CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Finalization of Key Factors Affecting Reuse Focused IWWM

The responses obtained by the experts were populated to obtain the total importance ratings (total score) for different factors, as shown in Figure 4.1.

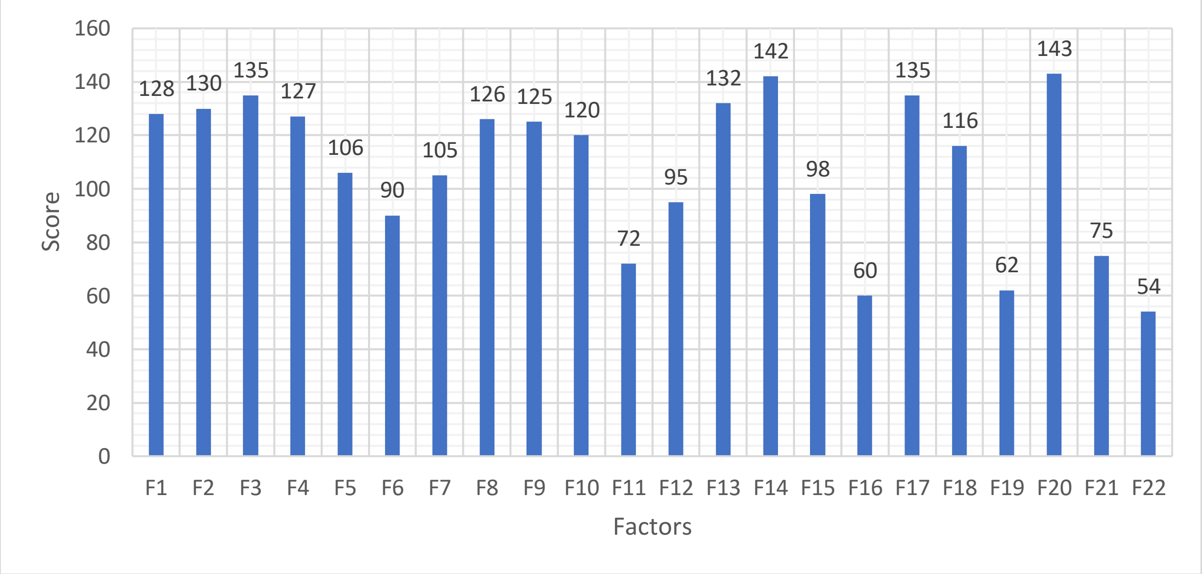


Fig. 4.1. Score obtained for identified influencing factors

Since ISM is not sensitive to the intensity of impacts or the importance magnitude of factors, the scores obtained were used only to identify the top twelve relevant factors. Using total scores obtained from the questionnaire survey, the key influencing factors, as presented in the following Table 4.1, were identified.

Table 4.1. Identified key factors affecting reuse focused IWWM

S.N.	Factor	Identified Key Factors	Total Score
1	F20	Policy and Regulations	143
2	F14	Treatment Technology	142
3	F3	Demand for Treated Wastewater	135
4	F17	Land Requirement	135
5	F13	Social Acceptance	132
6	F2	Post-Distribution Network	130
7	F1	Reuse Purpose	128
8	F4	Power Requirement	127
9	F8	Capital Cost	126
10	F9	Operation and Maintenance Cost (O&M)	125
11	F10	Water Pricing	120
12	F18	By-Products and GHGs	116

Ten factors, i. Material Requirement (F5), ii. Nutrient Recovery (F6), iii. Manpower Requirement (F7), iv. Availability of Raw Wastewater (F11), v. Ease of Operation (F12), vi. Technical Durability (F15), vii. Centralized or Decentralized WWTPs (F16), viii. Value of Saved Water (F19), ix. Funding Availability (F21), and x. Weather and Climatic Conditions (F22) were excluded from the study due to lower importance ratings provided by the experts. Most of the excluded factors influence only the technical aspect of the reuse focused IWWM network, whereas wide coverage of aspects, such as administrative, economic, social, technical, operational, environmental, and physical aspects, can be seen in the selected key factors.

4.2 Developing Importance Hierarchy of Key Factors Using ISM

4.2.1 Representation of Pairwise Relationships Between Factors in Structural Self-Interacting Matrix (SSIM)

To establish interrelationships between the identified affecting factors, whether one factor influences the other factor, SSIM was constructed. Experts' opinions were obtained by a questionnaire survey about their perception regarding the relationship between the identified factors. A total of 30 valid responses were received from academicians and engineers specializing in this field, and a Structural Self-Interacting Matrix (SSIM) was formed on the basis of the majority in responses. The interrelationships between the influencing factors are as shown in the SSIM matrix given in the following Table 4.2. It can be inferred from this table that the influencing factors are closely dependent on each other.

4.2.2 Binary Representation of Interrelationships Between Factors in Adjacency Matrix

SSIM is converted into the binary matrix to construct the "Adjacency Matrix" by assigning 1 and 0 in place of symbols W, X, Y, and Z as per substitution rules for further calculations as shown in following Table 4.3.

4.2.3 Establishment of Indirect Relationships Between Factors Using Reachability Matrix

The reachability matrix (Table 4.4) is then formed by using transitivity rules in which the indirect relationship between the considered factors is presented by "1*" in place of "0".

4.2.4 Identification of Hierarchical Relationships Between Factors Using Level Partitions

Reachability set, antecedent set, and level partitions obtained for key factors are as shown in Table 4.5. It was found that the factors F20 Policy and Regulation and F13 Social Acceptance are the major driving factors in the considered scenario.

Table 4.2. Pairwise Relationships Between Key Factors Represented in Structural Self-Interacting Matrix (SSIM)

Factor No.	F1	F2	F3	F4	F8	F9	F10	F13	F14	F17	F18	F20
F1	-	Z	X	Z	Z	W	W	X	W	Z	Z	X
F2		-	Z	W	W	W	W	Z	Z	W	Z	X
F3			-	Z	Z	Z	W	X	Z	Z	Z	X
F4				-	Z	W	W	Z	X	Z	W	X
F8					-	Z	W	Z	X	X	X	X
F9						-	W	Z	X	Z	X	X
F10							-	Z	X	Z	Z	X
F13								-	Z	Z	Z	Y
F14									-	W	W	X
F17										-	Z	X
F18											-	X
F20												-

Table 4.3. Binary Representation of Interrelationships Between Key Factors in Adjacency Matrix

Factor No.	F1	F2	F3	F4	F8	F9	F10	F13	F14	F17	F18	F20
F1	1	0	0	0	0	1	1	0	1	0	0	0
F2	0	1	0	1	1	1	1	0	0	1	0	0
F3	1	0	1	0	0	0	1	0	0	0	0	0
F4	0	0	0	1	0	1	1	0	0	0	1	0
F8	0	0	0	0	1	0	1	0	0	0	0	0
F9	0	0	0	0	0	1	1	0	0	0	0	0
F10	0	0	0	0	0	0	1	0	0	0	0	0
F13	1	0	1	0	0	0	0	1	0	0	0	1
F14	0	0	0	1	1	1	1	0	1	1	1	0
F17	0	0	0	0	1	0	0	0	0	1	0	0
F18	0	0	0	0	1	1	0	0	0	0	1	0
F20	1	1	1	1	1	1	1	1	1	1	1	1

Table 4.4. Indirect Relationships Between Key Factors Using Reachability Matrix

#	F1	F2	F3	F4	F8	F9	F10	F13	F14	F17	F18	F20
F1	1	0	0	1*	1*	1	1	0	1	1*	1*	0
F2	0	1	0	1	1	1	1	0	0	1	1*	0
F3	1	0	1	0	0	1*	1	0	1*	0	0	0
F4	0	0	0	1	1*	1	1	0	0	0	1	0
F8	0	0	0	0	1	0	1	0	0	0	0	0
F9	0	0	0	0	0	1	1	0	0	0	0	0
F10	1*	0	0	0	0	0	1	0	0	0	0	1*
F13	1	1*	1	1*	1*	1*	1	1	1*	1*	1*	1
F14	0	0	0	1	1	1	1	0	1	1	1	0
F17	0	0	0	0	1	0	1*	0	0	1	0	0
F18	1*	0	0	0	1	1	1*	0	0	0	1	1*
F20	1	1	1	1	1	1	1	1	1	1	1	1

Table 4.5. Hierarchical Relationships Between Key Factors Using Level Partitions

Factor No.	Reachability Set	Antecedent Set	Intersection	Level
F1	1, 4, 8, 9, 10, 14, 17, 18	1, 3, 10, 13, 18, 20	1, 10, 18	VI
F2	2, 4, 8, 9, 10, 17, 18	2, 13, 20	2	V
F3	1, 3, 9, 10, 14	3, 13, 20	3	VII
F4	4, 8, 9, 10, 18	1, 2, 4, 13, 14, 20	4	IV
F8	8, 10	1, 2, 4, 8, 13, 14, 17, 18, 20	8	II
F9	9, 10	1, 2, 3, 4, 9, 13, 14, 18, 20	9	II
F10	1, 10, 20	1, 2, 3, 4, 8, 9, 10, 13, 14, 17, 18, 20	1, 10, 20	I
F13	1, 2, 3, 4, 8, 9, 10, 13, 14, 17, 18, 20	13, 20	13, 20	VIII
F14	4, 8, 9, 10, 14, 17, 18	1, 3, 13, 14, 20	14	V
F17	8, 10, 17	1, 2, 13, 14, 17, 20	17	III
F18	1, 8, 9, 10, 18, 20	1, 2, 4, 13, 14, 18, 20	1, 18, 20	III
F20	1, 2, 3, 4, 8, 9, 10, 13, 14, 17, 18, 20	10, 13, 18, 20	10, 13, 18, 20	VIII

4.2.5 Importance Hierarchy Structure of Key Factors Obtained Using ISM

The interrelationships between the key factors and level partitions are shown in Figure 4.2. A total of 8 levels are obtained in this study. Two factors- Policy and Regulations (F20) and Social Acceptance (F13) are placed at the bottom-most level (level VIII) indicating highest relevance. These factors indicate the driving role of regulatory authorities, acceptability, and conducive environment for setting up of a reuse focused IWWM system. Five factors- Reuse Purpose (F1), Post-Distribution Network (F2), Demand of Treated Wastewater (F3), Power Requirement (F4), and Treatment Technology (F14) fall in intermediate-levels (level IV, level V, level VI, and level VII), depicting moderate importance. These factors cover the technical and demand aspects of a reuse focused IWWM. Five factors, Capital Cost (F8), Operation and Maintenance Cost (F9), Water Pricing (F10), Land Requirement (F17), and By-Products and GHGs (F18), are seen in top levels (level I, level II, and level III), these factors are subset to the technical aspects of the reuse focused IWWM. They indicate the operational, environmental, and economic aspects of a reuse focused IWWM.

Policy and Regulations (F20) and Social Acceptance (F13) are identified as the most crucial factors in the reclaimed water reuse scenario. Marleni and Raspati (2020) identified the lack of stringent policies and regulations as the major hindrance to wastewater resource recovery implementation. Lavrnić et al. (2017) emphasized that proper policies can promote wastewater reuse in a country. Sgroi et al. (2018) pointed out that encouraging policies and regulations is significant for implementing a successful water reuse system, as seen in Japan, where innovative reuse schemes are promoted. Social Acceptance (F13) indicates the perception of humans towards the utilization of treated wastewater. Das and Radhakrishnan (2019) stated that for implementing an efficient wastewater reuse system, social acceptance is an indispensable aspect as it greatly influences reclaimed water demand. For policymakers, the production of water that is socially accepted is of utmost significance (Zabala et al., 2019). The involvement of stakeholders and establishment of policies by the government will give a significant boost to the utilization of reclaimed water (Maryam and Büyükgüngör, 2019).

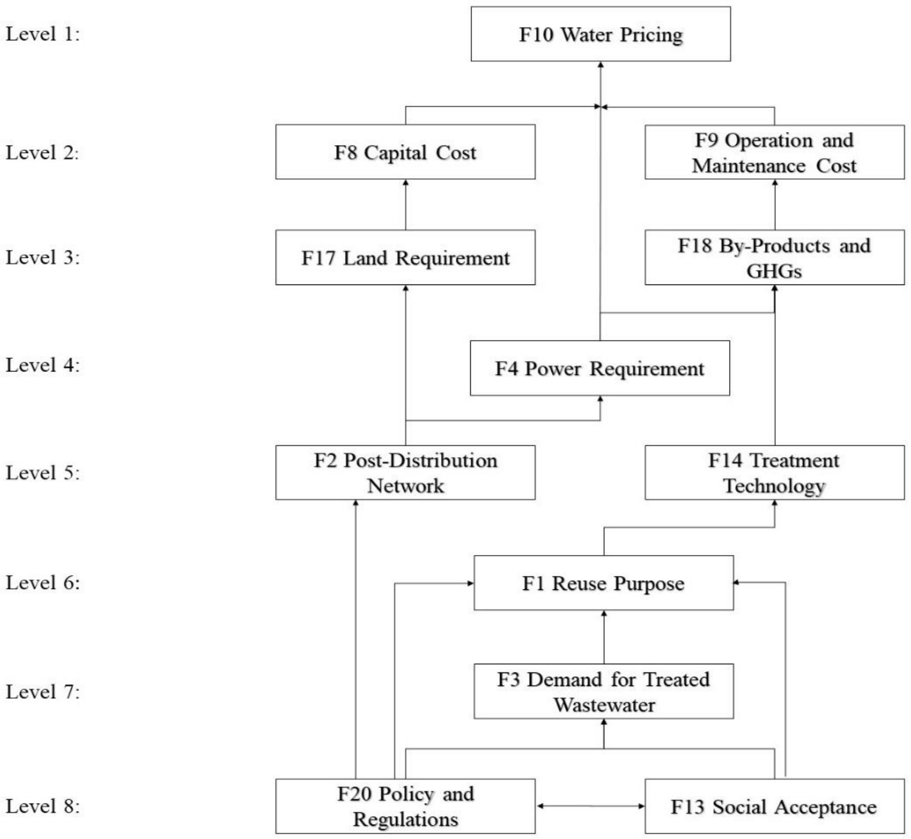


Fig. 4.2. ISM model showing interrelationships between identified key factors

Reuse Purpose (F1) and Demand of Treated Wastewater (F3) are obtained at the second and third levels respectively. Reuse Purpose (F1) is one of the major determinants for technology selection as it defines the desired quality criteria and the degree of treatment to be given to wastewater (Capodaglio, 2020). The type of technology required, and the quality and quantity of reclaimed water depend on the desired reuse purpose (Lyu et al., 2016). Assessment of Demand of Treated Wastewater (F3) is required to estimate the wastewater reuse potential as demand is the primary reason for producing reclaimed water (Chu et al., 2004; Yang and Abbaspour, 2007).

Treatment Technology (F14) is a significant determinant for assessing the performance of the

WWTP. Sgroi et al. (2018) established that treatment technology is very important for satisfying the required quality criteria. Several studies have been undertaken to determine suitable technology for obtaining effluent of the required quality while considering prevailing local conditions (Kalbar et al., 2012). Post-Distribution Network (F2) is essential for effectively completing the IWWM network and closing the human water-cycle loop (Sgroi et al., 2018).

These factors at the bottom levels need careful consideration during the planning stage as they play a significant role in the implementation of an IWWM network and also affect factors such as Power Requirement (F4), Capital Cost (F8), Operation and Maintenance Cost (F9), Water Pricing (F10) and Land Requirement (F17).

4.3 Classification of Key Factors using MICMAC

The classification of these factors is done by converting the driving and depending powers of the factors into a graph under MICMAC (Matrix of Cross Impact – Multiplications Applied to Classification) analysis. This diagram helps identify the driving and dependent powers of the key factors influencing the reuse focused IWWM network. The classification of factors is shown in Figure 4.3.

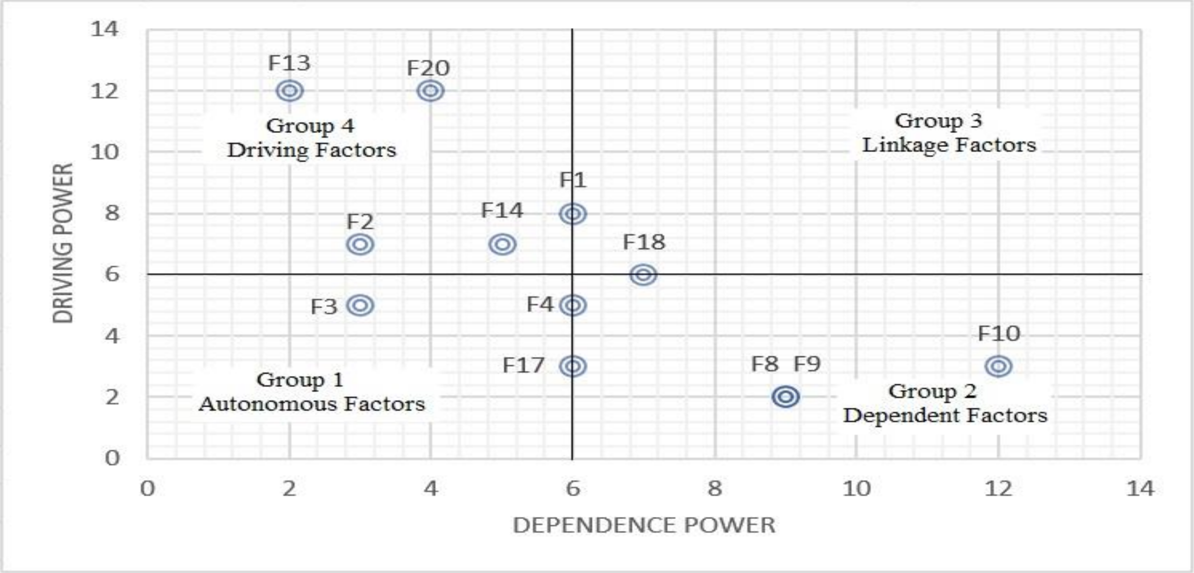


Fig. 4.3. Classification of identified key factors using MICMAC analysis

4.4 Discussion and Strategies for Efficient Reuse Focused IWWM

It can be seen that the factors such as, policy and regulations (F20) and social acceptance (F13) which were obtained at the bottom level belong to Group 4, that is, the driving factors group, whereas those lying in the top levels (water pricing (F10), capital cost (F8) and operation and maintenance cost (F9)) can be seen in Group 2, that is, the dependent factors group. These findings are in line with that of Maryam and Büyükgüngör (2019) which states that stakeholder involvement, willingness to use reclaimed water, and policies established by the government will give a major boost to the implementation of an IWWM network. However, factors lying in the dependent group (Group 2) are of lesser significance because of their lower capacity to influence other factors but the higher capacity of getting influenced by other factors.

The Demand for Treated Wastewater (F3) factor lies at level 3 of the hierarchy and has lesser driving and dependence powers (Group 1- Autonomous Factors). Even though the factor has less capacity to drive other factors, it is vital to implement an efficient IWWM network. The demand for reclaimed water depends on various factors like development in the city, occupation, the standard of living of people, etc. It is a determining factor as the capacity of a WWTP depends on the demand for reclaimed water (Yang and Abbaspour, 2007). By dividing the considered city into different wards and considering the major economic activities and land-use patterns, reclaimed water demand can be estimated. Therefore, proper estimation of the wastewater reuse potential of a city is required to ascertain the quantity and the respective quality of the reclaimed water.

