentioned in the scientific literature in selecting appropriate wastewater treatment technology, which could then be used in the context of the study area. Different combinations of search strings related to wastewater treatment technology are used to identify and screen the related peer-reviewed scientific articles. The term ‘urban water’ used in this paper was not used as a direct search string, as ‘wastewater’ is a more commonly used term in scientific articles which is synonymous to urban water. Several criteria were used to narrow the target number of articles related to the selection of treatment technologies relevant to similar contexts (Supplementary materials: Table S1).

The search strings resulted in 3707 articles in the Scopus database and relevant inclusion criteria (such as language and type of publication, year of publication, field of study) were used, followed by the removal of duplicates. Then, a manual screening of each title was conducted, which resulted in the exclusion of 3489 articles from the primary list. Some relevant articles may have been excluded during the title screening process, which is one of the limitations of performing systematic literature review with a large number of search results. Additionally, to perform a feasible systematic literature review with a large number of search results within a realistic time frame, only articles published around the last 20 years were included. The remaining 218 articles were then carefully reviewed on their abstracts, after which 73 articles remained for full-text assessment. Abstract and full-text screening aimed to exclude articles that did not primarily focus on the selection, choice or performance of wastewater treatment technology. Finally, 35 articles were selected for content analysis to identify the socioeconomic, environmental, and technical factors influencing treatment technology selection (Figure 2). Of these 35 articles, 11 articles were included for their specific focus on wastewater technologies for reuse, even though they did not explicitly analyse the factors related to technology selection.

Expert interviews

Expert interviews are often done in scientific research to validate the findings and fill the knowledge gaps (Faust et al., 2016; S. R. Harris-Lovett et al., 2015; Skambraks et al., 2017). In this study, expert interviews were used to gather their personal experiences to validate the outcomes of the systematic literature review, especially related to SET factors for technology selection in the context of both the Global South and Global North. In total, 12 expert interviews were conducted between 2020 and 2021 using a semistructured

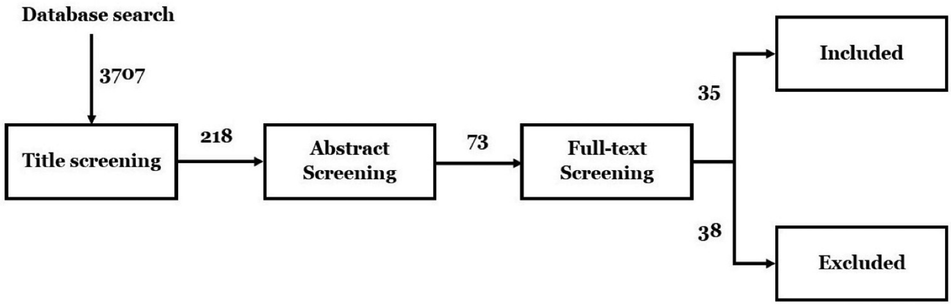

Figure 2. Process for identifying relevant literatures through systematic literature review.

questionnaire. The experts had diverse working backgrounds, including sanitary engineering, environmental engineering and water policy in the public and private sectors and were at different stages in their professional careers. During the expert interviews, interviewees were asked to respond and reflect on their professional experience working in the field of urban water management, especially questions related to factors considered during technology implementation, the role of geographic and economic conditions, centralized versus decentralized options, and challenges related to water reuse and prioritization of the infrastructure development. These experts have been working on water-related issues such as wastewater treatment, water management, environmental engineering, and water policy in the Global North and Global South context. Due to the COVID-19 pandemic, the interviews were conducted using online communication platforms like Skype and MS Teams. Transcripts of the expert interviews were further processed, analysed using Atlas.ti.

