

EXTENDED ABSTRACT

Exploding population, industrialization and an increase in water pollution have led to acute shrinkage in freshwater availability. Numerous countries have started exploring municipal wastewater as a new potential source of water to bring a paradigm shift from linearity to obtaining circularity in human water cycle management. Adoption of such an approach would require integrated water and wastewater management (IWWM) that enables creation of a new water source and a water-sufficient sustainable economy.

This study aims to develop a Decision Support System for IWWM (DSS_IWWM) towards re-use focused localized planning around sewage treatment plants (STPs). There are three primary objectives of this study, i. identification of key factors affecting IWWM focused on wastewater reclamation, ii. reuse-focused selection of appropriate wastewater treatment technology (WWTTs), iii. localized planning around STPs in terms of reclaimed water demand identification, estimation, allocation, and sustainable pricing.

The first objective of the study is to identify the key factors that affect reuse focused IWWM. Based on literature, initially twenty-two potential factors are identified, out of which 12 key influencing factors are distilled by compiling responses of experts. Next, using interpretive structural modelling (ISM), an eight-level hierarchical structure is formed for establishing interrelationships between the key factors. Then, the identified key factors are classified into four groups, namely autonomous, linkage, dependent, and driving, based on their influencing capacities, using the Matrix of Cross Impact— Multiplications Applied to Classification (MICMAC) analysis. Finally, strategies are suggested to address the identified factors. It is observed that social acceptance of reclaimed water, definition of proper policies, and regulations are the top three crucial factors which influence IWWM application. These findings are beneficial for the decision-makers to prioritize the critical factors affecting the system

and help formulate a roadmap for implementing an efficient IWWM.

Focusing on reuse of reclaimed water, the second objective in the present study is the selection of appropriate treatment technology required for production of water with desired quality. The first module of the developed DSS_IWWM under the present study works towards this purpose. It comprises of a repository of 14 reuses of reclaimed water, the associated quality criteria, and performance efficiencies and resource requirements of 25 WWTTs in 360 combinations. In this module, a least weighted cost approach based on four decision criteria: Capital cost, Operation and Maintenance cost, Land requirement, and Energy requirement has been used. Full Consistency Method (FUCOM) is employed for obtaining weights for decision criteria to converge the multiple aspects of technology selection into a single point objective, thereby facilitating ranking of WWTTs. The assignment of weights enables reflection of user's resource priorities and enhances sensitivity of the DSS_IWWM in local context.

The third objective of localized planning around STPs in terms of reclaimed water demand identification, estimation, allocation, and sustainable pricing is addressed in the second module of DSS_IWWM. In this module, a socio-economic and technology-focused methodology is used for reclaimed water demand allocation so that the demands of the socially prioritized users and the economic interests of investing agencies are addressed acceptably and viably. To this end, the reuse purposes are divided into five categories based on income potential of end-use customers, namely agriculture, public utilities, domestic demand, industrial demand, and commercial demand categories. Social prioritization is reflected through fixing minimum water demand percentages defined by user for different categories. To generate stable revenue stream and not burden socially prioritized sections for payment, proportional pricing of reclaimed water is done by rationing the minimum feasible average price required for cost recovery (obtained via

break-even analysis for appropriate WWTTs). In the methodology, firstly the reclaimed water demands in the vicinity of the STP are identified and estimated, then, the minimum allocation requirements of the socially prioritized categories are satisfied, then, reclaimed water is allocated to the income category with the highest price ratio and finally, the remaining reclaimed water demand is satisfied. The DSS_IWWM is a user-friendly tool that can be accessed by creating an account on hosting platform GitHub, using the url: https://github.com/maxDeCoder/water_reclamation.

To validate the application of the DSS_IWWM, it is first tested with data from five cities in the state of Uttar Pradesh (India) - Kanpur, Varanasi, Lucknow, Prayagraj and Agra. For the city of Kanpur, two reuse case studies are considered: 70 MLD reclaimed water demand for industrial cooling from Bingawan STP (UASB-based, 210 MLD) and 73 MLD non-potable reuse demand (toilet flushing, laundry washing, road cleaning, horticulture, outdoor bathing) in the vicinity of Sajari STP (ASP-based, 42 MLD). The Bingawan STP is suggested to be upgraded by adding nutrient removing Wuhrmann process (WP) followed by ultrafiltration (UF) and reverse osmosis (RO) as tertiary technologies. A minimum feasible average price of Rs. 18 per kl is suggested to be levied to recover costs by the fifth year of STP operation. The Sajari STP is suggested to be supplemented with Soil Biotechnology (SBT) process followed by WP. Since the STP capacity is 42 MLD, the demand for reclaimed water is socio-economically allocated in the following percentages 2.38% to agriculture, 5.95% to public utilities, 70.23% to domestic demand and 21.42% to commercial demand. A minimum feasible average price of Rs. 12 per kl is suggested for recovery after the fifth year of operation and the prices for the four categories- agriculture, public utilities, domestic demand, and commercial demand are obtained as Rs. 3.25 per kl, Rs. 3.25 per kl, Rs. 9.75 per kl and Rs. 22.76 per kl respectively while the revenue distribution is obtained as 0.65%, 1.61%, 57.09%, and