Power Requirement (F4) and Land Requirement (F17) are obtained at the common boundary of autonomous and dependent factors' groups. It indicates low driving power (5 and 3 respectively) in comparison to dependence power (6). However, these factors primarily affect the costs of the IWWM system. Also, these factors play an essential role when local resource availability is restrained; for example, at places with high population densities, the land will be a restricted resource while under-developed regions like rural areas prefer treatment technologies with lesser power consumption. Therefore, prediction of power requirement for the design period of the project and calculation of land area for setting up of the WWTP and laying of distribution network should be done in the planning stage and matched with their respective availabilities.

Three factors, Capital Cost (F8), Operation and Maintenance Cost (F9), and Water Pricing (F10), are obtained at the top levels of the hierarchical structure (level I, level II) and belong to Group 2, which is dependent factors group. These factors have higher dependence and driving powers and are influenced by the driving factors and linkage factors lying at the higher levels of the structure. Water Pricing (F10) alleviates the financial burden of implementing reuse focused IWWM network from the stakeholders. An optimum water price should be charged from the consumers, keeping in mind the capital costs (F8) and operation and maintenance costs (F9) incurred on the project (Chu et al., 2004). These findings align with those of Tare and Bose (2009), which pointed out the dependency of these factors (F8 and F9) on the land requirement, power requirement, and treatment technology.

The factor By-products and GHGs (F18) lies at the common boundary of linkage and dependent factors' group having dependence power of 7 and driving power of 6. Therefore, since this factor has both high driving and dependent nature, it will act as a connecting node between the driving and dependent factors while belonging to Group 3, the linkage factors group. Controlling this factor is essential to limit the transfer of impact from higher-level factors to lower-level factors. This factor is essential for checking the impact of the proposed project on the environment. Therefore, environmental impact studies of the proposed project, estimation of harmful by-products and gases, and the carbon footprint of treatment technologies should be accounted for while selecting the treatment technology.

Five factors, such as policy and regulations (F20), social acceptance (F13), reuse purpose (F1), post-distribution network (F2), and treatment technology (F14), are present at the bottom levels of the ISM structure and belong to Group 4, which is driving factors group. These are the most crucial driving factors for an IWWM network due to high driving powers and low dependence powers. Hence, considering these factors during the planning stage is essential as these factors can drive most of the other factors in an IWWM network. Chung and Ma (2012) stated that stringent water quality standards for each reuse purpose (F1) should be laid down by government agencies, further improving the social acceptability of the reclaimed water. Also stated by Maryam and Büyükgüngör (2019), encouraging policies by the government (F20) and the willingness to use reclaimed water (F13) are the most crucial factors for implementing the IWWM network. The government should introduce favorable policies for stakeholders such as interest-free loans, tax holidays, duty waivers for equipment procurement, and cheaper power for operation and maintenance. Also, these policies should spread awareness about the alarming state of depleting freshwater resources. It can be said that guidelines regarding the quality criteria for the desired reuse purpose promote social acceptance and boost the demand for reclaimed water in society. Therefore, the definition of quality standards and spreading awareness in public are the essential steps for promoting the willingness to utilize reclaimed water. Laying of the post-distribution network (F2) is essential to complete the human-water cycle loop and smooth delivery of the reclaimed water to the utilization site. As per the city's population density and development plan, a dual-reticulation system may be provided in the city. Several studies have been conducted for wastewater treatment technology (F14) selection considering different decision criteria as its performance determines whether the required quality standards can be satisfied or not. A major portion of the total cost incurred comes from installing, operating, and maintaining the treatment technology employed in the WWTP. Therefore, treatment technology (F14) is the most important technical component of the IWWM network, and its selection should be made considering all other factors such as local conditions, resource availability, quality standards, capital cost, operation and maintenance cost, carbon footprint, and harmful by-products produced.

The strategies suggested corresponding to each factor are given in Figure 4.4.

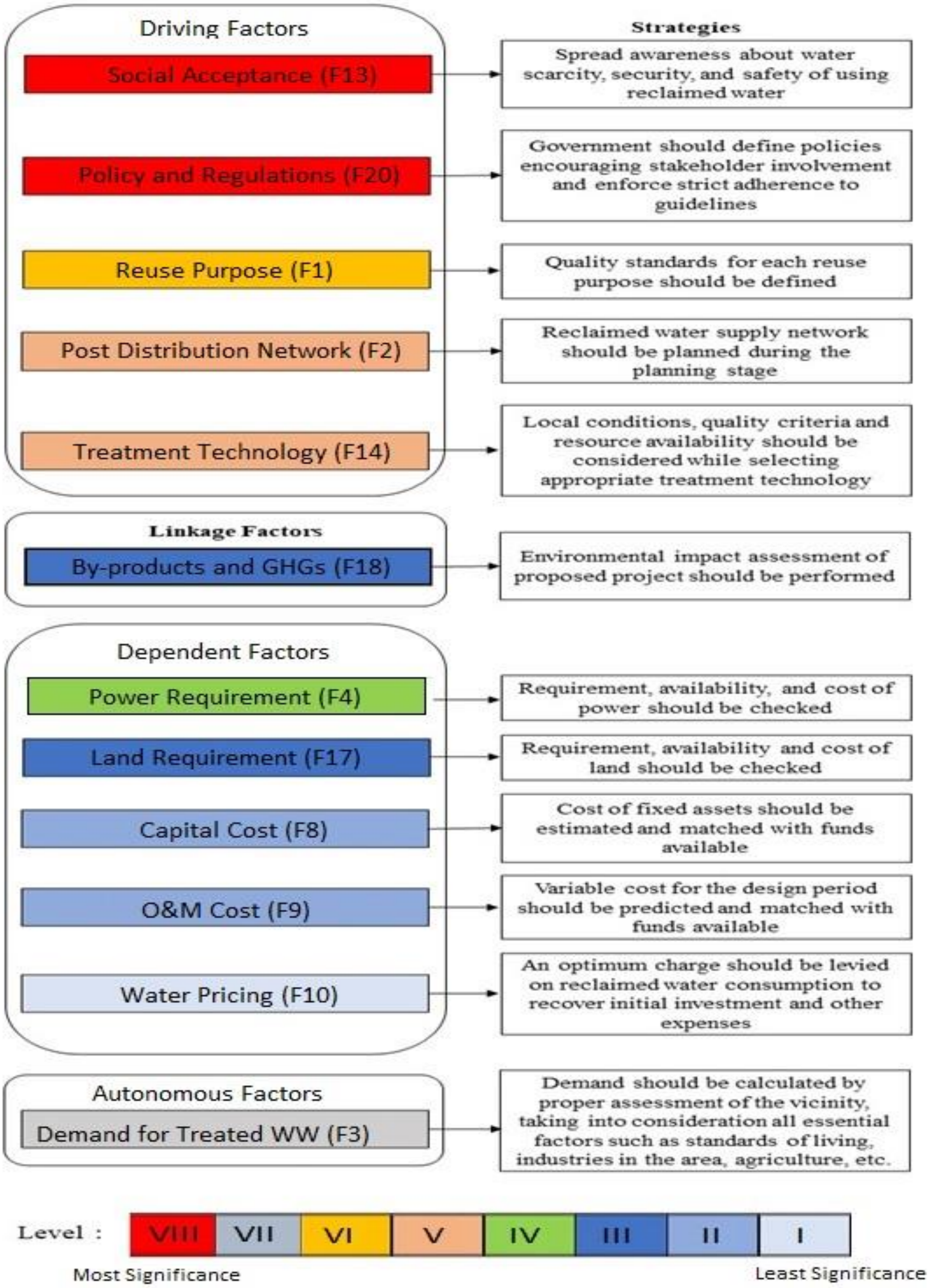


Fig. 4.4. Strategies for addressing identified key factors for efficient reuse focused IWWM.

The findings in this study can be helpful for planners, designers, environmentalists, and policymakers to make a progressive step towards closing the human-water cycle loop and achieving water sufficiency by implementing an efficient IWWM network. The research gap in this study is that since ISM does not address the strength of relationships between the influencing factors as it takes only binary numbers for defining a relationship, the quantified importance of factors and their impacts cannot be obtained. Future studies should be conducted to obtain a more detailed analysis of interrelationships, their importance intensities, and respective impacts.

In the proposed DSS_IWWM, eight out of the twelve identified key factors are directly employed for augmenting development of a reuse focused IWWM, namely, i. Demand for treated wastewater, ii. Reuse purpose, iii. Treatment technology, iv. Power requirement, v. Land requirement, vi. Capital cost, vii. O&M cost, and viii. Water Pricing.

Two factors- Social acceptance and Post-distribution network are indirectly considered in the study. The social acceptance factor is included indirectly by suggesting ways to enhance acceptance with the help of socially acceptable pricing and adherence to target quality criteria. The post-distribution network is addressed by suggesting the demand distribution in the community.

Two factors, policy and regulations, and by-products and GHGs are not addressed through the developed DSS_IWWM. They are suggested in the future scope of this study.

4.5 Validation of DSS_IWWM Through Case Studies of five cities of Uttar Pradesh

4.5.1 Kanpur city

Kanpur is a large metropolitan city located on the Ganga riverbank in the state of Uttar Pradesh (Figure 4.5). The city has a huge industrial economy and a metropolitan area of over 403 sq km. The population of the city is 4.68 million (Kanpur, 2013). The Pandu River, the Ganga River and private bore wells are the prime sources of water in the city (Kanpur, 2006). In India, 150 lpcd of water is recommended for supply in metro areas (CPHEEO, 2013).

Fig. 4.5. Kanpur city and location of STPs

Three sewerage treatment plants (STP) are operational in Kanpur City. Out of 425 MLD treatment capacity, 315 MLD capacity is utilized. The details of treatment plants are shown in Table 4.6.

4.5.1.1 Identification of Potential Reuses

Out of 14 reuse applications identified in this study, Kanpur can pose considerable water demand in eight applications, such i. as toilet flushing in residential buildings, commercial buildings or railway stations and locomotives, ii. construction activities, iii. road cleaning, iv. industrial cooling, v. landscape development, vi. vehicle washing including railway locomotives, vii. fire protection and viii. dust control. To demonstrate the application of DSS_IWWM, two cases are considered in this study.

Case 1: Reclaimed water production for utilization in industrial cooling at Panki Thermal Power Plant from neighboring UASB-based Bingawan (210 MLD) STP.

Case 2: Localized planning for non-potable reclaimed water demands (toilet flushing, laundry washing, road cleaning, horticulture, outdoor bathing) in the vicinity of ASP-based Sajari (42 MLD) STP.

4.5.1.2 Quality Criteria for Identified Reuses

For case 1, industrial cooling is taken as the target reuse purpose and the quality criteria are extracted from finalized quality criteria directly.

For case 2, where multiple non-potable reuses are identified (toilet flushing, laundry washing, road cleaning, horticulture, outdoor bathing), the strictest quality parameter for each reuse purpose will be taken using following equations.5

The quality criteria (each parameter) for the multiple reuse scenario will be as described below:

$BOD = Min (BOD_{RC}, BOD_{TF}, BOD_{OB}, BOD_{LW}, BOD_{H}) = 10$ mg/l;

$COD = Min (COD_{RC}, COD_{TF}, COD_{OB}, COD_{LW}, COD_{H}) = 30$ mg/l;

$TSS = Min (TSS_{RC}, TSS_{TF}, TSS_{OB}, TSS_{LW}, TSS_{H}) = 10$ mg/l;

$TN = Min (TN_{RC}, TN_{TF}, TN_{OB}, TN_{LW}, TN_{H}) = 10$ mg/l;

$FC = Min (FC_{RC}, FC_{TF}, FC_{OB}, FC_{LW}, FC_{H}) = 200$ MPN/l.

Where, RC: Road Cleaning, TF: Toilet Flushing; OB: Outdoor Bathing; LW: Laundry Washing; H: Horticulture.

The considered quality criteria are given in the input table as shown in Table 4.9. It can be observed that fecal coliform concentration separates the effluent quality required for industrial cooling and non-potable domestic reuse.

4.5.1.3 Importance Weightage for Decision Criteria

The priorities of the user in terms of resource availability are assessed and used for the evaluation of weights using FUCOM as shown in Table 4.7. The user was asked to rate each decision criterion in terms of significance on a scale of 1 to 4, with 1 as the most important and 4 as the least important. As per the ratings given by the user, using FUCOM, a weightage of 0.48, 0.24, 0.16 and 0.12 were obtained for land, capital cost, energy, and O&M cost respectively.

4.5.1.4 Estimation of Reclaimed Water Demand

Case 1: Reclaimed water production for utilization in industrial cooling at Panki Thermal Power Plant from neighboring UASB-based Bingawan (210 MLD) STP.

Panki Thermal Power Plant is an upcoming 660 MW coal-based power plant in Kanpur which derives water directly from the river Pandu. As per MoEF notification (MoEF, 2019), in a cooling tower of a thermal power plant, 3.5 m^3 of water is required per 1 MWh of electricity generation.

Water required for Cooling (MLD) = [{3.5 *1000* Power Plant Capacity (MWh) * 24}/1000000]

= 55.44 MLD

Considering a loss factor of 20%, a gross demand of 70 MLD is obtained for the said power plant.

Case 2: Localized planning for non-potable reclaimed water demands in the vicinity of ASP-based Sajari (42 MLD) STP.

The reuse purposes identified in the vicinity of Sajari STP are as shown in Figure 4.6.

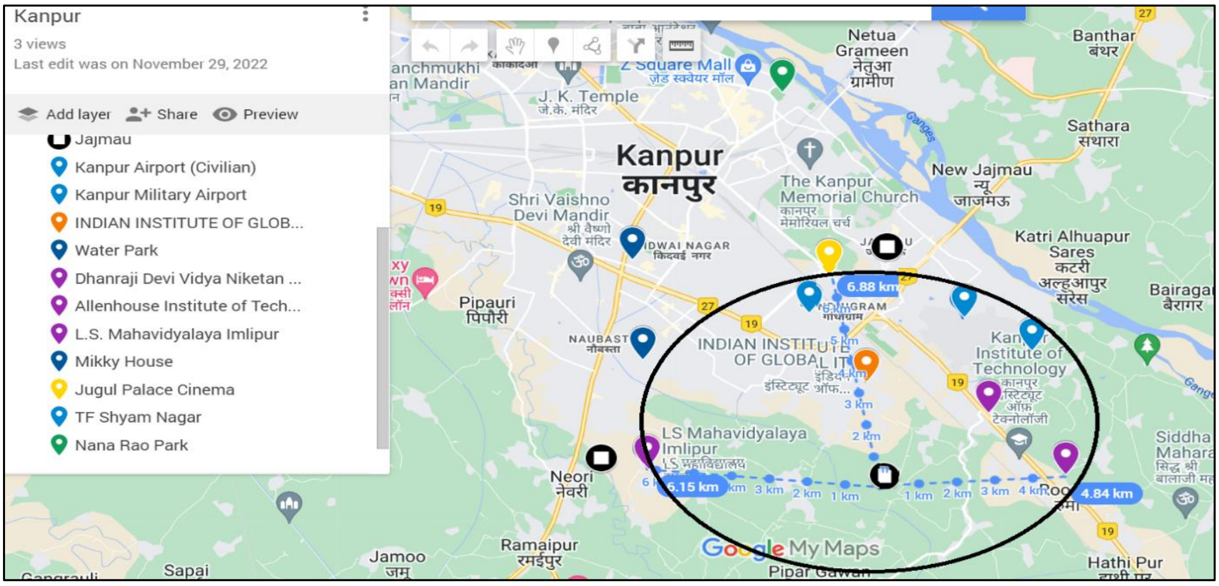


Fig. 4.6. Reuse purposes identified in the vicinity of the Sajari STP (42 MLD, ASP) in Kanpur city

There exists a gap of 215 MLD in the water demand and supply scenario of Kanpur city (Basse et al., 2019). In order to bridge the gap, it is proposed to meet 42 MLD water demand for non-potable domestic purpose through reclaimed water. The target effluent quality for this application must satisfy the quality criteria required for all the reuse purposes identified in the vicinity of the considered STP (within a radius of 6 km). The identified reuse purposes, categorization of reuses, price ratios and minimum allocation are shown in the Table 4.8.

Table. 4.6 Features of operational STPs in Kanpur city (CPCB, 2021)

STP Location	Technology Used	Installed Capacity (MLD)	Utilised Capacity (MLD)	Compliance to disposal norms (CPHEEO, 2013)	Effluent use
1. Bingawan	UASB	210	145	Partial	40 MLD TPP
2. Sajari	ASP	42	30	Yes	Irrigation
3. Jajmau	ASP	130	105	Yes	Irrigation
	ASP	43	35	Yes	Irrigation

Table 4.7. Weight calculation for decision criteria using FUCOM for Kanpur city

Number of Criteria = 4	Criterion 1	Criterion 2	Criterion 3	Criterion 4
Names of Criteria	**Land**	**Energy**	**Capital Cost**	**O&M Cost**
Rank	1	3	2	4
Criteria (according to rank)	**Land**	**Capital Cost**	**Energy**	**O&M Cost**
Criteria comparisons	1	2	3	4
$\phi_{1/2}$	$\phi_{2/3}$	$\phi_{3/4}$	$\phi_{1/3}$	$\phi_{2/4}$
2.00	1.5	1.33	3.00	2.00
Weights	**Land**	**Capital Cost**	**Energy**	**O&M Cost**
	0.480	0.240	0.160	0.120

*Weights were obtained by using the above data and applying linear programming model in equations (1) and (2) (Chapter 3)

Table. 4.8. Demand estimation in the vicinity of Sajari STP, categorization of reuses, price ratio and minimum demand allocation requirements in Kanpur city

Reuse Purpose	Place	Demand (MLD)	Category	Price Ratio	Minimum Allocation
Road Cleaning	NH 19	4	Public Utilities	1	50%
TF	Airport				
TF	Sajari	59	Domestic	3	50%
TF + LW + H	Dhanraji Devi Inter College				
	INDIAN INSTITUTE OF GLOBAL IT				
	Allenhouse Institute of Technology				
	L.S. Mahavidyalaya Imlipur				
Laundry Washing	Textile factories	9	Commercial	7	-
Outdoor Bathing	Water Park				
Horticulture	Park	1	Agriculture	1	50%
Total Demand		**73**			

4.5.1.5 Identification of inputs for application in DSS_IWWM

The quality criteria, target reuses, land cost, electricity cost, and raw wastewater characteristics are provided in Table 4.9.

Table 4.9. Inputs to DSS_IWWM for STPs in Kanpur City

Desired Reuse	Quantity (MLD)	Design Period (yrs)	Land Cost (Rs per ha)	Electricity Cost (Rs per kW-h)	Land (ha)	Energy (MWh)	Capital Cost (Rs in Cr)	O&M Cost (Rs in Cr)
Industrial Cooling (From Bingawan STP)	70	15	2 Cr	6.00	8	50	--	--
Non-Potable Reuse (TF + LW + RC + H + OB) (From Sajari STP)	42	15	2 Cr	6.00	8	50	--	--

Raw Wastewater Characteristics (CPCB, 2013)

Source	BOD (mg/l)	COD (mg/l)	TSS (mg/l)	TN (mg/l)	FC (MPN/l)
Municipal	314	672	969	19.2	9.4 x 10^7
Desired Characteristics of Reclaimed Water					
Industrial Cooling	10	60	10	10	2000
Non-Potable Reuse	10	40	10	10	250

* Due to absence of quality standards for COD parameters, a BOD/COD ratio of 0.3 is considered for the treated effluent in model applications

4.5.1.6 Selection of Appropriate Treatment Technologies

Case 1: Reclaimed water production for utilization in industrial cooling at Panki Thermal Power Plant from neighboring UASB-based Bingawan (210 MLD) STP.