Scenario planning

Scenario planning is widely used to stimulate strategic thinking to address future uncertainties (Amer et al., 2013; Lindgren & Bandhold, 2003; Peterson et al., 2003; UNEP, 2016) and aims to consider various possible directions of future development under varied local contexts (Peterson et al., 2003). Scenario planning is instrumental in decision-making as it helps organizations to be more flexible and innovative towards possible outcomes (Amer et al., 2013). Herbert Kahn first developed scenario planning while working at RAND Corporation and since then, scenario planning has been promoted as a key technique for strategy forming and still has many challenges to be resolved by effective execution (Kahn & Wiener, 1967; Lehr et al., 2017; Peterson et al., 2003).

Several approaches have been practiced globally for scenario planning and the four quadrants matrix is known as the minimal approach used for designing scenarios used for this study (Amer et al., 2013; Lindgren & Bandhold, 2003). This scenario planning method is also known as the double uncertainty or 2 × 2 matrix approach (Amer et al., 2013). This method is selected for this study due to the widespread usability and simplistic method for scenario building, considering two driving forces (uncertainties) or factors that can simulate future developments (Amer et al., 2013; Lindgren &

Bandhold, 2003; Pillkahn, 2008; Schwartz, 2012). The selection of these two driving forces that complement each other in a scenario quadrant is crucial in portraying the scenarios (Lindgren & Bandhold, 2003). The best known driving forces are population growth, rapid urbanization, economic growth, climate change, resource demand, etc. and in this paper, the drivers were used from a qualitative perspective (not actual quantification). During recent decades, Bangladesh has had significant economic progress with annual GDP growth between 4.1% and 8.2% since 1992 (except for 2021–2022, presumably due to COVID-19), along with an increase in per-capita income and purchasing power. Bangladesh gained the status of a lower-middle-income country in 2015 and by 2026 is expected to leave the UN's Least Developed Countries list (IMF, 2021; World Bank, 2021). Over the years, it has been observed that the budget allocation in the water sector either for infrastructural development or institutional capacity development has also increased to ensure safe access to water and sanitation. Additionally, intensified industrial and agricultural activities in many areas of Bangladesh have led to increased pollution of surface and groundwater (Datta et al., 2020; Islam et al., 2011; Khan et al., 2011; Pramanik & Sarker, 2013). The growing pollution of available water sources and climate change impacts such as salinization would further restrict the availability of quality irrigation water that adheres to national and international guidelines (FAO, WHO). Good-quality irrigation water adhering to the guidelines is very important for plant growth as well as to reduce the negative impact on environmental and human health. Under these circumstances, a qualitative description of economic growth and the demand for irrigation water complying with available guidelines were used as the most critical driving forces for formulating four scenarios of possible technological solutions in the context of the study area.

Results and discussion

Factors influencing the selection of appropriate technology and the need for adequate treatment for safe reuse

Previous studies indicate that decision-makers in the Global South selected technologies based only on the experience of developed countries, often ignoring the local contexts and frequently resulting in failure of the technology due to high cost and operation complexity (Barnes et al., 2014; Murphy et al., 2009; Singhirunnusorn & Stenstrom, 2009; Van Lier & Lettinga, 1999). This is also reflected in the expert interviews. To avoid such failure in technology selection, the concept of 'appropriate technology' was coined in the 1960s; it still needs wider attention (Murphy et al., 2009). Appropriate technology provides the best performance with the least cost and considers the local demands related to the environment, technology, institutional feasibility, and economic affordability, indicating the relevance to SET factors (Singhirunnusorn & Stenstrom, 2009; Ujang & Buckley, 2002). The systematic literature review indicates that several factors influence the selection of appropriate treatment technology and is categorized into three broad aspects: socioeconomic, environmental and technical (Table 1). Technical factors such as treatment efficiency as a form of nutrient removal are mentioned in around 65% of the selected literature for systematic literature review, followed by energy consumption (43%) and land requirement (29%). Then, economic factors such as initial investment

Table 1. SET factors influencing the selection of appropriate treatment technology reported in the reviewed literature.