40.65% respectively. For Varanasi city, three cases are considered: 20 MLD for railway washing around DLW STP (ASP, 12 MLD), 40 MLD for e-flow augmentation of Assi river from Ramna STP (SBR, 50 MLD) and 81 MLD non-potable reuse demand (road cleaning, toilet flushing, landscape, horticulture) around Goithaha STP (SBR, 120 MLD). For DLW STP, the new installation of BIOFOR-F technology is suggested as the most appropriate option. Since the capacity of the concerned STP is lesser than the imposed demand, 100% of reclaimed water produced will be allocated for railway washing with a minimum feasible average unit price of Rs. 5 per kl (recovery post 5th year). For Ramna STP, the existing SBR technology is obtained to be capable of producing reclaimed water suitable for e-flow augmentation and since the capacity of STP is more than the imposed demand, 100% allocation of reclaimed water to the purpose can be done at an average price of Rs. 9 per kl. For Goithaha STP, augmentation of existing SBR technology with Modified Ludzack Ettinger (MLE) process is obtained as the most appropriate WWTT, the reclaimed water to be sold at a minimum feasible average price of Rs. 5 per kl for recovery post 5th year. Since the STP capacity is more than the total identified demand, all the imposed demands will be 100% allocated while the prices for the agriculture, public utilities, domestic and commercial demands will be Rs. 1.39, Rs. 1.39, Rs. 4.18 and Rs. 9.74 per kl respectively.

Through the case studies of Lucknow, Prayagraj and Agra cities, application of DSS_IWWM for localized STP planning is demonstrated. In these cities, the potential reclaimed water demands in the vicinity of existing STPs (within a radius of 4-6 km) are identified and estimated. Based on these reuse purposes and the local-resource scenario in the city, appropriate WWTTs, demand allocation and pricings for cost recovery are suggested. In Lucknow, for 55 MLD non-potable reuse demand (landscape, e-flow augmentation, vehicle washing, toilet flushing, fire protection, laundry washing, road cleaning) around the Awasthi Vikas Parishad STP (SBR, 37.5 MLD), supplementation

of existing STP with SBT is obtained as the most appropriate option. For recovery after the 5th year, a minimum feasible average unit price of Rs. 5 per kl is obtained.

For the three categories, public utilities, domestic demand and commercial demand, unit prices of Rs. 2.04, Rs. 4.09 and Rs. 7.15 per kl respectively are obtained. The reclaimed water demand allocation distribution to these categories is 16.22%, 43.24% and 40.54% respectively while revenue recovery from each category is distributed as 6.65%, 35.70% and 57.65% respectively. In Prayagraj, for 87 MLD non-potable reuse demand (landscape, toilet flushing, irrigation, outdoor bathing, vehicle washing, road cleaning) around Naini STP (ASP, 80 MLD), supplementation of the STP with SBT followed by coagulation, flocculation, and rapid sand filtration (C+F+RSF) is obtained as the most appropriate suggestion. For the five categories of demands such as agriculture, public utilities, domestic, industrial, and commercial, finalized allocation is 100%, 100%, 74%, 100% and 100% of the imposed demands while the revenue contribution from these categories is distributed as 2.24%, 14.10%, 19.23%, 12.82% and 51.60% respectively. Similarly, in Agra city around Peelakhar STP (Oxidation Ditch, 10 MLD), 26 MLD non-potable reuse demand is estimated under commercial category (vehicle washing) and socially prioritized categories, public utilities (e-flow augmentation, landscape, and road cleaning) and domestic purpose (toilet flushing and horticulture). Supplementation of the existing Oxidation Ditch based STP with BIOFOR-F is obtained as the most appropriate suggestion. In this case, since the STP capacity is less than the estimated demand, the reclaimed water could only be allocated to socially prioritized categories, each of them getting 50% of reclaimed water, with the revenue contribution as 40% and 60% respectively. Finally, the application of DSS_IWWM has been extended to seven more Indian cities with changing influent quality, resource inputs and existing STP technologies while

keeping the same decision criteria prioritization and target quality criteria for non-potable reuse (vehicle washing, toilet flushing, laundry washing and horticulture).

The comparative evaluation for all the twelve cities: Kanpur, Varanasi, Lucknow, Prayagraj, Agra, Madurai, Hyderabad, Panjim, Jalandhar, Jaipur, Delhi, and Patna have been presented. It is concluded that influent quality, existing technology, and target quality criteria play significant role in selection of appropriate WWTTs. The traditional technologies such as UASB and ASP are required to be augmented and supplemented with high performing WWTTs, such as BIOFOR-F with (C+F+RSF) and SBT+ WP to obtain desired effluent quality. High performing advanced oxidation process (AOP) based systems such as A2O, SBR, and BIOFOR-F require WWTTs with relatively lower average costs (such as SBT and OD). SBT is more frequently recommended primarily due to lower costs and higher performance.

Overall, the present study embodies the development of a decision support system for IWWM (DSS_IWWM) emphasizing localized planning around existing or proposed STPs for reclaimed water use. The application has been validated initially for 5 cities of northern India and further tested on additional seven Indian cities located in varying geo-climatic zones of the country. After assessing the existing WWTTs for reuse applications, the results obtained in terms of supplementing or augmenting technology through the application of DSS_IWWM are found quite justifiable and close to the ground realities. Thus, the developed DSS_IWWM can be useful and beneficial for policymakers, government officials, engineers, and scientific community as it will facilitate rational decision-making for efficient investment planning in reuse focused wastewater treatment towards achieving circular economy in sustainable water resource management.