After applying the inputs and respective weights, based on required quality and least weighted cost, the following wastewater treatment technology combinations are suggested for industrial cooling in Kanpur city in increasing order of weighted cost as shown in Table 4.10.

The combination of MBR treatment method with Wuhrmann process (WP) is observed to be the most appropriate for obtaining effluents for reuse application in industrial cooling. After MBR process, the BOD, COD, TSS, TN and FC in secondary effluent will be 7.5 mg/l, 20.5 mg/l, 48.4 mg/l, 7.7 mg/l and 9400 MPN/l respectively. This effluent when passed through single-stage post-denitrification process, that is, WP, the resulting effluent will have following parameters, BOD 0.2 mg/l, COD 16.53 mg/l, TSS 0.3 mg/l, TN 0.85 mg/l and FC 940 MPN/l. Satisfaction of quality as well as adherence to resource-constraint and lesser cost requirement, makes MBR followed by WP the preferred technology.

However, since TDS is an important quality parameter for industrial cooling, ultrafiltration and reverse-osmosis preceded by either A2O or SBR are considered more suitable for producing the desired effluent. A schematic diagram representing A2O + UF + RO based plant system is as shown in Figure 4.7.

In the A2O + UF + RO-based system, the effluent will be firstly treated in A2O bioreactor and then solid-liquid separation will be achieved through membrane filtration. The expected contaminant concentration in the permeate will be BOD 5 mg/l, COD 15 mg/l, TSS 5 mg/l, TN 10 mg/l and FC 1222 MPN/l.

Table 4.10. Appropriate WWTT combinations to satisfy industrial cooling demand in the vicinity of Bingawan STP, Kanpur city

(UASB+EA, 70 MLD)

Rank	**WWTT Combinations**	**Weighted Cost (Rs in Cr)**	**Land (ha)**	**Energy (MWh per day)**	**Absolute capital cost (Rs in Cr)**	**Absolute O&M cost/yr (Rs in Cr)**
New Installation						
1	MBR + WP	71.67	7.70	24.50	200.57	11.02
2	A2O + UF + RO	93.18	23.10	300.38	9.76	9.76
3	SBR + UF + RO	97.21	6.65	33.60	335.36	7.52
Upgradation of Existing Technology *						
1	UASB + EA+ WP + UF + RO	71.99	6.3	29.4	183.96	13.79
Supplementation of Existing Technology*						
1	UASB + EA + SBR	42.65	3.85	18.90	94.01	3.59
2	UASB + EA + SBT + WP	53.62	4.90	25.27	99.12	6.58
3	UASB + EA + A2O + MLE	62.94	7.00	28.70	117.25	7.23

* Energy and O&M Cost both for existing and suggested WWTT are included

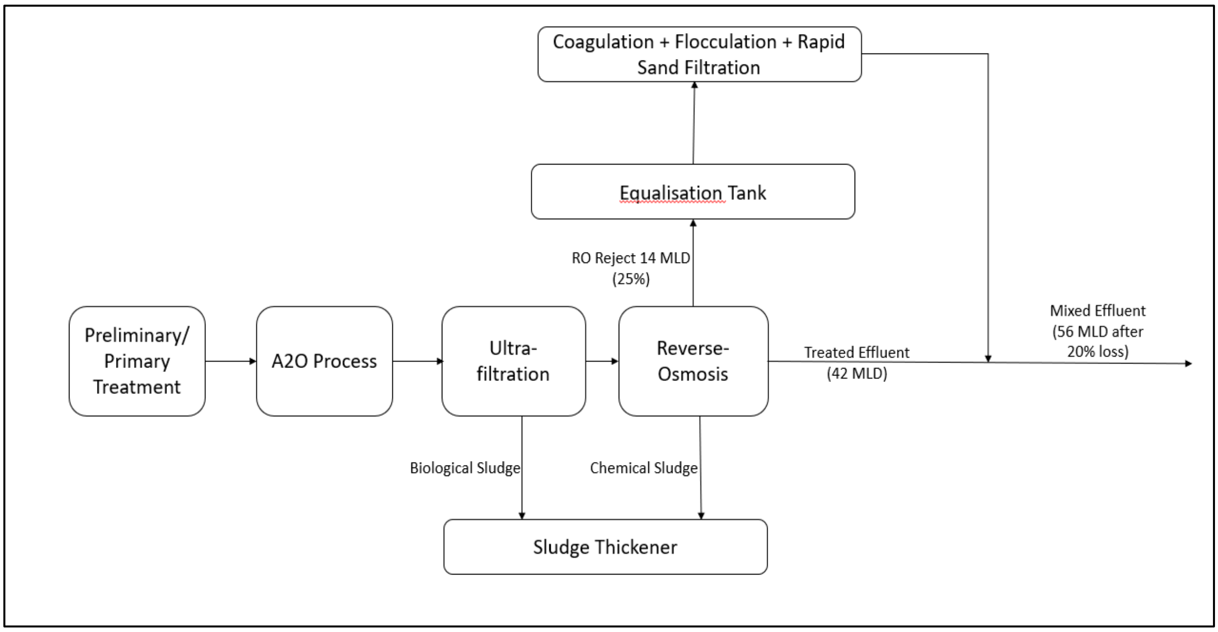


Fig 4.7. Proposed schematic diagram for A2O+UF+RO system

This water after passing the RO system will produce tertiary treated effluent with BOD, COD, TSS, TN and FC as <5.0 mg/l, <10.0 mg/l, <5.0 mg/l, <0.3 mg/l and <12.22 MPN/l respectively, obtained using effective contaminant concentration formula.

Assuming 25% rejection rate, the volume of RO reject will be 14 MLD (assuming overall 20% loss). This water will have the BOD, COD, TSS, TN and FC as 20 mg/l, 60 mg/l, 20 mg/l, 40 mg/l and 4888 MPN/l respectively. This water should be collected in an equalization tank and further treated by chemical coagulation leading to production of chemical sludge. The expected BOD, COD, TSS, TN and FC of treated reject water after coagulation-flocculation-rapid sand filtration will be 7 mg/l, 32 mg/l, 9.4 mg/l, 28.0 mg/l and 733 MPN/l respectively. Therefore, all the suggested technology train will need coagulation-flocculation-rapid sand filtration for RO reject treatment and so the suggested technology options will remain same.

The treated reject water can be mixed with the effluent from WWTP. This effluent will still satisfy the quality criteria and the expected BOD, COD, TSS, TN and FC of mixed effluent will be <5.0 mg/l, 6.1 mg/l, 4.0 mg/l, <10 mg/l and <200 MPN/l respectively.

The volume of biological sludge produced from the membrane filtration should be mixed with the obtained chemical sludge and thickened in a sludge thickener. This thickened sludge is further dewatered using a centrifuge decanter before disposal. The supernatant from the sludge thickener is sent back to the equalization tank discussed earlier.

For augmentation case, addition of WP followed by UF+RO to the existing UASB+EA technology is obtained as the most suitable technology. The WWTT supplementation suggestions are not considered in this case due to strict TDS requirements, which was not considered in this study. Between the suggested new installation (A2O+UF+RO) and augmentation WWTT (UASB+EA+WP+UF+RO), the weighted cost for the supplementation case is lesser as new investments in only WP, UF and RO are required and hence more appropriate for application.

Case 2: Localized planning for non-potable reclaimed water demands in the vicinity of ASP-based Sajari (42 MLD) STP.

After applying the inputs and weights, based on required quality and least weighted cost, the following wastewater treatment technology combinations are suggested for non-potable reuse in Kanpur city (Table 4.11).

Table. 4.11. Appropriate WWTT combinations to satisfy non-potable reuse demand in the vicinity of Sajari STP (ASP, 42 MLD) in Kanpur city

Rank	WWTT Combinations	Weighted Cost (Rs in Cr)	Land (ha)	Energy (MWh per day)	Absolute capital cost (Rs in Cr)	Absolute O&M cost/yr (Rs in Cr)
New Installation						
1	BIOFOR-F + WP + C-F-RSF	88.24	7.70	24.50	200.57	11.02
2	A2O + UF + RO	89.42	7.35	23.10	219.38	9.76
3	SBR + UF + RO	118.07	6.65	33.60	335.36	7.52
Upgradation of Existing Technology*						
1	-		-	-	-	-
Supplementation of Existing Technology *						
1	ASP + SBT + WP	45.33	8.8	18.63	73.63	5.29

* Energy and O&M Cost both for existing and suggested WWTT are included

It can be observed that supplementation of existing ASP technology with SBT and WP is obtained as the most appropriate WWTT. The quality criteria for the reuse are so high that upgradation of technology with only emerging or tertiary technologies (within the resource-constraint scenario) cannot augment the existing ASP-based STP to produce satisfactory results.

4.5.1.7 Reclaimed Water Demand Allocation and Pricing

For case 1, we do not require to run the demand allocation procedure as the estimated demand for industrial cooling (70 MLD) is lower than the treatment capacity of Bingawan STP (210 MLD) and the entire demand can be satisfied. Also, the cost recovery will also be solely done by selling reclaimed water for industrial cooling in this scenario. Therefore, the average cost obtained using the break-even point will be levied.

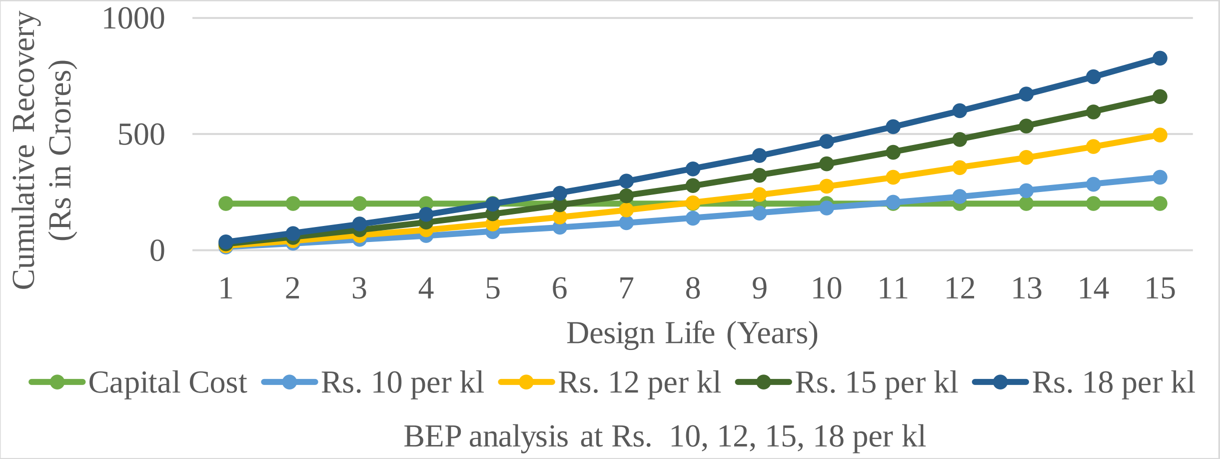


Fig. 4.8. BEP analysis for UASB + EA + WP + UF + RO at different reclaimed water prices for Bingawan STP

For the UASB + EA + WP + UF + RO technology combination, breakeven point analysis is done to obtain the minimum feasible average unit price of water. It can be seen in Figure 4.8 that as the average unit price of water is increasing, the recovery year is reducing. It is entirely a choice for the user to decide the recovery year. Here, to impose a sustainable price, 5th year is selected as the recovery year and accordingly a cost of Rs. 18 per kl will be levied.

For case 2, For the ASP + SBT + WP technology combination, breakeven point analysis is done to obtain the average unit price of water as shown in Figure 4.9.

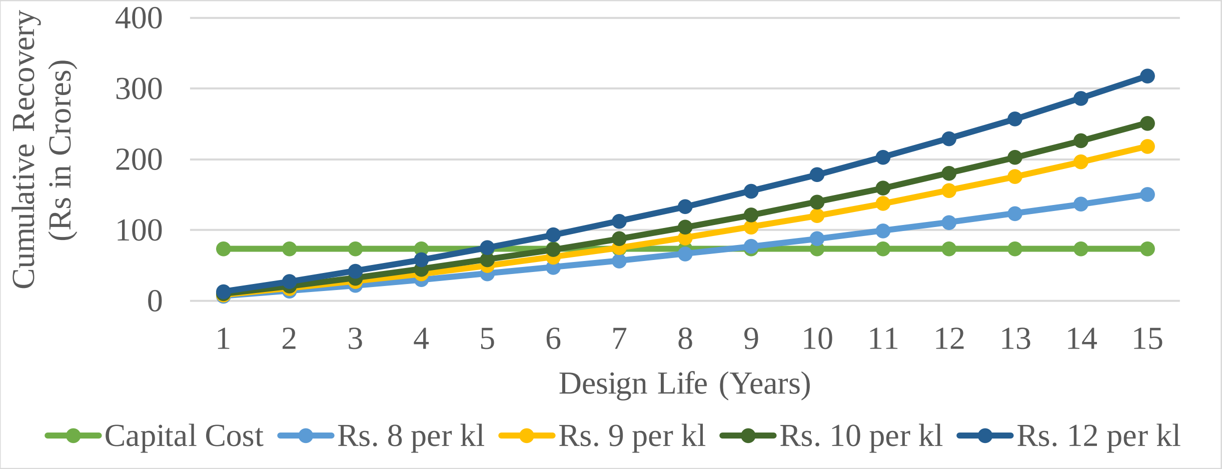


Fig. 4.9. BEP analysis for ASP + SBT + WP at different reclaimed water prices for Sajari STP

As defined in Table 4.8, a price ratio of 1:1:3:7 was selected for agriculture, public utilities, domestic demand, and commercial demand respectively. For recovery after the 5th year, a price of Rs. 12 per kl needs to be imposed on reclaimed water. Since total imposed demand is 73 MLD, prioritised allocation of available 42 MLD reclaimed water was made. The final demand allocated, the prices for all categories, the percentage of revenue generated from different sectors are as shown in Table 4.12.

Table 4.12. Final allocated demand and revenue generated for localised planning around Sajari STP

Appropriate Treatment Technology (ASP+SBT+WP)					
Minimum Feasible Average Price			**Rs. 12 per kl (5th year recovery)**		
Category	**Demand Allocated (MLD)**	**Demand Allocation (%)**	**Unit Price (Rs/kl)**	**Revenue (Rs in Cr / yr)**	**Revenue (%)**
Agriculture	1.0	5.95	3.25	0.12	0.65
Public Utilities	2.5	21.42	3.25	0.30	1.61
Domestic	29.5	70.23	9.75	10.50	57.10
Commercial	9.0	2.38	22.76	7.48	40.65
Total	**42.0**	**100.00**	**--**	**18.40**	**100.00**

4.5.1.8 Important Observations

The case study demonstrated the application of DSS_IWWM in Kanpur city. In the first case, 70 MLD of reclaimed water was required for industrial cooling process at Panki Thermal Power Station from the 210 MLD, UASB-based Bingawan STP and in the second case, non-potable reuses were identified in the vicinity of 42 MLD, ASP-based Sajari STP for localized planning around the STP.

It was observed that the major quality criteria difference between the two cases was requirement of lower concentration of fecal coliform in the reclaimed water for non-potable reuses than industrial cooling. For industrial cooling, TDS is also an important quality criterion, which was not considered in this study. The BOD, COD, TSS, TN, FC concentrations in municipal wastewater in the city are very high, indicating need for appropriate WWTTs. In Kanpur city, user had given maximum priority to land followed by capital cost, energy, and O&M cost and the same was reflected in the importance weightages obtained using FUCOM.

For industrial cooling, supplementation of UASB+EA based STP with SBR was obtained as the most appropriate WWTT based on least-weighted cost approach but since TDS plays a crucial role for industrial cooling, UASB + EA + WP + UF + RO was taken as the most appropriate technology. Therefore, results may vary based on the performance of technologies if more quality parameters are considered. While for localised planning around Sajari STP, supplementation of existing ASP technology with SBT and WP was obtained as the most appropriate. Here, a significant difference in the weighted cost values was observed between the new installation suggestion and supplementation suggestion, indicating the economic feasibility of not installing a new STP but supplementing the existing ASP-based STP. It can be concluded that conventional treatment technologies (ASP, UASB) cannot be used without augmentation or supplementation to obtain effluent for the mentioned reuse purposes.

For case 1: 70 MLD reclaimed water demand for industrial cooling around Bingawan STP

(UASB-based, 210 MLD), since the imposed demand is less than STP capacity, 100% allocation will be done for industrial cooling. For case 2: 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), a minimum allocation priority of 50% was defined for agriculture, public utilities, and domestic demand satisfaction. Following the socio-economic methodology, 2.5 ML.D (62.5% of initial demand), 9 MLD (100% of initial demand), 29.5 MLD (50% of initial demand) and 1 MLD (100% of initial demand) of reclaimed water was allocated to public utilities, commercial, domestic and agriculture demand respectively.

The minimum feasible average prices of reclaimed water for case 1 and case 2 were obtained as Rs. 18 per kl and Rs. 12 per kl respectively. Also, it was observed that as the average unit price of water is increased, the cost recovery year is reduced. As per the price ratio assigned by user for the second case, minimum unit price was imposed on agriculture and public utilities and maximum on commercial demand. However, maximum revenue was recovered from domestic demand due to high final demand and second-highest price (29.5 MLD, Rs. 10.50 Cr/yr), followed by commercial demand (9 MLD, Rs. 7.48 Cr/yr), public utilities (1 MLD, Rs. 0.30 Cr/yr) and agriculture (2.5 MLD, Rs. 0.12 Cr/yr). It can also be concluded that since the design period of STP is constant (15 years in this case), the incurred cost depends on the cost of the technology. If the capital and O&M costs are high, higher costs will be needed to be recovered in the design period, leading to higher prices.

4.5.2 Varanasi city

Varanasi city is situated on the left bank of the River Ganga in Uttar Pradesh (Figure 4.10). The main rivers flowing through the city are the Ganga, Varuna and the Assi river, which is now reduced to a few kilometers in length. The city has an area of 82.8 sq km (Varanasi, 2006). As per the 2011 census, the population in the city is 1.72 million. Ganga river and borewells are the main sources of water supplying about 330 MLD (Varanasi, 2015).

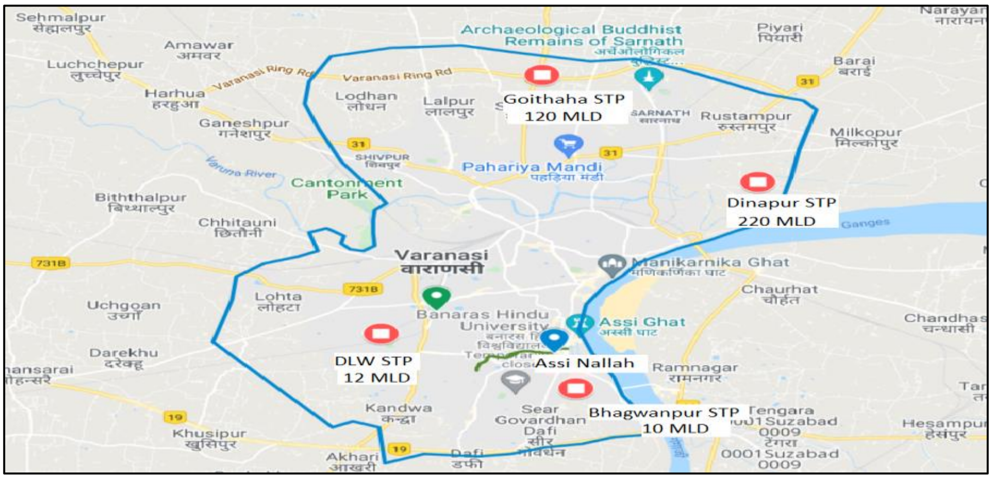


Fig. 4.10. Varanasi city and location of STPs

DLW, Bhagwanpur, Goithaha, Ramna, Ramnagar and Dinapur STPs are the six operational STPs, with a total capacity of 412 MLD and the utilized capacity of only 262 MLD (CPCB, 2021). The characteristics of the STPs are presented in Table 4.13. Only half of the wastewater generated is treated in STPs while the rest is released into drains leading to the rivers (Varanasi, 2015).