Socioeconomic	Environmental	Technical
• Initial investment • Operation and maintenance costs • Land (area) requirement • Land price and availability • Social acceptability • Odour, noise, visual impact • Population growth	• Nutrient removal • Micropollutant removal • Resource recovery potential • Sludge production • Energy consumption • Greenhouse gas emission	• Infrastructure • Local climatic condition • Service area • Reliability & robustness • Complexity or simplicity • Removal efficiency • Labour demand and availability

(54%) and social factors such as public acceptance (14%) were mentioned in the selected literature. Overall, it indicates that factors such as initial investment costs, operation and maintenance costs, price and availability of required land space and social acceptability play a pivotal role in implementing wastewater treatment systems (Arias et al., 2020; Dell'Osbel et al., 2020; Gherghel et al., 2020; Molinos-Senante et al., 2014; Padrón-Páez et al., 2020; Rathnaweera et al., 2020; Sun et al., 2020; Thaher et al., 2020; Woltersdorf et al., 2018). Expert interviews and systematic literature review also suggest that, in the past, decision-makers would opt for the treatment technology with the least financial cost involved by using only cost–benefit analysis tools in the decision-making process, often neglecting the general public's voice (Molinos-Senante et al., 2014; Padrón-Páez et al., 2020; Sun et al., 2020).

The negative attitude of the general public towards the treatment system due to the negative association with waste treatment resulting in odour, noise and visual impacts can also delay the implementation of treatment systems (Meena et al., 2019; Molinos-Senante et al., 2015; Muga & Mihelcic, 2008). Due to the growing consequences of anthropogenic activities, climate change and the growing importance of circularity, results from systematic literature review suggest that environmental factors such as greenhouse gas emissions, energy consumption and sludge production are becoming crucial in the decision-making process (Arias et al., 2020; Dell'Osbel et al., 2020; Gherghel et al., 2020; Kamble et al., 2019; Meena et al., 2019; Su et al., 2019). As a result, newly designed treatment technologies consume less energy or even produce energy, emit fewer greenhouse gases and generate less sludge (Arias et al., 2020; Lin et al., 2016; Meena et al., 2019).

Expert interviews indicate that the Global North countries with already developed wastewater infrastructure are successfully removing traditional contaminants to the levels required by the standards and are now transitioning towards more efficient treatment systems. The transition towards successfully recovering resources such as water, energy, gas, nutrients (N and P), cellulose (paper), volatile fatty acid (acetate, propionate, butyrate), CO_2 for potential market supply is becoming a priority for many developed coutries (Kehrein et al., 2020). Micropollutant removal from the waste streams has been gaining attention as an important further expansion step in wastewater treatment systems. Removal of these pollutants have been considered less urgent in the Global South as this is considered a minor factor in comparison to the lack of even basic wastewater infrastructure (Arias et al., 2020; García-Galán et al., 2020). Water circularity reduces the negative impact on the natural environment and, thus, planned water reuse potential and resource recovery have gained broader recognition in the recent past with the development of new series of advanced treatment technologies and systems (Dell'Osbel et al., 2020; Gherghel et al., 2020; S. Harris-Lovett et al., 2018; Lin et al., 2016; Singhirunnusorn & Stenstrom, 2009; Woltersdorf et al., 2018). However, expert interviews indicate that having simple, reliable and robust wastewater treatment systems would be more appropriate for developing countries. A similar suggestion is also evident in previous studies, as the adoption of a simple yet robust system will ensure long-term functioning and minimize specialized labour force, cost and energy demand (Rathnaweera et al., 2020; Singhirunnusorn & Stenstrom, 2009). Factors such as service area, labour demand and availability of skilled workforce should also be considered before selecting a treatment technology (Arias et al., 2020; Kalbar et al., 2013; Muga & Mihelcic, 2008; Rathnaweera et al., 2020). Nature-based treatment systems, such as different types of constructed wetlands or stabilization ponds, tend to perform better in a warm climate than in a cold climate and, thus, are more suitable for tropical regions (Su et al., 2019). Climatic conditions influence the removal efficiency of the biological and natural treatment system, meaning that consideration of the local climate should be prioritized (Dell'Osbel et al., 2020; Kalbar et al., 2013; Rathnaweera et al., 2020; Thaher et al., 2020). Designing wastewater treatment systems that consider technical, social and organizational factors would facilitate the design of sociotechnological solutions well suited for the local context (Baxter & Sommerville, 2011).