4.5.2.1 Identification of Potential Reuses

Out of the fourteen reuse applications considered in this study, Varanasi can use a significant amount of reclaimed wastewater for eight purposes such as toilet flushing (railway stations and locomotives, airport), construction activities, road cleaning, landscape development, vehicle washing including washing at railway stations and airports, fire protection, recreation, and environmental flow augmentation of river Assi or Varuna in the city zone.

To demonstrate the application of the DSS_IWWM, three different cases are presented in this case study.

Case 1: Reclaimed water requirement for railway washing at Varanasi railway station near existing ASP-based DLW STP (12 MLD).

Case 2: Reclaimed water requirement for e-flow augmentation of Assi river from under construction SBR-based Ramna STP (50 MLD).

Case 3: Localized planning for non-potable reclaimed water demands (road cleaning, toilet flushing, landscape, horticulture) in the vicinity of SBR-based Goithaha (120 MLD) STP.

4.5.2.2 Quality Criteria for Identified Reuses

For case 1 and case 2, vehicle washing, and e-flow augmentation (inland surface waters) are taken as the target reuse purpose respectively. The associated quality criteria are directly derived from the finalized quality criteria table. For case 3, which is localized planning around Goithaha STP for non-potable reuse (road cleaning, toilet flushing, landscape, horticulture), strictest quality parameter is taken following the equations:

The quality criteria (each parameter) for the multiple reuse scenario will be as described below:

$BOD = Min (BOD_{RC}, BOD_{TF}, BOD_{L}, BOD_{H}) = 10$ mg/l

$COD = Min (COD_{RC}, COD_{TF}, COD_{L}, COD_{H}) = 30$ mg/l

$TSS = Min (TSS_{RC}, TSS_{TF}, TSS_{L}, TSS_{H}) = 10$ mg/l

$TN = Min (TN_{RC}, TN_{TF}, TN_{L}, TN_{H}) = 10$ mg/l

$FC = Min (FC_{RC}, FC_{TF}, FC_{L}, FC_{H}) = 200$ MPN/l

Where, RC: Road Cleaning, TF: Toilet Flushing, L: Landscape, H: Horticulture.

The quality criteria for the three cases are defined in the input Table 4.16.

4.5.2.3 Importance Weightage for Decision Criteria

The priorities of the user in terms of resource availability are assessed and used for the evaluation of weights using FUCOM as shown in Table 4.14. The user was asked to rank the decision criteria based on importance and perform a pairwise comparison and rate each decision criterion in terms of significance for the previous criteria on a scale of 1 to 4, with 1 as the most important and 4 as the least important.

Table 4.13. Features of the operational STPs in Varanasi city (CPCB, 2021)

STP Location	Technology Used	Installed Capacity (MLD)	Utilised Capacity (MLD)	Compliance to disposal norms (CPHEEO, 2013)	Effluent use
1. Goithaha	SBR	120	30	Partial	Discharge in Sharda canal
2. Dinapur	ASP	220	165	Partial	Discharge in Varuna River
3. DLW	ASP	12	8	Partial	Discharge in Assi River
4. Bhagwanpur	ASP	9.8	9.8	Partial	Discharge in Ganga River
5. Ramna	SBR	50	50	Yes	Discharge in Ganga River
6. Ramnagar	A2O	10	10	Yes	Discharge in Ganga River

Table 4.14. Weight calculation for decision criteria using FUCOM for Varanasi city

Number of Criteria = 4	**Criterion 1**	**Criterion 2**	**Criterion 3**	**Criterion 4**
Names of Criteria	**Land**	**Energy**	**Capital Cost**	**O&M Cost**
Rank	1	3	2	4
Criteria (according to rank)	**Land**	**Capital Cost**	**Energy**	**O&M Cost**
Criteria comparisons	1	2	3	4
$\phi_{1/2}$	$\phi_{2/3}$	$\phi_{3/4}$	$\phi_{1/3}$	$\phi_{2/4}$
2.00	1.5	1.33	3.00	2.00
Weights	**Land**	**Capital Cost**	**Energy**	**O&M Cost**
	0.480	0.240	0.160	0.120

*Weights were obtained by using the above data and applying a linear programming model in equations (1) and (2) (Chapter 3).

4.5.2.4 Estimation of Reclaimed Water Demand

Case 1: Reclaimed water requirement for railway washing at Varanasi railway station near DLW STP (12 MLD, ASP-based)

As per Indian Railway Works Manual (IRWM, 2005), in a railway station, for apron and platform washing, 10 liter and 5 liter of water is required per sq m per day. For washing carriages on washing lines, 3600 litres and 2600 litres of water are required per carriage per day for broad gauge (BG) and meter gauge (MG) respectively. For cleaning of carriages on the platform 500 litre of water is required per carriage per day. For the Varanasi railway station, the total number of passengers is about 363000 per day. Also, the number of platforms is 9 of approximately 200 sq m area each. About 40 trains originate or terminate at this station and more than 250 trains stop at this station every day. For assessing non-potable reuse options around Varanasi, water demand from railways is considered from platform, apron and carriage washing works only. A probability of 0.57 is taken considering four washing days in a week.

Thus, Water Demand for washing operations in railways:

= (Water per carriage per day for BG/MG * number of trains terminating/originating* probability of washing)

+ (Water for cleaning carriage at platform *number of platforms * number of stopping trains * probability of washing)

+ (Number of platforms * average area of platform/apron * water required for platform and apron * probability of washing)

+ (Number of passengers * average water demand * probability of use)

= (3600* 40 *0.5 + 500* 9* 250 *0.7 +9*200*(10+5) *1 + 363000*45*0.6)

= 10.68 MLD

Therefore, for washing operations in railways, around 11 MLD water is required. Considering 20% losses, 20 MLD plant is considered enough to meet this water demand.

Case 2: Reclaimed water requirement for e-flow augmentation of Assi river from under construction SBR-based Ramna STP (50 MLD).

River Assi has taken the form of almost a nallah, which has flow of around 24 MLD of sewage discharge in its stream (Varanasi CDP, 2015). It has been thought that augmenting its flow using treated effluents from the nearby STP can lead to dilution of pollution and may revive the dying river. The quality criteria for e-flow augmentation are taken from CPHEEO manual which has defined quality standards for inland surface waters (CPHEEO, 2013). Therefore, considering loss of 20%, around 40 MLD of treated effluent water may be reused in augmenting flow suitable for e-flow (inland surface water) in the Assi catchment.

Case 3: Localized planning for non-potable reclaimed water demands (road cleaning, toilet flushing, landscape, horticulture) in the vicinity of SBR-based Goithaha (120 MLD) STP.

In this case, Goithaha STP (SBR-120 MLD) is selected as the target STP and the potential reuse purposes in the vicinity of this STP are identified as shown in Figure 4.11. Potential reclaimed water demands within a radius of maximum 6.33 km of the STP are considered so that the cost of laying pipes is minimised while most of the demands within the vicinity are served.

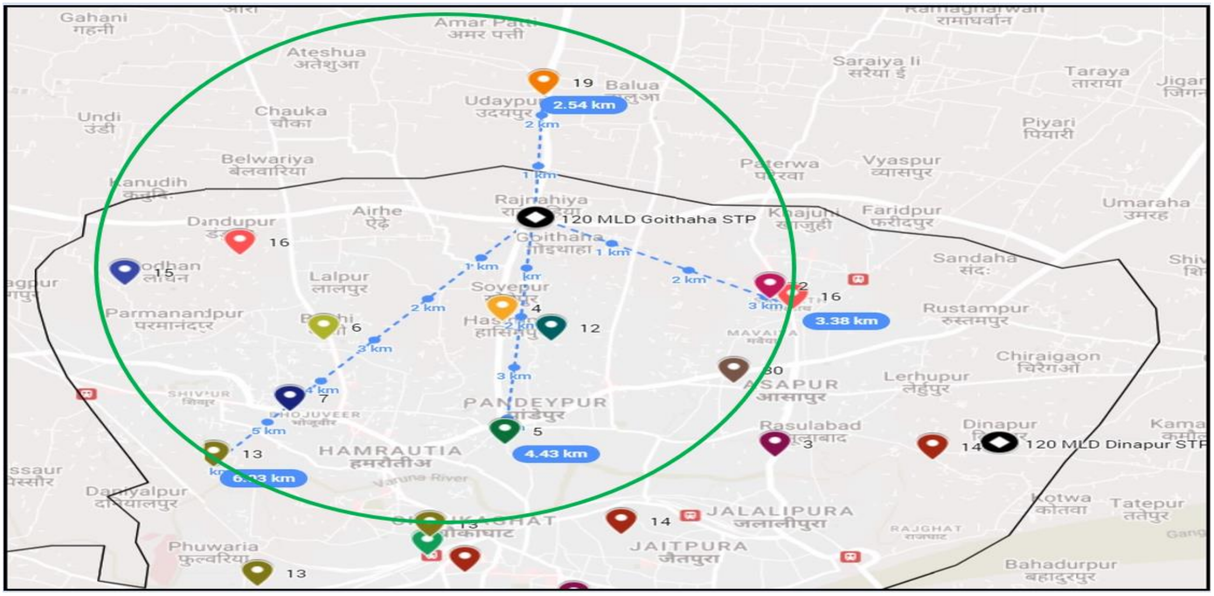


Fig. 4.11. Reuse purposes identified in the vicinity of Goithaha STP (120 MLD, SBR)

The identified demands are quantified using the formulas discussed in the methodology section. The demands are further classified into five categories based on end-users to socio-economically allocate demand and to levy proportional pricing on the categories. The demands identified are shown in Table. 4.15.

4.5.2.5 Identification of inputs for application in DSS_IWWM

The quality criteria, target reuses, land cost, electricity cost, obtained through primary surveys, raw wastewater characteristics and the target quality characteristics are also provided in Table 4.16.

4.5.2.6 Selection of Appropriate Treatment Technologies

Case 1: Reclaimed water requirement for railway washing at Varanasi railway station near existing ASP-based DLW STP (12 MLD).

After applying the required inputs and weights, based on required quality and least weighted cost, the following wastewater treatment technologies are suggested as shown in Table 4.17.

BIOFOR-F technology is obtained as the most appropriate technology for railway-related vehicle washing operations in Varanasi, followed by supplementation of ASP with SBT. The slight difference between their respective weighted costs is due to higher energy and O&M costs required for operation od ASP along with SBT technology.

Case 2: Reclaimed water requirement for e-flow augmentation of Assi river from under construction SBR-based Ramna STP (50 MLD).

Appropriate WWTTs combinations based on the least weighted cost for e-flow augmentation in Varanasi city are shown in Table 4.18.

For E-flow Augmentation, it is observed that the existing technology SBR in itself is capable of producing effluent satisfying the desired quality criteria. However, as per the suggestions by DSS_IWWM, it is the third most appropriate suggestion, with SBT being the most appropriate, followed by BIOFOR-F and SBR. Therefore, no modification in the existing SBR-based STP is required for e-flow augmentation of Assi river.

Case 3: Localized planning for non-potable reclaimed water demands in the vicinity of SBR-based Goithaha (120 MLD) STP.

Appropriate WWTTs combinations based on the least weighted cost for non-potable reuse in the vicinity of Goithaha STP in Varanasi city are shown in Table 4.19.

It is observed that upgrading the existing SBR technology with emerging technology Modified-Ludzack Ettinger (MLE) process is obtained as the most appropriate treatment technology combination while supplementing options are costlier than the upgrading option. The energy and the O&M cost obtained for this technology combination are inclusive of those required for the base technology while the land and the capital cost are exclusive of the same for the base technology.

Table 4.15. Demand estimation in the vicinity of Goithaha STP, categorization of reuses, price ratio and minimum demand allocation requirements in Varanasi city

Reuse Purpose	Place	Demand Calculation	Demand (MLD)	Category	Price Ratio	Minimum Allocation
RC	NH 28	7l * 4.5km*12m	4	Public Utilities	1	50%
RC	NH 31	7l * 13km*12m		Public Utilities		50%
RC	NH 44	7l * 5km*12m		Public Utilities		50%
TF	Hospitals	4*340l*40	15	Commercial	7	
TF	Hotels	5(180 rooms*150 l per room + 70*50 pool volume)		Commercial		
L+ TF	Resort 1	4L*200 sq m garden		Commercial		
L+ TF	Resort 2	4l * 250sq m garden		Commercial		
TF	Goithaha vicinity	0.39 *60 sq km *11000 people per sq km* 150 lpcd	60	Domestic	3	50%
Horticulture	Sarnath	10 l * 500sq m	2	Agriculture	1	50%
Total Demand			**81**			

Table 4.16. Inputs to DSS_IWWM for STPs in Varanasi city

Desired Reuse	Quantity (MLD)	Design Period (yr)	Land Cost (Rs/ha))	Electricity Cost (Rs/ kW-h)	Land (ha)	Energy (MWh)	Capital Cost (Rs)	O&M Cost (Rs)
Vehicle Washing	20	15	1.4 Cr	6.00	6	7	--	--
E-flow	40	15	1.4 Cr	6.00	8	15	--	--

Raw Wastewater Characteristics (CPCB, 2013)

Source	BOD (mg/l)	COD (mg/l)	TSS (mg/l)	TN (mg/l)	FC (MPN/l)
Municipal	101	289	198	12	1x 10^7

Desired Characteristics of Reclaimed Water

Reuse	BOD (mg/l)	COD (mg/l)	TSS (mg/l)	TN (mg/l)	FC (MPN/l)
VW	10	30	20	10	2000
E-flow	10	40	10	10	2300
RC+TF+L+H	10	30	10	10	200

Table 4.17. Appropriate WWTT combinations to satisfy railway washing demand in the vicinity of DLW STP (ASP, 12 MLD) in Varanasi city

Rank	**WWTT Combinations**	**Weighted Cost (Rs in Cr)**	**Land (ha)**	**Energy (MWh per day)**	**Absolute capital cost (Rs in Cr)**	**Absolute O&M cost/yr (Rs in Cr)**
New Installation						
1	BIOFOR-F	4.10	0.80	1.80	9.31	0.21
2	SBR	4.77	0.55	1.50	13.43	0.25
3	BIOFOR	6.71	0.40	2.77	13.07	1.02
Upgradation of Existing Technology*						
1	ASP + MF + RO	8.02	0.80	3.52	16.12	0.98
Supplementation of Existing Technology*						
1	ASP + SBT	4.53	0.30	3.23	7.16	0.50
2	ASP + BIOFOR-F	5.64	0.80	3.82	9.31	0.48
3	ASP + A2O	5.91	0.60	3.72	10.75	0.54

* Energy and O&M Cost both for existing and suggested WWTT are included

Table 4.18. Appropriate WWTT combinations to satisfy e-flow augmentation demand in the Assi River in the vicinity of Ramna STP (SBR, 50 MLD) in Varanasi city

Rank	WWTT Combinations	Weighted Cost (Rs in Cr)	Land (ha)	Energy (MWh per day)	Absolute capital cost (Rs in Cr)	Absolute O&M cost/yr (Rs in Cr)
New Installation						
1	SBT	19.84	2.2	6.0	53.72	1.28
2	BIOFOR-F	31.84	4.8	12.0	65.24	3.68
3	SBR	32.72	7.2	12.8	51.56	4.88

Table 4.19. Appropriate WWTT combinations to satisfy non-potable demand in the vicinity of Goithaha STP (SBR, 120 MLD) in Varanasi city

Rank	WWTT Combinations	Weighted Cost (Rs in Cr)	Land (ha)	Energy (MWh per day)	Absolute capital cost (Rs in Cr)	Absolute O&M cost/yr (Rs in Cr)
New Installation						
1	BIOFOR-F+WP	45.15	14.40	36.00	195.72	11.04
Upgradation of Existing Technology*						
1	SBR + MLE	38.86	4.8	32.40	72.00	11.04
Supplementation of Existing Technology*						
1	SBR + SBT	40.35	3.6	32.90	81.73	8.52
2	SBR + MBBR	44.47	7.2	34.24	85.92	8.48
3	SBR + BIOFOR-F	55.07	9.6	39.61	111.72	8.21

* Energy and O&M Cost both for existing and suggested WWTT are included

4.5.2.7 Reclaimed Water Demand Allocation and Pricing

For case 1, we do not require to run the demand allocation procedure as the estimated demand for railway washing (20 MLD) is higher than the treatment capacity of DLW STP (12 MLD) and hence, all the effluent from DLW STP will be sold to the Varanasi railway station. Also, the cost recovery will also be solely recovered from the Varanasi railway station. Therefore, for the appropriate suggestion of BIOFOR-F technology, the average cost based on suitable recovery year, obtained using the break-even point will be levied as shown in Figure 4.12.

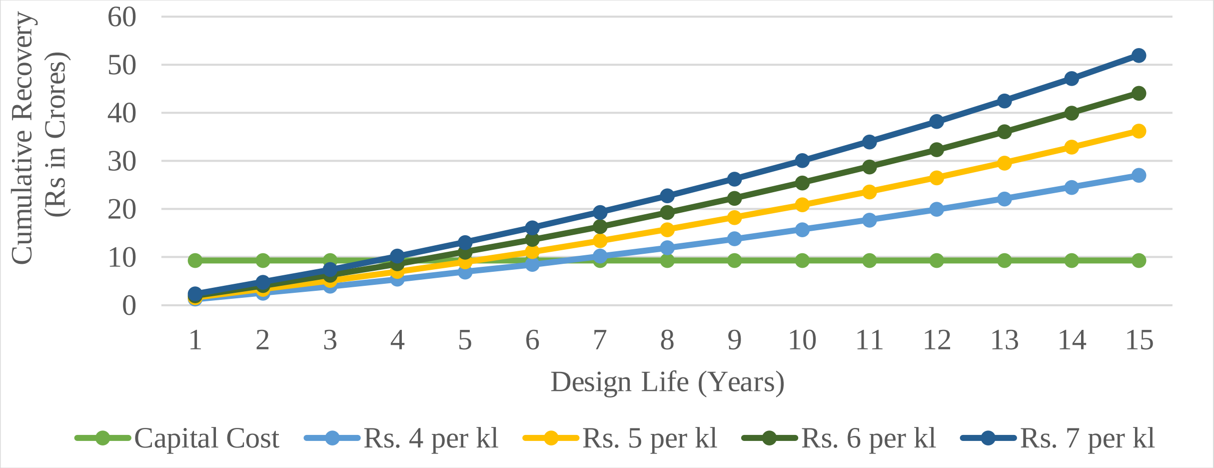


Fig. 4.12. BEP analysis for BIOFOR-F at different reclaimed water prices for DLW STP

For cost recovery post 5th year, minimum feasible average unit price of Rs. 5 per kl should be levied. It can be concluded that since the design period is constant, the treatment technology suggested is also comparatively lower, lower price would need to be imposed for recovery of cost.

For the second case, where SBR is suggested to produce reclaimed water suitable for e-flow augmentation, the breakeven point analysis is performed to obtain the average costs. Again, in this case demand allocation procedure is not required since STP capacity (50 MLD) is higher than imposed demand of 40 MLD. Therefore, reclaimed water will be allocated to the public utilities for satisfying e-flow augmentation demand. The breakeven graph based on the SBR technology's resource requirements, as shown in Figure 4.13.

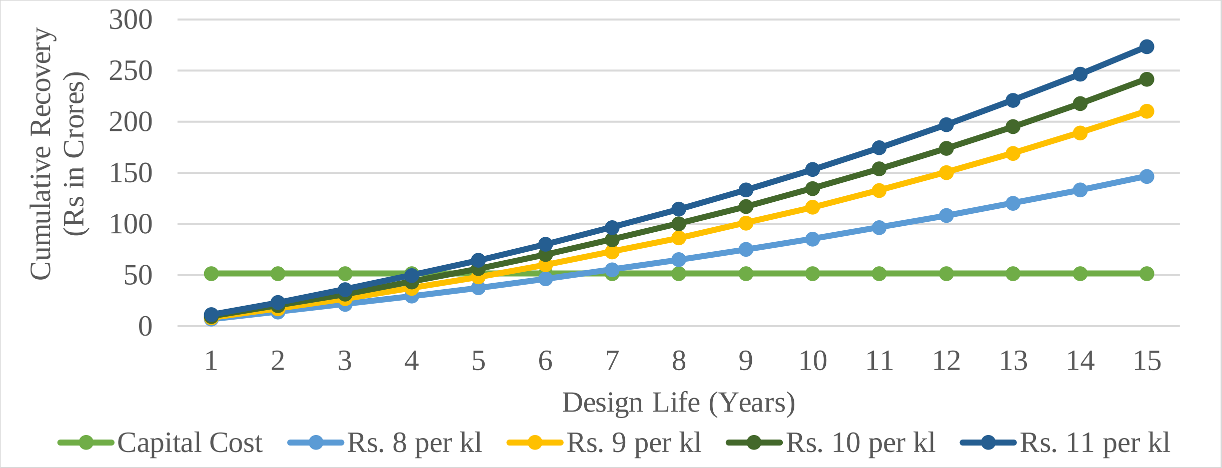


Fig. 4.13. BEP analysis for SBR at different reclaimed water prices for Ramna STP

If recovery cost is 5th year, minimum feasible average unit price of Rs. 9 per kl should be levied on the reclaimed water.

For case 3, where the reclaimed water is required for sa.tisfying the non-potable reuses in the vicinity of Goithaha STP (SBR, 120 MLD), the breakeven point analysis was performed to obtain suitable average price for SBR + MLE combination as shown in the Figure 4.14.

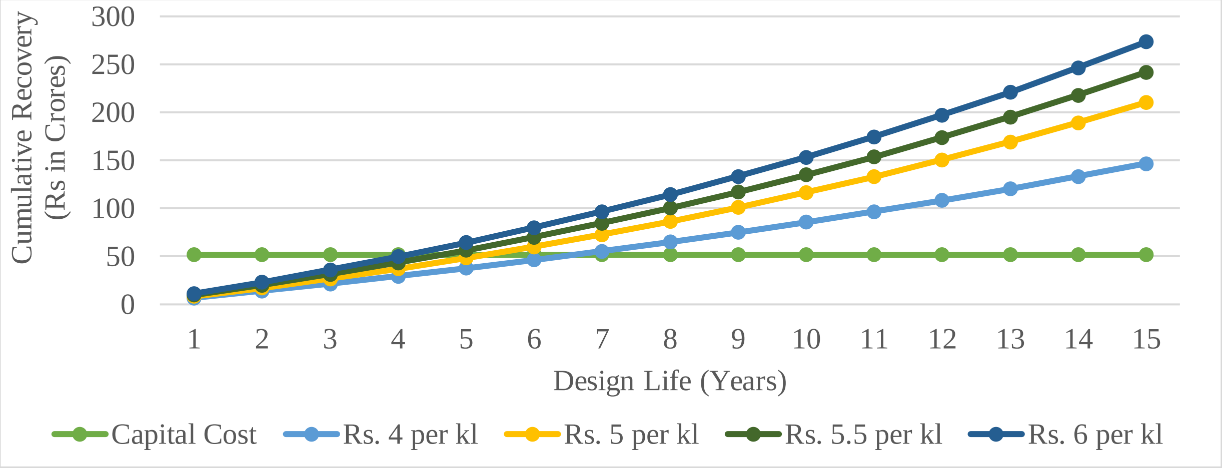


Fig. 4.14. BEP analysis for SBR+MLE at different reclaimed water prices for Goithaha STP

For recovery post 5th year, the average price of Rs. 5 kl will be proportionately shared between the four categories based on end-use classification. A minimum allocation of 50% for prioritized sectors and the price ratio for the same (1:1:3:7 for agriculture, public utilities, domestic, commercial) are shown in Table 4.15. Since total imposed demand is 81 MLD, while reclaimed water available is 120 MLD, 100% of initial demand will be satisfied. After running the DSS_IWWM, the following prices and final demand allocations are obtained for this case as shown in Table 4.20.

Table 4.20. Final allocated demand and revenue generated for localised planning around Goithaha STP

Appropriate Treatment Technology: SBR + MLE (120 MLD)					
Minimum Feasible Average Price			**Rs. 5 per kl (For 5th year recovery)**		
Category	**Demand Allocated (MLD)**	**Demand Allocation (%)**	**Unit Price (Rs/kl)**	**Annual Revenue (Rs in Cr/yr)**	**Revenue (%)**
Public Utilities	4	4.94	1.39	0.20	1.37
Commercial	15	18.52	9.74	5.33	36.08
Domestic	60	74.07	4.18	9.14	61.86
Agriculture	2	2.47	1.39	0.10	0.69
Total	**81**	**100.00**	**-**	**14.78**	**100.00**

It is observed that the highest price was imposed on the commercial sector. Since the domestic demand is very high, the revenue from the domestic sector is more. The costs levied on the agriculture sector and public utilities are lesser to reduce the burden of payment from low-income categories.

4.5.2.8 Important Observations

The case study demonstrated the application of DSS_IWWM in Varanasi city. The three cas.es of producing reclaimed water for railway washing from DLW STP, e-flow augmentation from Ramna STP and localized planning around Goithaha STP, present different scenarios of DSS_IWWM application.

In terms of quality, case 3 requiring satisfaction of community's non-potable reuse requirement posed the strictest quality criteria, followed by railway washing and finally e-flow augmentation. It is observed that the municipal wastewater quality characteristics in Varanasi are better than those for Kanpur city. In Varanasi, the decision criteria priority was land followed by capital cost, energy and O&M cost.

For case 1: 20 MLD for railway washing around DLW STP (ASP, 12 MLD), a new installation of BIOFOR-F technology was obtained as the most appropriate. The supplementation of ASP technology with SBT was ranked lower than BIOFOR-F due to higher land, energy and O&M cost requirements for the functioning of ASP+SBT than BIOFOR-F. For case 2: 40 MLD for e-flow augmentation of Assi river from Ramna STP (SBR, 50 MLD), SBR in itself was observed to be capable of satisfying the desired quality criteria. For case 3: 81 MLD non-potable reuse demand (road cleaning, toilet flushing, landscape, horticulture) around Goithaha STP (SBR, 120 MLD), upgrading existing SBR based STP with emerging technology MLE was obtained as the most appropriate WWTT. In this case, augmentation with emerging technology was ranked lowest in terms of weighted cost because the existing technology at the STP, itself is a high performing technology and just augmentation with MLE technology will enable the existing STP to satisfy the strictest quality criteria considered in the Varanasi city. Therefore, it can be concluded that when the existing STP is based on an advanced oxidation treated technology or a high performing technology, while the influent characteristics are in the range exhibited by Varanasi city, less extra expenditure will be required to produce reuse-focused effluent. However, in the case of existing technologies where conventional technologies were employed, even in case of less polluted influent, new installations or supplementation with another biological technology was seen.

For case 1 and case 2, 100% satisfaction of reclaimed water demand for railway washing and e-flow augmentation will be obtained as demands were less than STP capacity. For case 3, a minimum allocation priority of 50% was defined for agriculture, public utilities, and domestic demand satisfaction. Following the socio-economic methodology, 4 MLD (100% of initial demand), 15 MLD (100% of initial demand), 60 MLD (100% of initial demand) and 2 MLD (100% of initial demand) of reclaimed water was allocated to public utilities, commercial, domestic and agriculture demand respectively. The minimum feasible average prices of reclaimed water taken for the three cases were Rs. 5 per kl, Rs. 9 per kl and Rs. 5 per kl respectively. For case 3, as per the price ratio assigned by user (1:1:3:7 for agriculture: public utilities: domestic: commercial), minimum unit price was imposed on agriculture and public utilities and maximum on commercial demand. Maximum revenue recovery was seen from the second-highest priced sector, which is domestic demand as the allocated demand was the highest (Rs. 9.14 Cr/yr and 60 MLD) and minimum recovery from agriculture (Rs. 0.10 Cr/yr, 2 MLD).

4.5.3 Lucknow city

Lucknow city is one of the largest metropolitan cities of Uttar Pradesh. It is the state's capital city and has an area of 631 sq km. The city is divided into the Trans-Gomti and Cis-Gomti regions by the river Gomti that flows through the city (Lucknow, 2015). The population as per the 2011 census is 3.85 million. The geographical map of the city is as shown in Figure 4.15.

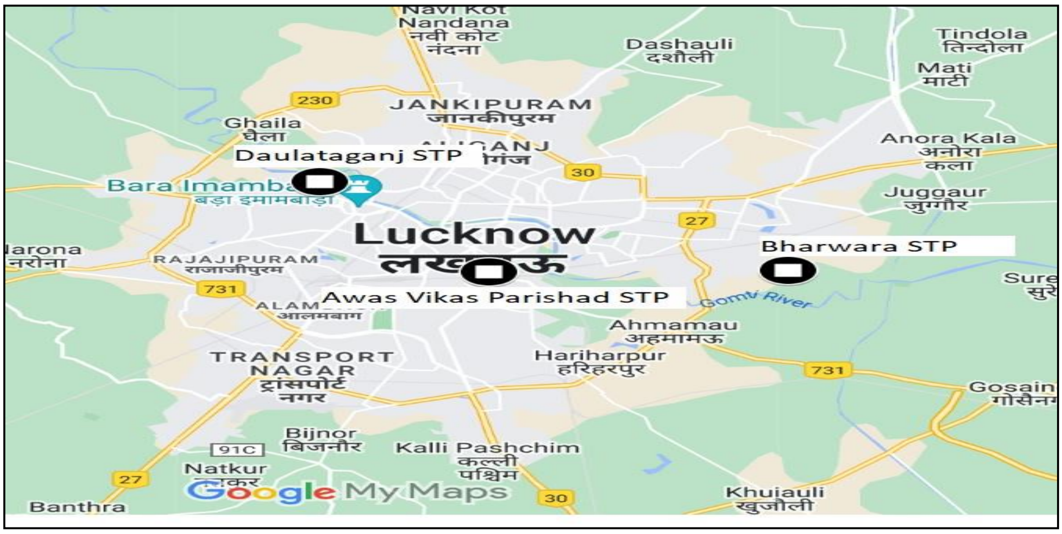


Fig. 4.15. Lucknow city and location of STPs

The ground water level in the city is declining rapidly due to higher exploitation than replenishment. Out of 490 MLD of total supply, fifty percent comes from groundwater and the rest from surface water (Lucknow, 2015). Four sewage treatment plants (STP) are in operation in Lucknow City with total treatment capacity of 473 MLD, out of which only 418 MLD capacity is utilized (CPCB, 2021). The details of treatment plants are shown in Table 4.21.

It is reported that the wastewater generated within the city is drained into River Gomti, causing extreme pollution in the river. The city's reliance on groundwater and high pollution in the river Gomti often leads to a state of crisis in the city. There is a high number of private tube wells in the city as well.

4.5.3.1 Identification of Potential Reuses

Out of the fourteen reuses, seven reuses: i. Toilet flushing, ii. Horticulture, iii. Vehicle washing, iv. Landscape, v. Road cleaning, vi. Laundry washing, vii. E-flow augmentation were identified in the city. In this case, we demonstrate the application of DSS_IWWM in the city of Lucknow for appropriate treatment technology selection for the Awas Vikas Parishad STP (SBR, 37.5 MLD) by identifying potential demands in STP's vicinity. The reclaimed water demands identified in the vicinity of the 37.5 MLD, Awas Vikas Parishad STP, within a radius of 6 km are presented in the Table 4.23.

4.5.3.2 Quality Criteria for Identified Reuses

For localized planning around Awas Vikas Parishad STP for non-potable reuse (landscape, e-flow augmentation, vehicle washing, toilet flushing, fire protection, laundry washing, road cleaning), strictest quality parameter was taken using the following equations:

The quality criteria for the multiple reuse scenario will be as described below:

$BOD = Min(BOD_{L}, BOD_{EF}, BOD_{VW}, BOD_{TF}, BOD_{F}, BOD_{LW}, BOD_{RC}) = 10$ mg/l

$COD = Min(COD_{L}, COD_{EF}, COD_{VW}, COD_{TF}, COD_{F}, COD_{LW}, COD_{RC}) = 30$ mg/l

$TSS = Min(TSS_{L}, TSS_{EF}, TSS_{VW}, TSS_{TF}, TSS_{F}, TSS_{LW}, TSS_{RC}) = 10$ mg/l

$TN = Min(TN_{L}, TN_{EF}, TN_{VW}, TN_{TF}, TN_{F}, TN_{LW}, TN_{RC}) = 10$ mg/l

$FC = Min(FC_{L}, FC_{EF}, FC_{VW}, FC_{TF}, FC_{F}, FC_{LW}, FC_{RC}) = 200$ MPN/l

Where, L: Landscape, EF: E-flow augmentation, VW: Vehicle Washing, TF: Toilet Flushing, F: Fire protection, LW: Laundry Washing, RC: Road Cleaning.

The quality criteria for the three cases are defined in the input Table 4.24.

4.5.3.3 Importance Weightage for Decision Criteria

The priorities of the user in terms of resource availability are assessed and used for the evaluation of weights using FUCOM as shown in Table 4.22. The user was asked to rank the decision criteria based on importance and perform a pairwise comparison and rate each decision criterion in terms of significance for the previous criteria on a scale of 1 to 4, with 1 as the most important and 4 as the least important.

4.5.3.4 Estimation of Reclaimed Water Demand

In this case, Awas Vikas Parishad STP (ASP-37 MLD) is selected as the target STP and the potential reuse purposes in the vicinity of this STP are identified (max radius 6 km) as shown in Figure 4.16.

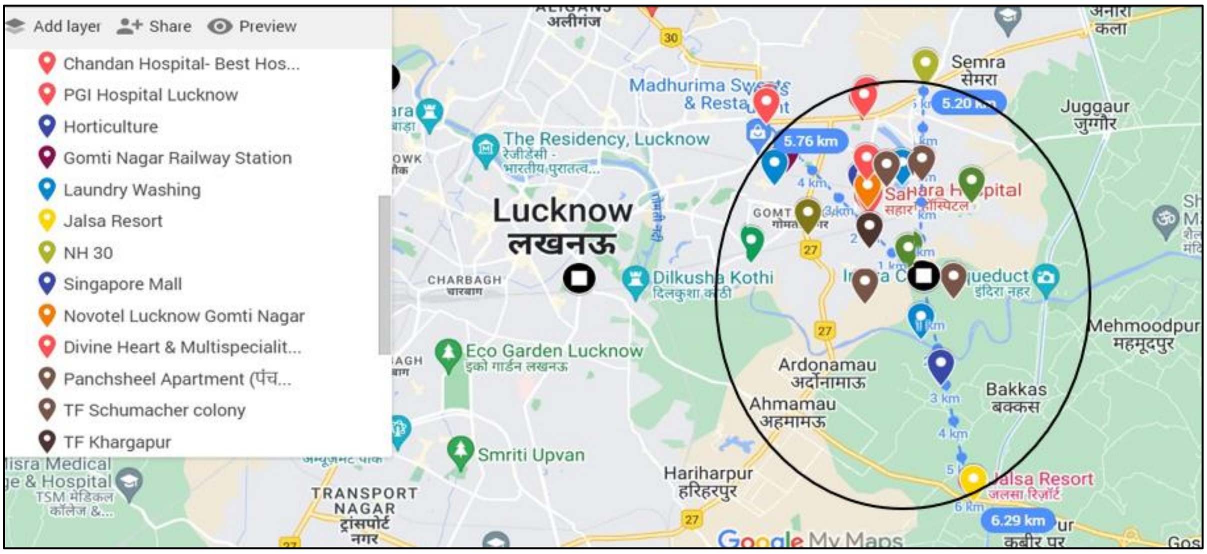


Fig. 4.16. Reuse purposes identified in the vicinity of the Awas Vikas Parishad STP (37.5 MLD, ASP)

The identified demands are quantified and further classified into five categories based on end-users to socio-economically allocate demand and to levy proportional pricing on the categories. The demands identified are shown in Table. 4.23.

Table 4.21. Features of operational STPs in the Lucknow city (CPCB, 2021)

STP Location	Technology Used	Installed Capacity (MLD)	Utilised Capacity (MLD)	Compliance to disposal norms (CPHEEO, 2013)	Effluent use
1. Bharwara	UASB	345	345	Yes	Discharge in Gomti River
2. Daulataganj	FAB	84	56	Partial	Discharge in Gomti River
3. Awas Vikas Parishad	SBR	37.5	12	Partial	Discharge in Gomti River
4. Awas Vikas Parishad	SBR	6.5	5	Partial	Discharge in Gomti River

Table 4.22. Weight calculation for decision criteria using FUCOM for Lucknow city

Names of Criteria	**Land**	**Energy**	**Capital Cost**	**O&M Cost**
Rank	4	3	1	2
Criteria (according to rank)	**Capital Cost**	**O&M Cost**	**Energy**	**Land**
Criteria comparisons	1	2	3	4
$\phi_{1/2}$	$\phi_{2/3}$	$\phi_{3/4}$	$\phi_{1/3}$	$\phi_{2/4}$
2.00	1.5	1.33	3.00	2.00
Weights	**Capital Cost**	**O&M Cost**	**Energy**	**Land**
	0.480	0.240	0.160	0.120

*Weights were obtained by using the above data and applying a linear programming model in equations (1) and (2) (Chapter 3).

Table 4.23. Demand estimation in the vicinity of Awas Vikas Parishad STP, categorization of reuses, price ratio and minimum demand allocation requirements in Lucknow city

Reuse Purpose	Place	Demand (MLD)	Category	Demand (MLD)	Price Ratio	Minimum Allocation
TF + LW + pool + G + R + VW + F	Jalsa Resort	2	Commercial	19	7	-
TF + LW + F	Sahara Hospital	1				
TF + LW + F	Nova College Of Pharmacy	1				
TF (staff + visitor)	Singapore Mall	1				
TF + LW+ F + G	Amity University	5				
TF + LW+ F	Chandan Hospital	1				
TF + LW+ F	PGI Hospital Lucknow	3				
TF + LW + pool + G + R + VW + F	Novotel Lucknow Gomti Nagar	3				
TF + LW+ F	Divine Heart Hospital	2				
TF + LW + pool + G + R + VW + F	Lonapur, Badhamau, Panchsheel colony, Khargapur	26	Domestic	26	4	50%
RC	NH 27	1	Public Utilities	10	2	50%
RC	NH 30	1				
Platform+ apron+ carriages+TF	Charbagh Railway Station	8				
Total Demand		**55**				

4.5.3.5 Identification of inputs for application in DSS_IWWM

The raw wastewater characteristics, the target quality characteristics, the priorities of the decision criteria for weight calculation using FUCOM method, the land cost and electricity cost, obtained through primary surveys are provided in the following Table 4.24.