Treatment of wastewater and its further use, especially in Global North countries, has multifaceted benefits, including preventing environmental pollution, combating water scarcity, and contributing to the utilization of resources (Fito & Van Hulle, 2020; Haldar et al., 2020; Yang & Abbaspour, 2007). The traditional wastewater treatment system produces legally dischargeable effluents but often fails to deal with emerging pollutants such as pesticides, pharmaceuticals, pathogens and microplastics, which already raises concern among the authorities (Fito & Van Hulle, 2020; Jelić et al., 2012). To tackle the emerging pollutants, in addition to biological systems, which are 85–90% efficient in BOD, N, P and TSS removal,[1] wastewater treatment plants can use advanced biological or chemical systems, which can have very high micropollutant removal compared to traditional systems (Caicedo et al., 2019; De Wilt et al., 2016; Falås et al., 2016; Hunter et al., 2019; Jelić et al., 2012; Luo et al., 2014; Margot et al., 2013). Expert interviews indicated that advanced treatment systems are expensive and complex to operate and due to a lack of awareness on issues such as micropollutants, pharmaceuticals and personal care products, many countries in the Global South still rely on conventional treatment systems.

Wastewater infrastructure in the Global South relies heavily on on-site technologies such as pit latrines and septic tanks, especially for blackwater management (Andersson et al., 2016; Qadir et al., 2010). A similar situation existed in the study area, which has started to improve with the set-up of the Khulna Water Supply and Sewerage Authority (KWASA), a dedicated agency to manage urban water in the study area. Expert interviews and previous studies indicate that building wastewater infrastructure requires investment from central government agencies and often, governments prioritize other development activities (i.e., building roads and bridges) over wastewater infrastructure (Andersson et al., 2016; Thaher et al., 2020). Neglecting the investment in wastewater infrastructure can hinder the success of other development initiatives because the absence of proper wastewater infrastructure leads to environmental pollution and affects the quality of living (Andersson et al., 2016). Nevertheless, the economic cost of technology also plays an essential role in the decision-making process (Molinos-Senante et al., 2014; Padrón-Páez et al., 2020). Finding an appropriate technology at a reasonable price is a traditional way of investment among decision-makers of the Global South as it ensures the proper utilization of available financial resources. However, the selection of technology without consideration of the local factors, such as geographic condition, available infrastructure (energy and water supply), socioeconomic, political and institutional situations, would hinder the successful implementation and long-term operation (Singhirunnusorn & Stenstrom, 2009). Thus, Global South countries should consider the SET factors to ensure the adequate treatment of urban water and prioritize investing in appropriate technologies while also providing additional resources to combat the water scarcity for food production.

Scenarios for circular urban water management for the study area

Over the years, the coastal areas of Bangladesh have suffered from water scarcity and growing surface water pollution. Adequate wastewater infrastructure and its management could have played a role in protecting the surface waters and providing much-needed irrigation water for sustaining food production in the study area and surrounding regions (Abedin et al., 2014 2019). Simulating future scenarios for technological solutions for the study area based on driving forces would be useful to identify the appropriate treatment technology facilitating safe urban water reuse. Economic growth and good-quality water for irrigation are placed on the axis to identify four descriptive scenarios: Gold Scenario, Green Scenario, Red Scenario and Grey Scenario (Figure 3).