Table 4.24. Inputs to DSS_IWWM for Awas Vikas Parishad STP in Lucknow city

<table>
<tr><td colspan="2">STP: Awas Vikas Parishad, Lucknow</td><td colspan="4">Capacity: 37.5 MLD</td><td colspan="3">Technology: SBR</td></tr>
<tr><td colspan="9">Raw Water Characteristics (CPCB, 2013)</td></tr>
<tr><td>Source</td><td>BOD (mg/l)</td><td colspan="2">COD (mg/l)</td><td colspan="2">TSS (mg/l)</td><td colspan="2">TN (mg/l)</td><td>FC (MPN/l)</td></tr>
<tr><td>Municipal</td><td>122</td><td colspan="2">515</td><td colspan="2">260</td><td colspan="2">18</td><td>5.49×10^7</td></tr>
<tr><td colspan="9">Local Resource Scenario (Primary Data)</td></tr>
<tr><td>Desired Reuse</td><td rowspan="2">Design Period (yr)</td><td rowspan="2">Land Cost (Rs/ha)</td><td colspan="2" rowspan="2">Electricity Cost (Rs per KW-h)</td><td rowspan="2">Land (ha)</td><td rowspan="2">Energy (MWh)</td><td rowspan="2">Capital Cost (Rs)</td><td rowspan="2">O&M Cost (Rs)</td></tr>
<tr><td rowspan="2">L, E-flow, VW, TF, Fire, LW, RC</td></tr>
<tr><td>15</td><td>2.5 Cr</td><td colspan="2">6.00</td><td>8</td><td>15.0</td><td>--</td><td>--</td></tr>
<tr><td colspan="5">Decision Criteria Preference</td><td>4</td><td>3</td><td>1</td><td>2</td></tr>
<tr><td colspan="9">Desired Characteristics of Reclaimed Water</td></tr>
<tr><td>Desired Reuse</td><td>BOD (mg/l)</td><td colspan="2">COD (mg/l)</td><td colspan="2">TSS (mg/l)</td><td colspan="2">TN (mg/l)</td><td>FC (MPN/l)</td></tr>
<tr><td>L + Eflow + VW + TF + F+ LW + RC</td><td>10</td><td colspan="2">30</td><td colspan="2">10</td><td colspan="2">10</td><td>200</td></tr>
</table>

* Due to absence of quality standards for COD parameters, a BOD/COD ratio of 0.3 is considered for the treated effluent in model application.

4.5.3.6 Selection of Appropriate Treatment Technologies

After applying the inputs and respective weights, based on required quality and least weighted cost, the following wastewater treatment technology combinations are suggested for non-potable reuse in the given case (Table 4.25).

Table 4.25. Appropriate WWTT combinations to satisfy non-potable demand in the vicinity of Awas Vikas Parishad STP (SBR-Based, 37.5 MLD) in Lucknow city

Rank	WWTT Combinations	Weighted Cost (Rs in Cr)	Land (ha)	Energy (MWh per day)	Absolute capital cost (Rs in Cr)	Absolute O&M cost/yr (Rs in Cr)
New Installation						
1	**BIOFOR-F + UF + RO**	77.13	4.94	13.68	103.44	5.28
2	**A2O + UF + RO**	82.01	4.18	13.30	108.91	5.97
3	**SBR + UF + RO**	83.96	3.99	12.54	119.09	5.28
Upgradation of Existing Technology*						
1	**SBR + UF + RO**	58.23	1.90	12.54	68.06	5.28
Supplementation of Existing Technology *						
1	**SBR + SBT**	25.29	2.28	10.66	27.21	1.65
2	**SBR + MBBR**	30.16	3.04	12.37	35.38	1.60

* Energy and O&M Cost both for existing and suggested WWTT are included

It can be observed that BIOFOR-F in combination with ultrafiltration and reverse osmosis process is suggested as the most appropriate treatment technology combination for new installation. However, for upgrading the existing SBR-based technology to produce the effluent of the same quality, addition of ultrafiltration and reverse osmosis technologies is suggested. It can be seen that supplementing SBR technology with SBT technology has obtained the least weighted cost, hence, the most appropriate suggestion is supplementing with SBT. A significant difference between the weighted costs can be seen between the different types of suggestions.

4.5.3.7 Reclaimed Water Demand Allocation and Pricing

The total demand identified is of 55 MLD while the capacity of the STP is 37.5 MLD. Three different categories of demands are identified such as, commercial, domestic, and public utilities categories. In this case, a minimum allocation percentage of 60% is taken while the price ratio for the three categories: commercial: domestic: public utilities is taken in the ratio 7:4:2 respectively. Breakeven point analysis is performed on all three technology combinations obtained in the different categories of technology suggestions as shown in Figure 4.17.

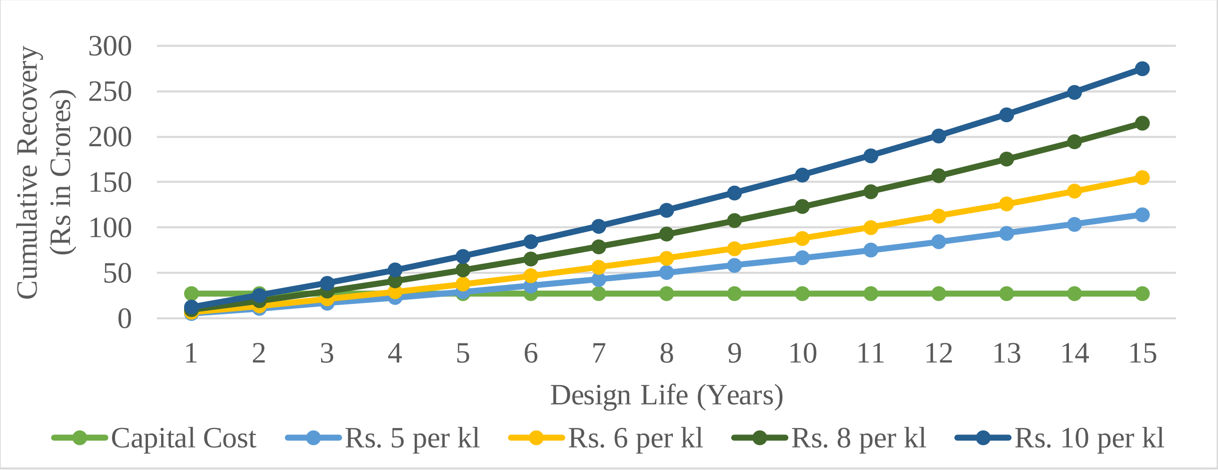


Fig. 4.17. BEP analysis for SBR+SBT at different reclaimed water prices for Awas Vikas Parishad STP

It can be seen that as the cost of technology increases, the minimum feasible average unit price of reclaimed water also increases. Here, since SBR supplemented by SBT is obtained as the most appropriate solution due to its least weighted cost, the average price obtained for the supplementation scenario is considered for obtaining the final pricing for all the identified categories as shown in Table 4.26.

Minimum feasible average price of Rs. 5 per kl needs to be levied on reclaimed water sale to recover cost after 5th year.

Table 4.26. Final allocated demand and revenue generated for localised planning around Awas Vikas Parishad STP

Appropriate Treatment Technology: SBR + SBT (37 MLD)					
Minimum Feasible Average Price			**Rs. 5 per kl (For 5th year recovery)**		
Category	**Demand Allocated (MLD)**	**Demand Allocation (%)**	**Unit Price (Rs/kl)**	**Annual Revenue (Rs in Cr/yr)**	**Revenue (%)**
Public Utilities	6	16.22	2.04	0.45	6.63%
Domestic Demand	16	43.24	4.09	2.39	35.36%
Commercial Demand	15	40.54	7.15	3.92	58.01%
Total	**37**	**100.00**	**-**	**6.75**	**100.00**

In the above table, the final demand allocated and the prices for different demands are represented categorically. It is observed that using the socio-economic approach for demand allocation and proportional pricing approach for reducing cost burden from general public is beneficial in satisfying prioritised needs and shifting the cost burden. In this case, almost same allocation (about 40%) is obtained for domestic and commercial demands while significant difference in revenue from the two categories can be seen. Overall, the costs are recovered, but the high-income categories are exposed more to higher costs, this approach will also lead to prevention of wasteful use of water.

4.5.3.8 Important Observations

The case study demonstrated the application of DSS_IWWM in Lucknow city for localized planning for non-potable reuse (landscape, e-flow augmentation, vehicle washing, toilet flushing, fire protection, laundry washing, road cleaning), in the vicinity of Awas Vikas Parishad

STP (SBR-based, 37.5 MLD). The municipal wastewater in Lucknow has quality characteristics better than Kanpur but worse than Varanasi city. In Lucknow, the taken decision criteria priority was capital cost followed by O&M cost, land and energy.

For producing reclaimed water suitable for non-potable reuse purposes identified in the vicinity of Awas Vikas Parishad STP, supplementation of existing SBR technology with SBT was obtained as the most appropriate treatment technology. It was obtained so, as high performing SBT technology was already installed, and major land and capital cost expenditure required for its installation will be saved and only those for SBT and operational expenditure of both the technologies (SBR and SBT) will now be considered. Therefore, it can be concluded that when the existing STP is based on an advanced oxidation treated technology or a high performing technology, while the influent quality characteristics are in the lower range, less extra expenditure will be required to produce reuse-focused effluent. However, in the case of existing technologies where conventional technologies are employed, even in case of less polluted influent, new installations or supplementation with another biological technology was seen.

A minimum allocation priority of 60% was defined for public utilities, and domestic demand satisfaction. Following the socio-economic methodology, 6 MLD (60% of initial demand), 16 MLD (62% of initial demand), and 15 MLD (79% of initial demand) of reclaimed water was allocated to public utilities, domestic, commercial demand respectively. The minimum feasible average price of reclaimed water obtained was Rs. 5 per kl for the selected appropriate WWTT. It was observed that new installation and augmentation cases required would require higher average prices for cost recovery due to higher associated costs. This means that supplementation of high performing existing technology can save significant costs by avoiding the use of costlier technology combinations and DSS_IWWM puts forth all options so that the user can better assess the economic and resource feasibilities.

As per the price ratio assigned (2:4:7 for public utilities: domestic demand: commercial demand), minimum unit price was imposed on public utilities and maximum on commercial demand. Maximum revenue recovery was seen from the highest priced sector, which is commercial demand with second-highest demand allocated (Rs. 3.92 Cr/yr and 15 MLD) and second-highest recovery was seen from domestic sector (Rs. 2.39 Cr/yr and 16 MLD).

4.5.4 Prayagraj city

Prayagraj is a metropolis in the state of Uttar Pradesh. It is the state's judicial capital. The rivers Yamuna, Ganga and Saraswati form the Triveni Sangam in the city. It has a metropolitan area of over 403 sq km. The city has a population of 1.37 million with a population density of 4200 per sq km (Allahabad, 2022).

The location of the city is shown in Figure 4.18.

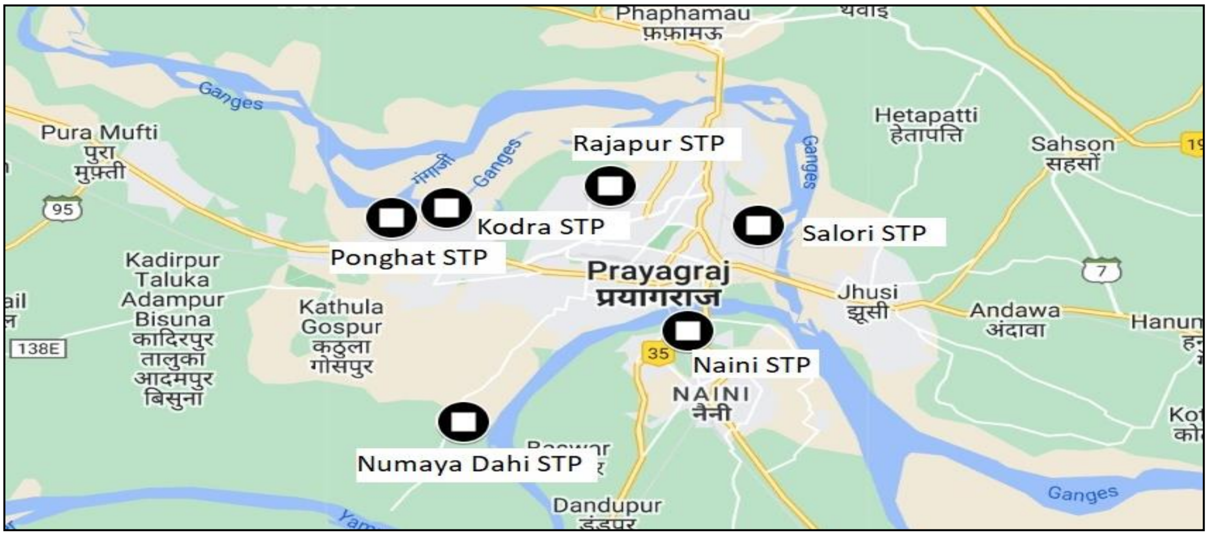


Fig. 4.18. Prayagraj city and location of STPs

The surface water and groundwater sources form the major portion of water supply, that is, 240 MLD. Seven sewerage treatment plants (STP) are in operation in the city with total treatment capacity of 268 MLD, out of which 263 MLD capacity is utilized. The details of treatment plants are shown in Table 4.27.

About 45% of the city is connected to a sewage collection system (Allahabad, 2014). The water tariff varies between domestic and non-domestic users. In this case, we demonstrate the application of DSS_IWWM in the city of Prayagraj by considering appropriate WWTT selection for the Naini STP (ASP, 80 MLD) for the potential demands in STP's vicinity.

4.5.4.1 Identification of Potential Reuses

Out of the fourteen reuses, Six Reuses: i. Toilet flushing, ii. Vehicle washing, iii. Landscape, iv. Irrigation, v. Laundry washing, vi. Road cleaning, vii. Outdoor bathing is identified. Multiple reuse purposes identified in the vicinity of the STP within a radius of maximum 7 km as shown in Figure 52.

4.5.4.2 Quality Criteria for Identified Reuses

For localized planning around Naini STP for non-potable reuse (landscape, toilet flushing, irrigation, outdoor bathing, vehicle washing, road cleaning), strictest quality parameter was taken using the following equations:

$BOD = Min (BOD_L, BOD_{TF}, BOD_I, BOD_{OB}, BOD_{VW}, BOD_{RC}) = 3$ mg/l

$COD = Min (COD_L, COD_{TF}, COD_I, COD_{OB}, COD_{VW}, COD_{RC}) = 10$ mg/l

$TSS = Min (TSS_L, TSS_{TF}, TSS_I, TSS_{OB}, TSS_{VW}, TSS_{RC}) = 10$ mg/l

$TN = Min (TN_L, TN_{TF}, TN_I, TN_{OB}, TN_{VW}, TN_{RC}) = 10$ mg/l

$FC = Min (FC_L, FC_{TF}, FC_I, FC_{OB}, FC_{VW}, FC_{RC}) = 200$ MPN/l

Where, L: Landscape, TF: Toilet Flushing, I: Irrigation, OB: Outdoor Bathing, VW: Vehicle Washing, RC: Road Cleaning. The quality criteria are defined in the input Table 4.30.

4.5.4.3 Importance Weightage for Decision Criteria

The priorities of the user in terms of resource availability are assessed and used for the evaluation of weights using FUCOM as shown in Table 4.28.

Table 4.27. Features of operational STPs in the Prayagraj city (CPCB, 2021)

STP Location	Technology Used	Installed Capacity (MLD)	Utilised Capacity (MLD)	Compliance to disposal norms (CPHEEO, 2013)	Effluent use
1. Salori	FAB	29	26	Yes	Discharge in Ganga River
2. Salori	SBR	14	16	Yes	
3. Naini	ASP	80	60	Yes	Discharge in Yamuna River
4. Rajapur	UASB	60	79	Yes	Discharge in Ganga River
5. Ponghat	UASB	10	7	Yes	Discharge in Ganga River
6. Numayadahi	ASP	50	50	Yes	Discharge in Yamuna River
7. Kodra	UASB	25	25	Yes	Discharge in Ganga River

Table 4.28. Weight calculation for decision criteria using FUCOM for Prayagraj city

Names of Criteria	**Land**	**Energy**	**Capital Cost**	**O&M Cost**
Rank	4	1	2	3
Criteria (according to rank)	**Energy**	**Capital Cost**	**O&M Cost**	**Land**
Criteria comparisons	1	2	3	4
$\phi_{1/2}$	$\phi_{2/3}$	$\phi_{3/4}$	$\phi_{1/3}$	$\phi_{2/4}$
2.00	1.5	1.33	3.00	2.00
Weights	**Energy**	**Capital Cost**	**O&M Cost**	**Land**
	0.480	0.240	0.160	0.120

*Weights were obtained by using the above data and applying a linear programming model in equations (1) and (2) (Chapter 3).

4.5.4.4 Estimation of Reclaimed Water Demand

In this case, Naini STP (ASP-80 MLD) is selected as the target STP and the potential reuse purposes in the vicinity of this STP are identified as shown in Figure 4.19. Potential reclaimed water demands within a radius of maximum 6.29 km of the STP are considered so that the cost of laying pipes is minimised while most of the demands within the vicinity are served.

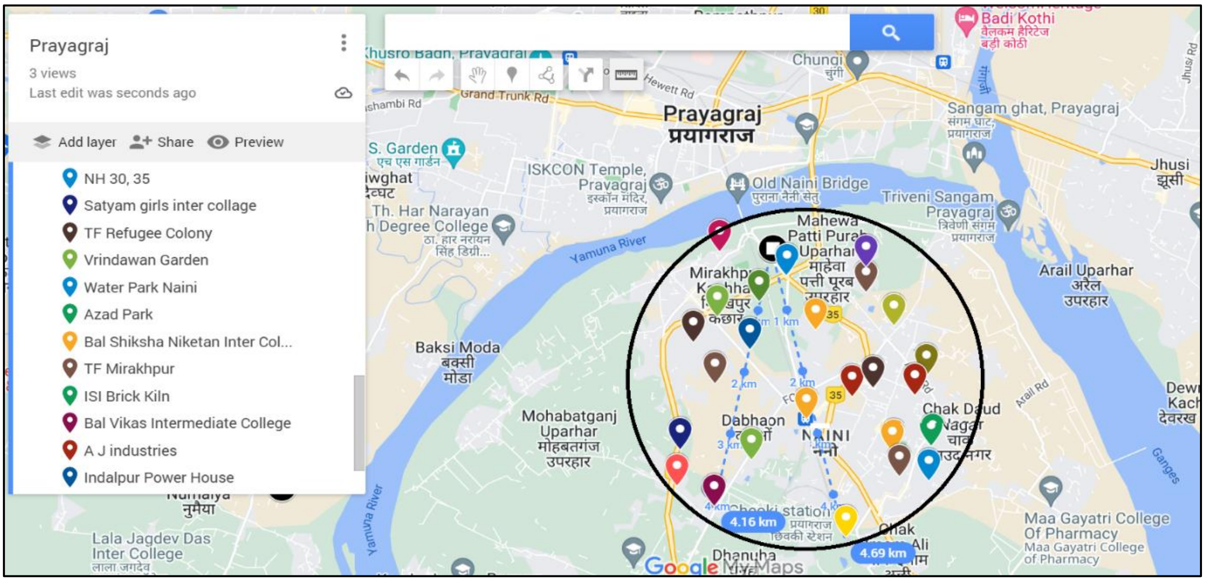


Fig. 4.19. Reuse purposes identified in the vicinity of the Naini STP (ASP, 80 MLD)

The identified demands are quantified using the formulas discussed in the methodology section. The demands are further classified into five categories based on end-users to socio-economically allocate demand and to levy proportional pricing on the categories (agriculture : public utilities : domestic demand : industrial demand : commercial demand :: 1:2:3:5:7. The area covered in the vicinity of the Naini STP is 21.6 sq km area. Six types of reuses are identified in the vicinity such as: toilet flushing, road cleaning, outdoor bathing, horticulture, laundry washing and vehicle washing. A minimum allocation of 70% was defined for the demand allocation. The identified reuses, estimated demands, categorization of demand, price ratio and minimum allocation requirements are presented in Table 4.29.

4.5.4.5 Identification of Inputs for DSS_IWWM

The raw wastewater characteristics, the target quality characteristics, the priorities of the decision criteria for weight calculation using FUCOM method, the land cost and electricity cost, obtained through primary surveys are provided in the following Table 4.30.

4.5.4.6 Selection of Appropriate Treatment Technologies

It can be observed that BIOFOR-F in combination with microfiltration and reverse osmosis processes is obtained for new installation. While to upgrade the existing ASP-based STP, nutrient removing technology wuhrmann process along with ultrafiltration and reverse osmosis is suggested. The most appropriate treatment technology as per the least-weighted cost approach is supplementation of the ASP-based STP with secondary treatment technology SBT along with tertiary treatment technology combination of coagulation, flocculation and rapid sand filtration (C+F+RSF). Suggestion of such combinations indicate the high effluent quality required for the identified reuse purposes. Supplementation of existing technology in this case would lead to substantial reduction in new capital cost investment while the operating costs remain higher than that suggested for new installation. Overall, the supplementation of existing technology would be a better choice to produce the effluent of the required quality in the present scenario. The reclaimed water demand identified in the vicinity of the 80 MLD, Naini STP is presented in the Table 4.31.

Table 4.29. Demand estimation in the vicinity of Naini STP, categorization of reuses, price ratio and minimum demand allocation requirements in Prayagraj city

Reuse Purpose	Place	Demand (MLD)	Category	Demand (MLD)	Price Ratio	Minimum Allocation
Outdoor Bathing	Water Park Naini	3	Agricultural	7	1	70%
Horticulture	Vrindawan Garden	2				
Horticulture	Azad Park	2				
TF + LW	Adarsh Siksha Niketan Inter College	3	Commercial	23	7	
TF + LW	Dr. Murali Manohar Joshi Inter College	3				
TF + LW	SHUATS Main Campus	4				
Horticulture	SHUATES agriculture fields	2				
TF	Cotton Mill	3				
TF + LW	Bal Shiksha Niketan Inter College	2				
TF + LW	Hospital	3				
TF	Indalpur College	3				
TF	TF Naini	26	Domestic	27	3	70%

TF + LW	Allahabad Agricultural Institute Intermediate College					
TF + LW	Citizen Girls college					
TF	TF Gangotri Nagar					
TF + LW	Satyam girls inter collage					
TF	TF Refugee Colony					
TF	TF Mirakhpur					
TF + LW	Bal Vikas Intermediate College					
RC	Brick kiln	1	Industrial	8	5	
RC	ISI Brick Kiln	4				
TF	AJ industries	3				
VW + TF	Cheoki station	3	Public Utilities	22	2	70%
TF + LW	Government Hospital	5				
VW + TF	Naini Junction	7				
TF + LW	Naini Central Jail	4				
RC	NH 30	3				
Total Demand		**87**				

Table 4.30. Inputs to DSS_IWWM for Naini STP in Prayagraj city

<table>
<tr><th colspan="3">STP: Naini, Prayagraj, UP</th><th colspan="4">Capacity: 80 MLD</th><th colspan="3">Technology: ASP</th></tr>
<tr><th colspan="10">Raw Water Characteristics</th></tr>
<tr><th>Source</th><th colspan="2">BOD (mg/l)</th><th>COD (mg/l)</th><th colspan="3">TSS (mg/l)</th><th colspan="2">TN (mg/l)</th><th>FC (MPN/l)</th></tr>
<tr><td>Municipal</td><td colspan="2">86</td><td>176</td><td colspan="3">147</td><td colspan="2">16</td><td>9.4 x 10^7</td></tr>
<tr><th colspan="10">Local Resource Scenario (Primary Data)</th></tr>
<tr><th colspan="2">Desired Reuse</th><th rowspan="2">Design Period (years)</th><th colspan="2" rowspan="2">Land Cost (Rupees per hectare)</th><th rowspan="2">Electricity Cost (Rupees per KW-h)</th><th rowspan="2">Land (ha)</th><th rowspan="2">Energy (MWh)</th><th rowspan="2">Capital Cost (Rupees)</th><th rowspan="2">O&M Cost (Rupees)</th></tr>
<tr><td colspan="2" rowspan="2">Landscape, Toilet Flushing, Horticulture, Outdoor Bathing, Vehicle Washing, Road Cleaning</td></tr>
<tr><td>15</td><td colspan="2">1.1 Crore</td><td>6.00</td><td>15</td><td>30.0</td><td>--</td><td>--</td></tr>
<tr><th colspan="6">Decision Criteria Preference</th><th>4</th><th>1</th><th>2</th><th>3</th></tr>
<tr><th colspan="10">Desired Characteristics of Reclaimed Water</th></tr>
<tr><th>Desired Reuse</th><th colspan="2">BOD (mg/l)</th><th>COD (mg/l)</th><th colspan="3">TSS (mg/l)</th><th colspan="2">TN (mg/l)</th><th>FC (MPN/l)</th></tr>
<tr><td>Quality Criteria</td><td colspan="2">3</td><td>10</td><td colspan="3">10</td><td colspan="2">10</td><td>200</td></tr>
</table>

* Due to absence of quality standards for COD parameters, a BOD/COD ratio of 0.3 is considered for the treated effluent in model application.

After applying the inputs and respective weights, based on required quality. and least weighted cost, the following wastewater treatment technology combinations are suggested for the identified reuse purposes as shown in Table 4.31.

Table 4.31. Appropriate WWTT combinations to satisfy non-potable demand in the vicinity of Naini STP (ASP, 80 MLD) in Prayagraj city

Rank	Technology Combination	Weighted Cost (crore Rupees)	Land (ha)	Energy (MWh per day)	Capital Cost (Rupees in Crore)	O&M Cost (Rupees in Crore)
New Installation						
1	**BIOFOR-F + MF + RO**	118.83	12.8	26.4	203.44	11.12
2	**A2O + MF + RO**	123.58	11.2	25.6	214.96	12.56
3	**SBR + UF + RO**	126.76	10.8	24.4	250.72	11.12
Upgradation of Existing Technology*						
1	**ASP + WP + UF + RO**	124.44	7.2	24.0	199.28	15.76
Supplementation of Existing Technology*						
1	**ASP + SBT + C + F + RSF**	110.41	10.4	37.08	85.92	12.48
2	**ASP + BIOFOR-F + C + F + RSF**	121.74	14.4	41.80	103.12	12.16

* Energy and O&M Cost both for existing and suggested WWTT are included

4.5.4.7 Reclaimed Water Demand Allocation and Pricing

The identified demand in the vicinity of the STP is 87 MLD while the STP capacity is 80 MLD. The minimum allocation prioritisation in this case is 70%, that is a minimum of 70% of demand imposed by prioritised categories should be satisfied before allocating reclaimed water for non-prioritised categories. The breakeven point analysis is done for most appropriate suggestion as shown in Figure 4.20.

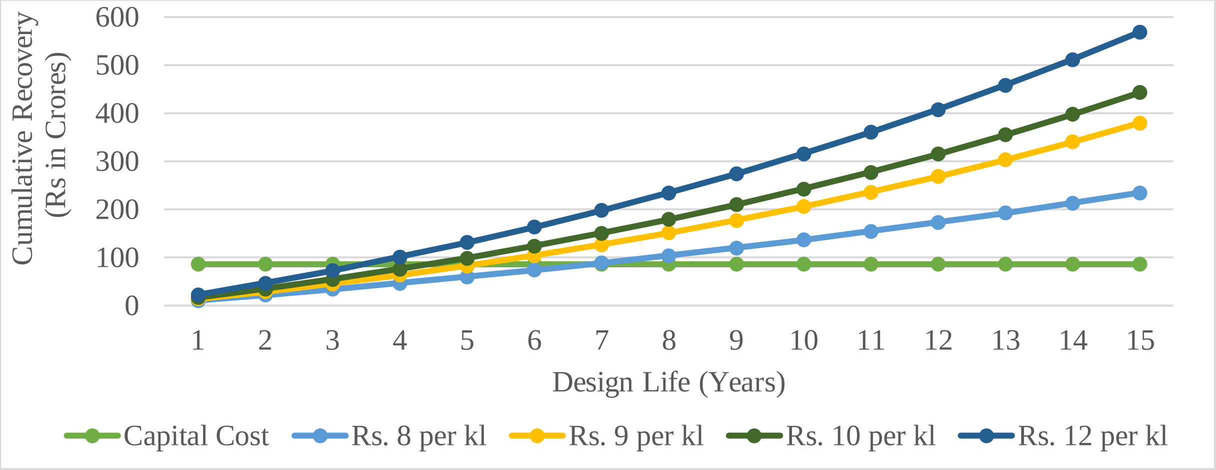


Fig. 4.20. BEP analysis for ASP+SBT+C-F-RSF at different reclaimed water prices for Naini STP

For recovery after the 5th year, minimum feasible average unit price of Rs. 10 per kl needs to be imposed on reclaimed water and proportionally levied in the ratio 1:2:3:5:7 for agriculture, public utilities, domestic, industrial and commercial categories respectively. The final pricing, demand allocated, and the proportion of allocation and cost borne by different categories is presented in Table 4.32.

It is observed from the Table 4.32 that the final demand allocated and the prices for different demands are represented categorically. Due to the proportional pricing based on socialist approach, the profit-making end-users are levied with higher costs per volumetric consumption. It is observed that the revenue generated is highest from industrial category, followed by domestic demand and commercial demand.

Table 4.32. Final allocated demand and revenue generated for localised planning around Naini STP

Appropriate Treatment Technology: ASP + SBT + C-F-RSF (80 MLD)					
Minimum Feasible Average Price			**Rs. 10 per kl (For 5th year recovery)**		
Category	**Demand Allocated (MLD)**	**Demand Allocation (%)**	**Unit Price (Rs/kl)**	**Annual Revenue (Rs in Cr/yr)**	**Revenue (%)**
Agriculture	7	8.75	2.56	0.66	2.24%
Public Utilities	22	27.50	5.13	4.12	14.10%
Domestic Demand	20	25.00	7.69	5.62	19.23%
Industrial Demand	8	10.00	12.82	3.74	12.82%
Commercial Demand	23	28.75	17.95	15.07	51.60%
Total	**80**	**100.00**	**-**	**29.20**	**100.00**

4.5.4.8 Important Observations

The case study demonstrated the application of DSS_IWWM in Prayagraj city for localized planning for non-potable reuse (landscape, toilet flushing, irrigation, outdoor bathing, vehicle washing, road cleaning) in the vicinity of Naini STP (ASP-based, 80 MLD). The municipal wastewater in Prayagraj city has quality characteristics better than Kanpur but worse than Varanasi city. In Lucknow, the taken decision criteria priority was capital cost followed by O&M cost, land and energy.

For producing reclaimed water suitable for non-potable reuse purposes identified in the vicinity of Naini STP, supplementation of existing ASP technology with SBT followed by coagulation, flocculation and rapid sand filtration was obtained as the most appropriate treatment technology. BIOFOR-F followed by microfiltration and reverse osmosis was obtained as the next most appropriate WWTT (new installation). A significant weighted cost difference can be seen in the two suggestions. This validates the fact that utilization of existing technology can help save costs if it is able to meet the desired quality. ASP is a conventional technology with lower performance and so it needs to be combined with multiple technologies to satisfy the desired quality.

A minimum allocation priority of 70% was defined for agriculture, public utilities, and domestic demand satisfaction. Following the socio-economic methodology, 7 MLD (100% of initial demand), 22 MLD (100% of initial demand), 20 MLD (74% of initial demand), 8 MLD (100% of initial demand), and 23 MLD (100% of initial demand) of reclaimed water was allocated to agriculture, public utilities, domestic, industrial, and commercial demand respectively. The minimum feasible average unit price of reclaimed water taken was Rs. 10 per kl, obtained in supplementation scenario.

As per the price ratio assigned (1:2:3:5:7 for agriculture, public utilities, domestic demand, industrial demand, and commercial demand), minimum unit price was imposed on agriculture and maximum on commercial demand. Maximum revenue recovery was seen from the highest priced sector, which is commercial demand with highest demand allocated (Rs. 15.07 Cr/yr and 23 MLD) and second-highest recovery was seen from domestic sector (Rs. 5.62 Cr/yr and 20 MLD). Due to proportional pricing mechanism, the cost-burden is shared based on income of users.

4.5.5 Agra city

Agra city is located on the bank of river Yamuna in Uttar Pradesh state. The area is drained by the rivers Ganga, Yamuna and the Agra canal. It has a metropolitan area of over 121 sq km. The city has a population of 2.31 million as per 2011 census. Agriculture was the primary economic activity in the city while leather and manufacturing industries have boomed in the city post-independence (Agra, 2013). The map of the city showing the location of STPs is given in Figure 4.21.

The Yamuna River is highly polluted, and it is the primary water source for the city (280 MLD). Due to high saline and fluorine content, groundwater is also not suitable for potable use. Under

Gangajal project, a 130 km long pipeline from Bulandshahr's Upper Ganga canal is being brough to Agra to satisfy increasing water demands (Agra, 2020).

Fig 4.21 Agra city and location of STPs

There is a total of nine STPs having a total capacity of 232.75 MLD and utilised capacity of 185.03 MLD. Presently, all 9 STPs are functioning and are in good condition (CPCB, 2021). The features of the STPs are as shown in Table 4.33.

The effluents are not utilized but disposed in nearby river system, leading to water pollution.

4.5.5.1 Identification of Potential Reuses

Out of the fourteen reuses, seven reuses: i. Toilet flushing, ii. Horticulture, iii. Vehicle washing, iv. Landscape, v. Road cleaning, vi. Laundry washing, vii. E-flow are identified in the city. In this case, we demonstrate the application of DSS_IWWM in the city of Agra by considering appropriate treatment technology selection for the Peelakhar STP (Oxidation Pond, 10 MLD) by identifying the potential demands in STP’s vicinity.

4.5.5.2 Quality Criteria for Identified Reuses

For localized planning around Peelakhar STP for non-potable reuse (vehicle washing, e-flow augmentation, landscape, road cleaning, toilet flushing and horticulture), strictest quality parameter was taken, shown in Table 4.26, using the following equations:

The quality criteria (each parameter) for the multiple reuse scenario will be as described below:

$BOD = \text{Min}(BOD_{VW}, BOD_{EF}, BOD_{L}, BOD_{RC}, BOD_{TF}, BOD_{H}) = 10$ mg/l

$COD = Min(COD_{VW}, COD_{EF}, COD_{L}, COD_{RC}, COD_{TF}, COD_{H}) = 30$ mg/l

$TSS = Min(TSS_{VW}, TSS_{EF}, TSS_{L}, TSS_{RC}, TSS_{TF}, TSS_{H}) = 10$ mg/l

$TN = Min(TN_{VW}, TN_{EF}, TN_{L}, TN_{RC}, TN_{TF}, TN_{H}) = 10$ mg/l

$FC = Min(FC_{VW}, FC_{EF}, FC_{L}, FC_{RC}, FC_{TF}, FC_{H}) = 200$ MPN/l

Where, VW: Vehicle Washing, EF: E-flow augmentation, L: Landscape, RC: Road Cleaning, TF: Toilet Flushing and H: Horticulture.

4.5.5.3 Importance Weightage for Decision Criteria

The priorities of the user in terms of resource availability are assessed and used for the evaluation of weights using FUCOM as shown in Table 4.34.

4.5.5.4 Estimation of Reclaimed Water Demand

In this case, Peelakhar STP (OP-10 MLD) is selected as the target STP and the potential reuse purposes in the vicinity of this STP are identified as shown in Figure 4.22.

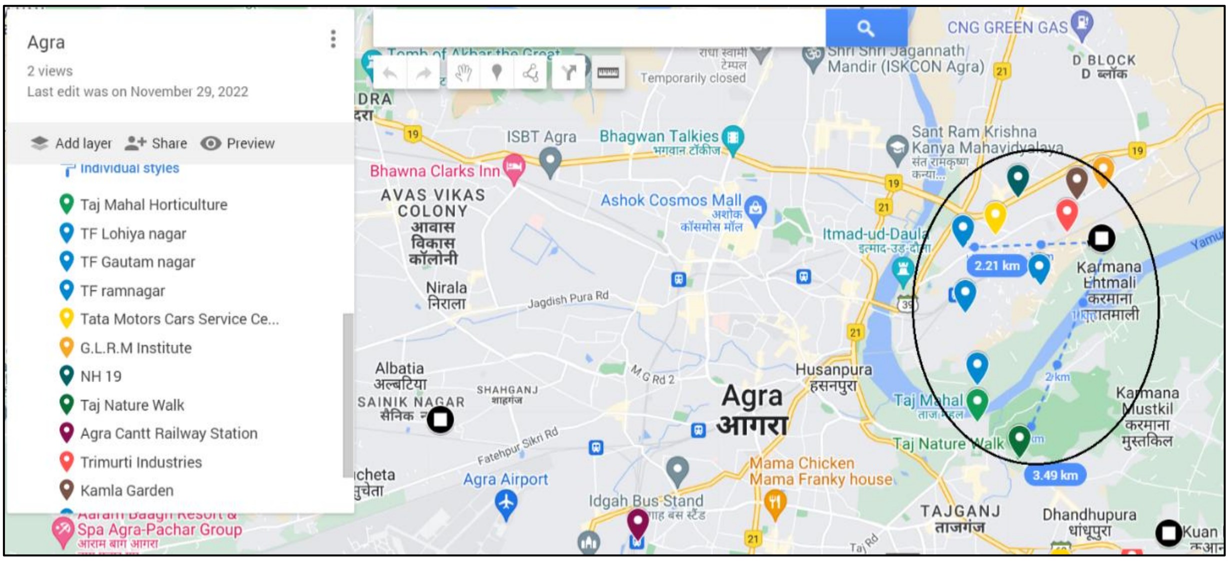


Fig. 4.22. Reuse purposes identified in the vicinity of the Peelakhar STP (OP, 10 MLD)

The demands are further classified into five categories based on end-users to socio-economically allocate demand and to levy proportional pricing on the categories. The reclaimed water demands identified in the vicinity of the Peelakhar STP are presented in the Table 4.35.