Red scenario

Under 'Red Scenario', lower economic growth and high demand for good-quality irrigation water are expected. Given the economic constraints and higher treatment requirements to improve the water quality, traditional, mechanized, biological treatment systems such as suspended growth activated sludge (AS) or attached growth biofilms reactors such as a moving bed biofilm reactor (MBBR) or trickling filters could be implemented. This situation is evident in the study area as an AS-based treatment plant is being built with financial assistance from the Asian Development Bank (ADB, 2011; KWASA, 2016). Given that these technologies are adapted based on the local context with external finances, farmers would still be able to avail the required amount of irrigation water. AS is a widely used technology and uses microorganisms to treat wastewater under aerobic conditions (Sperling & De Lemos Chernicharo, 2005). The AS system has high reliability in removing traditional macropollutants such as organic matter (COD/BOD), suspended solids, nutrients (N, P) and, to a certain extent, pathogens from wastewater and is not extremely complex to operate, and thus is suited to the local contexts (Kalbar et al., 2013; Rathnaweera et al., 2020). However, the AS system is energy-intensive and produces a high volume of sludge and some odour, which could be a nuisance for the people living in nearby areas (Kalbar et al., 2013; Kamble et al., 2019; Meena et al., 2019; Su et al., 2019). The MBBR uses the same principle as AS by growing biomass in suspension but adhering to carrying material (biofilm) and a one-stage or multiple-stage system. MBBR consists of an AS aeration system and can be an alternative

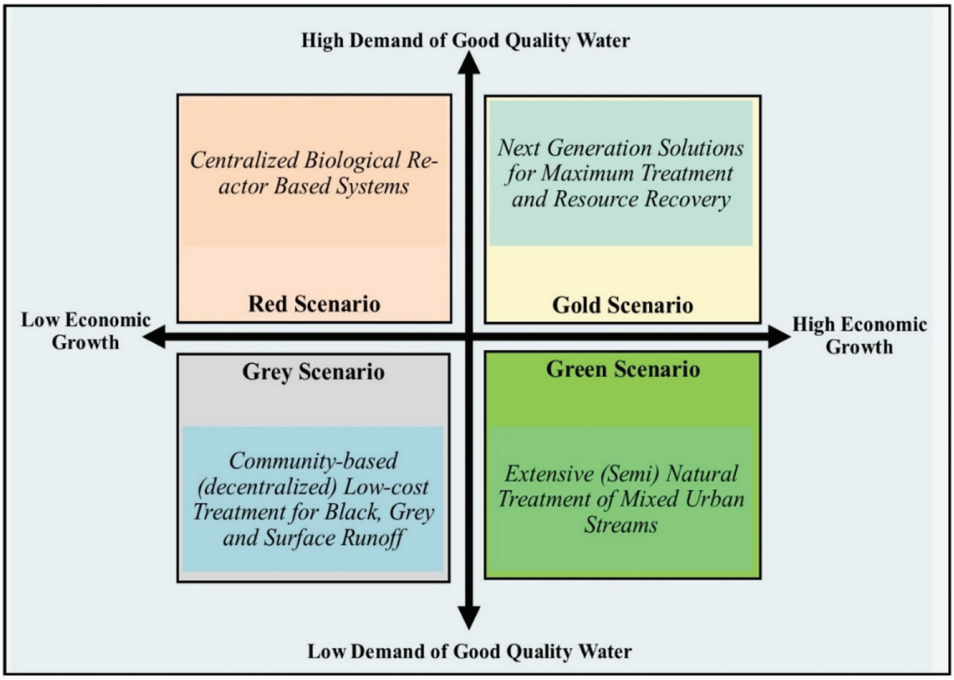

Figure 3. Scenarios of circular urban water management for the study area.

to conventional AS systems due to similar performance at a lower cost (Andreottola et al., 2000; Oliveira, 2014). Both AS and MBBR systems have multiple advantages and disadvantages in the context of the study area and authorities can prioritize different factors such as resource recovery, nutrient removal, land area availability, energy requirement to decide the appropriate technology that would suit the local demand.

Grey scenario

Under a 'Grey Scenario', lower economic growth and demand for irrigation water are assumed for the study area. Thus, the urban water might not receive required treatment and the focus should be given to further expansion and improvement of community-based (decentralized) low-cost treatment of black- and greywater as other systems would be too expensive. Emphasizing the low-cost treatment of blackwater would contribute to lowering the pollution of urban water. Additionally, nature-based technologies such as constructed wetlands or stabilization pond systems can also be implemented, especially in peri-urban areas. The land price in peri-urban areas is comparatively lower than in core urban areas, thus reducing the initial investment cost, and the treated water would then be easily supplied to the adjacent agricultural areas. The associated odour, noise, visual impact would be outside the urban neighbourhoods, contributing to the overall social acceptability of such a nature-based system. The city dwellers of the study area are currently using individual septic tanks for blackwater management, and with the stalled economic growth, this form of on-site technology could improve and expand further by incorporating a value chain for resource recovery. Further improving and expanding the technology would also restrict the leaching of blackwater into the natural streams, allowing farmers to use less polluted water for irrigation activities. In septic tanks, the settling occurs and partial anaerobic digestion provides the efficient primary treatment; therefore, septic tanks are used worldwide, especially in areas where the basic sewer system is absent (Su et al., 2019; Tilley, 2014). The septic tank is a low-cost, simple yet effective technology requiring minimal labour and no sewer system and has moderate (around 50% depending on the temperature) pollutant removal efficiency, which would also suit the local situation under a Grey Scenario (Goel & Kansal, 2020; Moussavi et al., 2010; Su et al., 2019). The use of a small-scale septic tank system upgraded to an anaerobic treatment system or even a biodigester to generate biogas was commonly advocated in Bangladesh in the last decade (Kabir et al., 2013; Khan & Martin, 2016; Nasiruddin et al., 2020). A biodigester typically has an airtight chamber to provide anaerobic digestion to blackwater and could be a more efficient alternative to septic tanks for serving a bigger community (Tilley, 2014). Under lower economic growth, investment in wastewater infrastructure would be limited; thus, the focus on small-scale community-based technologies would still provide some form of treatment to the effluents. Compliance in the setting-up of an effluent treatment plant should be enforced for industries to restrict the untreated discharge of wastewater, limiting the pollution of natural streams, which would still be a crucial source for irrigation as the quality demand is also low in this scenario.

Gold scenario

Under a 'Gold Scenario', high economic growth accompanied by high demand for good-quality irrigation water is assumed and advanced wastewater treatment systems would be justifiable solutions to address the climate change impact on irrigation water availability in the future. The Bangladesh Delta Plan 2100 also formulated futuristic strategies considering the country's economic growth potential and emphasized the treatment of wastewater and recovery of resources. Under this scenario, favourable economic conditions would finance the next-generation, innovative, advanced solutions as factors such as initial investments, operation and maintenance costs, land price, infrastructure, energy requirement, nutrient removal would not be the limiting factors in selecting appropriate advanced technologies. Advanced wastewater treatment technologies, for instance, intensified biological systems (e.g., membrane bioreactor (MBR); aerobic granular sludge technology, Nereda® or UASB) followed by chemical–physical post-treatment oxidation techniques (e.g., ozone treatment, UV, advanced oxidation, membrane filtration) could be implemented to attain a high level of treatment efficiency (Høibye et al., 2008; Kehrein et al., 2020; Wenzel et al., 2008). For example, MBR combines a biological-activated sludge process and membrane filtration, removing COD, nitrogen and phosphorous and can also successfully remove 99.9% of the microplastics with a smaller fraction size (20–100 μm) and has higher pathogen removal efficiency compared to the conventional activated sludge system (Radjenović et al., 2008; Talvitie et al., 2017). Similarly, Nereda®, anaerobic granular biomass-based technology, has been gaining attention recently and has the potential to expand due to compactness, low energy consumption, less capital and operation costs and high (>90%) organic and nutrient removal efficiency (Khan et al., 2015; Guo et al., 2020; Van der Roest et al., 2011). UASB technologies may be feasible to combine energy production (biogas) with waste and wastewater treatment for sludges and high COD waters from septic tanks or industries if necessary factors are taken into account when planning the infrastructure development. For tertiary or post-treatment, ozonation is an important technology for the removal of organic micropollutants, such as pharmaceuticals, pesticide residues, personal care products and pathogenic microorganisms and could be used to maximize the treatment efficiency (Carballa et al., 2007; Chen et al., 2012; Ikehata et al., 2006; Snyder et al., 2006). Given the high economic support under this scenario, authorities would be able to implement advanced technologies that not only remove the pollutants to produce high-quality irrigation water for farmers but also facilitate resource recovery to be used in the study area.

Green scenario

Under the ‘Green Scenario’, high economic growth coupled with low demand for quality irrigation water is assumed and thus, nature-based systems such as constructed wetland or stabilization pond systems could be implemented to provide semi-extensive treatment for mixed urban streams. Constructed wetland is engineered vegetated natural treatment technologies, generally suitable for small- to medium-sized communities or as a polishing step of effluents of advanced treatment systems. Constructed wetlands are aquatic-based systems composed of shallow basins that can be built in peri-urban areas due to land availability. Smaller constructed wetlands can also be developed within the city area, but the high land price and low land availability would be a critical limiting factor in implementing such a system. In constructed wetlands, water slowly flows through the wetland and the particles settle on the bottom of the wetland and pollutants (COD, nutrients, micropollutants), including pathogens, are removed via sorption, biodegradation and phytoremediation. The plants utilize the nutrients from the water and can – when smartly designed – also be used for commercial plant production (Mara, 2013; Sabri et al., 2021; Sithamparanathan et al., 2021; Tilley, 2014). Stabilized pond systems, commonly found in countries with warm climates (García-Galán et al., 2020; Molinos-Senante et al., 2012; Zurita et al., 2012), also use natural processes (e.g., sedimentation, UV-radiation from sunlight, algal–bacterial symbiosis) to treat wastewater, i.e., removing COD, nutrients, micropollutants and pathogens, but this is often less efficient and stable as advanced treatments of the Gold Scenario. The stabilized pond systems and constructed wetlands also provide storage, which is crucial for matching temporal disbalances in water supply (effluents) and use (agriculture) in the context of the study area. Both systems have a low environmental impact, require little conveyance system and give a positive visual impact if operated well (Dell’Osbel et al., 2020; Molinos-Senante et al., 2014; Su et al., 2019; Sun et al., 2020). Installation of such a nature-based system would reduce the energy requirement, suit the local condition and create a positive social acceptability towards the treatment and reuse of urban water in the study area.

Feasibility of scenarios in the context of the study area

Implementing sociotechnological systems requires overcoming four types of barriers: technological, market, institutional and cultural (Grafström & Aasma, 2021). Similarly, socioeconomic, environmental and technical factors play a crucial role in the decision-making process related to the selection of wastewater treatment technology (Molinos-Senante et al., 2014, 2015; Su et al., 2019). Economic factors, such as initial investment, operational and maintenance costs, often seem to be the main limiting factors for adopting advanced technology as wastewater treatment is a low priority and receives little investment (Andersson et al., 2016; Zhang et al., 2014). The recent success in economic growth encourages the adoption of appropriate technology that contributes to overall pollution control and facilitates resource recovery for the local market. However, in the case of economic constraints, adopting nature-based technology, especially in the peri-urban areas (if adequate space is still available), constructed wetlands or pond-based systems would be more appropriate as these provide the required treatment to make the wastewater reusable in agriculture and suit the climate (Mustafa, 2013; Zhang et al., 2014). The importance of institutions and policies in the decision-making process related to wastewater treatment technology selection would also be an integral part of successful implementation in other similar regions of the Bengal Delta. In many Global South countries, weaker institutions often limit the implementation of proper wastewater treatment technologies (Andersson et al., 2016; Møller et al., 2012). Thus, the technological solutions should always be supported by required rules and regulations, public support and the market demand for water reuse in the region.

Intersectoral partnership: pre-requisite for successful urban water reuse

Sustainable urban water management requires an integrated, adaptive, resilient, coordinated and participatory approach (Brown & Farrelly, 2009). A transition from a technocratic urban management style to an adaptive and participatory style was adopted in the 1970s in several climate-vulnerable delta areas (Loorbach & Rotmans, 2006; Wen et al., 2015). Governance of urban water management, including policies and regulatory framework and stakeholder involvement and collaboration, are crucial for the wider adoption of urban water reuse (Frijns et al., 2016). However, complexities related to sustainable urban water management at the institutional level are due to the interorganizational settings of these institutions and thus, institutional changes are favoured over structural rearrangement (Briassoulis, 2004; Frijns et al., 2016; Mitchell, 2005). Similar complexity already exists in the study area as well as in the region due to the involvement of multiple institutions on the issues related to urban water. In addition to limited cooperation in the decision-making process, shifting responsibilities to other organizations and specific working areas has polarized water governance responsibilities in the study area (Haldar et al., 2021). This points out the need for a transition favouring intersectoral collaboration and partnership among all sectors, including governmental agencies, knowledge institutions, and industries, which was also reflected in the expert interviews. A partnership at the city or regional level where representatives of local councils, officials of governmental and non-governmental organizations, and representatives of the relevant stakeholder groups (farmers, market vendors, citizens) should be formed to formulate strategies to be implemented in the area. The partnership would bring all the involved parties under one umbrella where trust, continuous economic support and incentives for participation would be ensured to overcome the existing barriers in urban water management (Österblom & Bodin, 2012; Waddell & Brown, 1997).

The involvement of root-level stakeholder groups such as farmers and market vendors will increase trust in policymakers and institutions, improving the public acceptance of water reuse projects (Dolnicar et al., 2011; Frijns et al., 2016; Hartley, 2006).

Conclusion

Peri-urban agriculture in the Bengal Delta substantially contributes to local food production and income generation for people, especially marginalized farmers. Farmers have struggled to secure irrigation water in adequate quantity and quality over the years due to the growing salinization of natural streams, which are the primary source of irrigation water. Farmers are also confronted with the dilemma of balancing the need for water with concerns about potential health and environmental risks due to growing pollution. Under these circumstances, urban water is a viable irrigation source for food production in the coastal areas of Bangladesh if the necessary treatment of wastewater is ensured. Therefore, selecting the appropriate technology becomes paramount and factors such as local conditions, treatment efficiency, energy consumption, labour demand, robustness of the technology, social acceptance and initial investment cost should be considered before adopting a treatment technology that suits the local condition and quality demand. Scenario planning indicated that different technologies are possible in the context of the study area depending on the economic capability and desired water quality for user groups such as farmers. However, technological interventions must also be supported by the proper regulatory framework, which is absent in the study area at this moment. Agencies that work in the field related to urban water also need to enhance inter-collaboration to stop the polarization of responsibilities. Finally, end-users, such as farmers, also need to be involved in the decision-making process to understand their perspective and provide much-needed irrigation water to sustain agricultural practices. The input would also be essential for ensuring the technological solutions are practical, acceptable and sustainable in the long term. Incorporating the perspectives and needs of farmers into the long-term vision, inclusive and sustainable solutions for water management and food production will be further enhanced. Adapting circular resource management strategies like planned urban water reuse would contribute to sustaining food production, both in the Bengal Delta and in other areas facing similar challenges.

Note

1. BOD, Biological Oxygen Demand; COD, Chemical Oxygen Demand; N, Nitrogen; P, Phosphorus; TSS, Total Suspended Solids.

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CRediT authorship contribution statement

KH: Conceptualization, Methodology, Data analysis, Writing the original draft. DD: Methodology, Investigation, Data Collection and analysis, Manuscript – editing. KKR, DKD and HR: Conceptualization, Supervision, Manuscript – review & editing.

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