Table 4.33. Features of the operational STPs in the Agra city (CPCB, 2021)

STP Location	Technology Used	Installed Capacity (MLD)	Utilised Capacity (MLD)	Compliance to disposal norms (CPHEEO, 2013)	Effluent use
1. Dhadhupura	UASB	102	87	Yes	Agriculture on land
2. Budi ka Nagla	OP	2.25	2.97	NO	Discharge in Yamuna River
3. Devri Road	UASB	12	6.35	Yes	Discharge in Yamuna River
4. Peelakhar	OP	10	9.74	NO	Discharge in Yamuna River
5. Bhimnagri	UASB	12	6.35	Yes	Discharge in Yamuna River
6. Jaganpur	UASB	14	13.39	Yes	Discharged in Yamuna River
7. Sadarban	UASB	40	18.73	Yes	Agriculture on land
8. Kalindi Vihar	UASB	4.5	4.5	Yes	Discharge in Karwan River
1. Sadarwan	SBR	36	36	Yes	Agriculture on land

Table 4.34. Weight calculation for decision criteria using FUCOM for Agra city

Names of Criteria	**Land**	**Energy**	**Capital Cost**	**O&M Cost**
Rank	2	4	1	3
Criteria (according to rank)	**Capital Cost**	**Land**	**O&M Cost**	**Energy**
Criteria comparisons	1	2	3	4
$\phi_{1/2}$	$\phi_{2/3}$	$\phi_{3/4}$	$\phi_{1/3}$	$\phi_{2/4}$
2.00	1.5	1.33	3.00	2.00
Weights	**Capital Cost**	**Land**	**O&M Cost**	**Energy**
	0.480	0.240	0.160	0.120

*Weights were obtained by using the above data and applying a linear programming model in equations (1) and (2) (Chapter 3).

Table 4.35. Demand estimation in the vicinity of Peelakhar STP, categorization of reuses, price ratio and minimum demand allocation requirements in Prayagraj city

Reuse Purpose	Place	Demand (MLD)	Category	Total Demand (MLD)	Price Ratio	Minimum Allocation (%)
Vehicle Washing	Tata Motors Cars	2	Commercial	2	7	
TF+H	Lohiya nagar	3	Domestic	11	3	50
TF+H	Gautam nagar	3	Domestic			
TF+H	Ramnagar	3	Domestic			
TF+H	G.L.R.M Institute	2	Domestic			
Landscape	Taj Mahal	3	Public Utilities	13	2	50
RC	NH 19	2	Public Utilities			
RC	Taj Nature Walk	2	Public Utilities			
E flow	Yamuna river	4	Public Utilities			
Landscape	Kamla Garden	2	Public Utilities			
Total Demand				**26**		

4.5.5.5 Identification of inputs for application in DSS_IWWM

The raw wastewater characteristics, the target quality characteristics, the priorities of the decision criteria for weight calculation using FUCOM method, the land cost and electricity cost, obtained through primary surveys are provided in the following Table 4.36.

Table 4.36. Inputs to DSS_IWWM for Peelakhar STP in Agra city

STP: Peelakhar, Agra, UP		**Capacity: 10 MLD**			**Technology: Oxidation Pond**		
Raw Water Characteristics							
Source	**BOD (mg/l)**	**COD (mg/l)**	**TSS (mg/l)**		**TN (mg/l)**		**FC (MPN/l)**
Municipal	87.6	248.6	204		18		3.3×10^7
Local Resource Scenario (Primary Data)							
Desired Reuse	**Design Period (yr)**	**Land Cost (Rs/ha)**	**Electricity Cost (Rs per KW-h)**	**Land (ha)**	**Energy (MWh)**	**Capital Cost (Rs)**	**O&M Cost (Rs)**
VW, e-flow, L, H, TF, RC	15	1.1 Cr	6.00	5	11.0	--	--
FUCOM weights		**Decision Criteria Preference**		**2**	**4**	**1**	**3**
Desired Characteristics of Reclaimed Water							
Desired Reuse	**BOD (mg/l)**	**COD (mg/l)**	**TSS (mg/l)**		**TN (mg/l)**		**FC (MPN/l)**
Quality Criteria	10	20	10		10		2000

* Due to absence of quality standards for COD parameters, a BOD/COD ratio of 0.3 is considered for the treated effluent in model application.

4.5.5.6 Selection of Appropriate Treatment Technologies

After applying the inputs and respective weights, based on required quality and least weighted cost, the following wastewater treatment technology combinations are suggested as shown in Table 4.37.

Table 4.37. Appropriate WWTT combinations to satisfy non-potable demand in the vicinity of Peelakhar STP (OP, 10 MLD) in Agra city

Rank	Technology Combination	Weighted Cost (crore Rupees)	Land (ha)	Energy (MWh per day)	Capital Cost (Rupees in Crore)	O&M Cost (Rupees in Crore)
New Installation						
1	**BIOFOR-F + C-F-RSF**	10.84	1.80	3.20	12.89	1.22
2	**SBR + C-F-RSF**	12.63	1.55	2.90	17.01	1.22
3	**UASB + EA+ MF + RO**	15.54	1.90	2.70	21.49	1.52
Upgradation of Existing Technology *						
-	**-**		-	-	-	-
Supplementation of Existing Technology *						
1	**OP + BIOFOR-F**	7.83	0.80	3.30	9.31	0.77
2	**OP + A2O**	8.86	0.60	3.20	10.74	0.95
3	**OP + SBR**	9.62	0.55	3.00	13.43	0.77

* Energy and O&M Cost both for existing and suggested WWTT are included

It can be observed that BIOFOR-F in combination with coagulation, flocculation and rapid sand filtration is suggested for new installation. The quality criteria for the reuse are so high that upgradation of technology with only emerging or tertiary technologies (within the resource-constraint scenario) cannot augment the existing Oxidation Pond-based STP to produce satisfactory results. However, supplementation of the Oxidation Pond-based STP with sophisticated secondary technology BIOFOR-F can produce the effluent of required quality and as this suggestion has the least-weighted cost, it is the most appropriate technology combination in this scenario. It can be seen that the supplementation scenario would incur lesser capital and O&M costs and also require lesser land and energy.

4.5.5.7 Reclaimed Water Demand Allocation and Pricing

The breakeven point analysis is performed for the technology suggestions for new installation and supplementation cases as shown in Figure 4.23. The imposed demand is 26 MLD while the STP capacity is 10 MLD, hence the final allocation is done using the socio-economic approach given the price ratio assumed in this case for public utilities: domestic: commercial is 2:3:7.

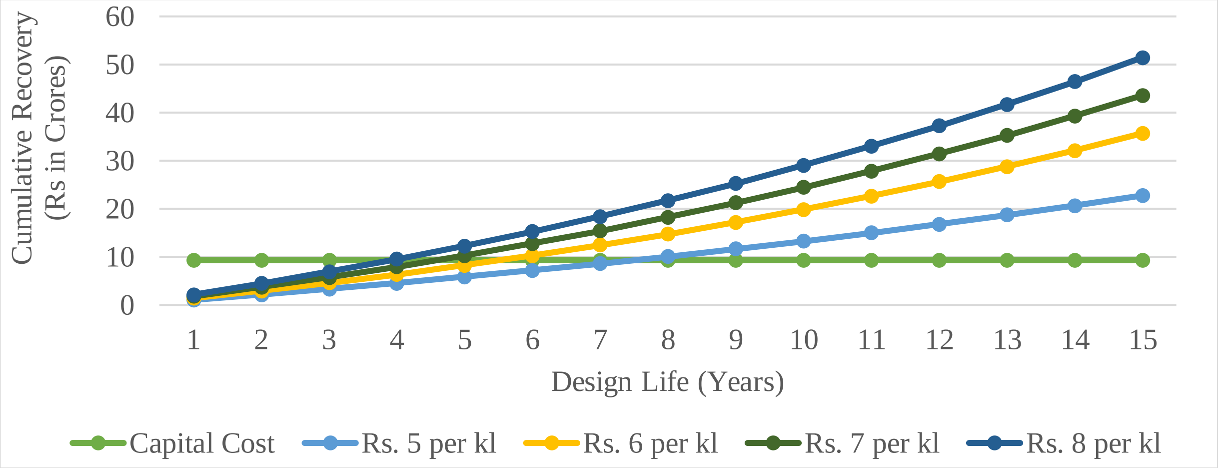


Fig. 4.23. BEP analysis for OP+BIOFOR-F at different reclaimed water prices for Peelakhar STP

It can be seen that for the recovery after 5th year, the supplementation case requires minimum feasible average unit price of Rs. 7 per kl. This validates that the suggested technology for supplementation is the most economically feasible while producing the same quality of effluent as required and considering the local conditions as well. The final demand allocated, unit prices imposed on different categories of uses, proportion of demand and cost borne by the categories are presented in Table 4.38.

Table 4.38. Final allocated demand and revenue generated for localised planning around Peelakhar STP

<table>
<tr><th colspan="6">Appropriate Treatment Technology: Oxidation Pond + BIOFOR-F (10 MLD)</th></tr>
<tr><th colspan="3">Minimum Feasible Average Price</th><th colspan="3">Rs. 7 per kl (For 4th year recovery)</th></tr>
<tr><th>Category</th><th>Demand Allocated (MLD)</th><th>Demand Allocation (%)</th><th>Unit Price (Rs/kl)</th><th>Annual Revenue (Rs in Cr/yr)</th><th>Revenue (%)</th></tr>
<tr><td>Public Utilities</td><td>5</td><td>50</td><td>5.60</td><td>1.02</td><td>40</td></tr>
<tr><td>Domestic Demand</td><td>5</td><td>50</td><td>8.40</td><td>1.53</td><td>60</td></tr>
<tr><td>Total</td><td>10</td><td>100.00</td><td>-</td><td>2.56</td><td>100.00</td></tr>
</table>

Since reclaimed water was not allocated to commercial demand, it is not considered for proportional pricing and hence the costs need to be shared by the public utilities and domestic categories. It was observed that due to proportional pricing, the prices levied on public utilities is lesser and maximum revenue is coming from domestic demand even when same demand is allocated to both the categories.

4.5.5.8 Important Observations

The case study demonstrated the application of DSS_IWWM in Agra city for localized planning for non-potable reuse (vehicle washing, e-flow augmentation, landscape, horticulture, toilet flushing, road cleaning) in the vicinity of Peelakhar STP (OP-based, 10 MLD). The municipal wastewater in Agra has quality characteristics similar to Prayagraj city. In Agra, the decision criteria priority was capital cost followed by land, O&M cost, and energy.

For producing reclaimed water suitable for non-potable reuse purposes identified in the vicinity of Peelakhar STP, supplementation of existing OP technology with BIOFOR-F was obtained as the most appropriate treatment technology. For new installation, BIOFOR-F followed by C-F-

RSF was obtained while no suggestion was obtained for upgrading scenario. This means that none of the emerging or tertiary technologies couls augment oxidation pond to produce reclaimed water satisfying the desired quality.

A minimum allocation priority of 50% was defined for public utilities, and domestic demand satisfaction. Following the socio-economic methodology, 5 MLD (38.46% of initial demand), and 5 MLD (45.45% of initial demand) of reclaimed water was allocated to public utilities and domestic demand respectively while no allocation was made to commercial demand as the produced reclaimed water was used up completely to satisfy demands for prioritized sectors. Also, the minimum requirements for the prioritized demands were not allocated completely due to lesser supply. Hence Agra needs to set up new STP or re-direct water from other nearby STPs to the area.

The minimum feasible average unit price of reclaimed water was obtained as Rs. 7 per kl for the appropriate WWTT. As per the price ratio assigned (2:3 for public utilities: domestic demand), minimum unit price was imposed on public utilities and maximum on domestic demand. Since no water was allocated to commercial sector, the costs will be imposed only on public and domestic sector. Out of the total demand allocated 50% each was allocated to the two sectors while cost recovery from domestic sector was 60% and public utilities 40%.

4.6 Application of DSS_IWWM in Cities of Other States of Indis

After validation with five cities of Uttar Pradesh state, the application of DSS_IWWM is extended to seven more cities from different regions of India, **South region-** i. Madurai (Tamil Nadu), ii. Hyderabad (Andhra Pradesh), iii. Panjim (Goa), **North region-** iv. Jalandhar (Punjab), v. Delhi, **West Region-** vi. Jaipur (Rajasthan), **East region-** vii. Patna (Bihar) (Table 4.39 – 4.45) for non-potable reuses (TF+VW+LW+H). Same reclaimed water quality and decision criteria weightages are considered for comparison of results. The sources of applied inputs are taken from reports including CPCB (2013), CPCB (2021), Jaipur (2015), and Delhi (2020).

SOUTH REGION

Table 4.39. Appropriate WWTT suggestions for non-potable reuse in Madurai, Tamil Nadu

<table>
<tr><th colspan="7">Tamil Nadu: Madurai (Sakkimanglam STP, SBR-Based, 46 MLD)</th></tr>
<tr><td rowspan="2">Raw wastewater quality</td><td>BOD (mg/l)</td><td>COD (mg/l)</td><td colspan="2">TSS (mg/l)</td><td>TN (mg/l)</td><td>FC (MPN/l)</td></tr>
<tr><td>230</td><td>536</td><td colspan="2">3940</td><td>20</td><td>$2x10^{7}$</td></tr>
<tr><td rowspan="2">Reuse
Quality</td><td>BOD (mg/l)</td><td>COD (mg/l)</td><td colspan="2">TSS (mg/l)</td><td>TN (mg/l)</td><td>FC (MPN/l)</td></tr>
<tr><td>10</td><td>30</td><td colspan="2">10</td><td>10</td><td>200</td></tr>
<tr><td rowspan="2">Weightage</td><td>Land</td><td>Energy</td><td colspan="2">CC</td><td colspan="2">O&M</td></tr>
<tr><td>1</td><td>3</td><td colspan="2">2</td><td colspan="2">4</td></tr>
<tr><td colspan="2">Technology</td><td>Weighted Cost (Cr Rs.)</td><td>Land (ha)</td><td>Energy (MWh)</td><td>CC (Cr Rs.)</td><td>O&M per year (Cr. Rs.)</td></tr>
<tr><td colspan="2">NEW: SBR + WP + C-F-RSF</td><td>57.48</td><td>8.97</td><td>18.86</td><td>110.45</td><td>8.37</td></tr>
<tr><td colspan="2">UPGRADE: SBR + WP + C-F-RSF</td><td>31.50</td><td>6.44</td><td>18.86</td><td>48.66</td><td>8.37</td></tr>
<tr><td colspan="2">SUPPLEMENT: SBR + A2O</td><td>25.37</td><td>2.76</td><td>11.57</td><td>49.45</td><td>3.10</td></tr>
<tr><td colspan="4">Minimum Feasible Average Price</td><td colspan="3">Supplement: Rs. 7 per kl for recovery post 5th year</td></tr>
</table>

SOUTH REGION

Table 4.40. Appropriate WWTT suggestions for non-potable reuse in Hyderabad, Andhra Pradesh

<table>
<tr><th colspan="7">Andhra Pradesh: Hyderabad (Nagole STP, UASB+EA-Based, 172 MLD)</th></tr>
<tr><td rowspan="2">Raw wastewater quality</td><td>BOD (mg/l)</td><td>COD (mg/l)</td><td colspan="2">TSS (mg/l)</td><td>TN (mg/l)</td><td>FC (MPN/l)</td></tr>
<tr><td>212</td><td>358</td><td colspan="2">212</td><td>18</td><td>2x10^7</td></tr>
<tr><td rowspan="2">Reuse Quality</td><td>BOD (mg/l)</td><td>COD (mg/l)</td><td colspan="2">TSS (mg/l)</td><td>TN (mg/l)</td><td>FC (MPN/l)</td></tr>
<tr><td>10</td><td>30</td><td colspan="2">10</td><td>10</td><td>200</td></tr>
<tr><td rowspan="2">Weightage</td><td>Land</td><td>Energy</td><td colspan="2">CC</td><td colspan="2">O&M</td></tr>
<tr><td>1</td><td>3</td><td colspan="2">2</td><td colspan="2">4</td></tr>
<tr><td colspan="2">Technology</td><td>Weighted Cost (Cr Rs.)</td><td>Land (ha)</td><td>Energy (MWh)</td><td>CC (Cr Rs.)</td><td>O&M per year (Cr Rs.)</td></tr>
<tr><td colspan="2">NEW: SBT+WP+C-F-RSF</td><td>184.72</td><td>29.24</td><td>65.53</td><td>305.13</td><td>31.20</td></tr>
<tr><td colspan="2">UPGRADE: UASB+EA+WP+MF+RO</td><td>210.33</td><td>20.64</td><td>67.08</td><td>397.66</td><td>36.54</td></tr>
<tr><td colspan="2">SUPPLEMENT: UASB+EA+SBT+C-F-RSF</td><td>146.56</td><td>22.36</td><td>65.53</td><td>184.73</td><td>29.30</td></tr>
<tr><td colspan="3">Minimum Feasible Average Price</td><td colspan="4">Supplement: Rs. 10 per kl for recovery post 5th year</td></tr>
</table>

SOUTH REGION

Table 4.41. Appropriate WWTT suggestions for non-potable reuse in Panjim, Goa

Goa: Panjim (Tonca STP, SBR-Based, 12 MLD)						
Raw wastewater quality	**BOD (mg/l)**	**COD (mg/l)**	**TSS (mg/l)**		**TN (mg/l)**	**FC (MPN/l)**
	140	340	204		21	$2x10^8$
Reuse Quality	**BOD (mg/l)**	**COD (mg/l)**	**TSS (mg/l)**		**TN (mg/l)**	**FC (MPN/l)**
	10	30	10		10	200
Weightage	**Land**	**Energy**	**CC**		**O&M**	
	1	3	2		4	
Technology		**Weighted Cost (Cr Rs.)**	**Land (ha)**	**Energy (MWh)**	**CC (Cr Rs.)**	**O&M per year (Cr Rs.)**
NEW: SBT+UF+RO		12.85	0.96	3.61	30.08	1.71
UPGRADE: SBR + MF + RO		6.92	0.96	3.60	19.24	1.28
SUPPLEMENT: SBR + OP		5.13	1.80	1.82	5.38	0.92
Minimum Feasible Average Price			**Supplement:** Rs. 4 per kl for recovery post 5th year			

NORTH REGION

Table 4.42. Appropriate WWTT suggestions for non-potable reuse in Jalandhar, Punjab

Punjab: Jalandhar (Fulariwal STP, SBR-Based, 25 MLD)						
Raw wastewater quality	**BOD (mg/l)**	**COD (mg/l)**	**TSS (mg/l)**		**TN (mg/l)**	**FC (MPN/l)**
	154	324	177		10	$5.4x10^6$
Reuse Quality	**BOD (mg/l)**	**COD (mg/l)**	**TSS (mg/l)**		**TN (mg/l)**	**FC (MPN/l)**
	10	30	10		10	200
Weightage	**Land**	**Energy**	**CC**		**O&M**	
	1	3	2		4	
Technology		**Weighted Cost (Cr Rs.)**	**Land (ha)**	**Energy (MWh)**	**CC (Cr Rs.)**	**O&M per year (Cr Rs.)**
NEW: BIOFOR-F + C-F-RSF		20.44	4.50	8.00	32.23	3.04
UPGRADE: SBR + C-F-RSF		13.10	2.5	7.20	8.95	3.03
SUPPLEMENT: SBR + OP		10.65	3.75	3.80	11.20	1.91
Minimum Feasible Average Price			**Supplement:** Rs. 4 per kl for recovery post 5th year			

NORTH REGION

Table 4.43. Appropriate WWTT suggestions using DSS_IWWM for non-potable reuse in Delhi

<table>
<tr><th colspan="7">Jattal Road STP, Delhi (UASB+EA Based, 10 MLD)</th></tr>
<tr><td rowspan="2">Raw wastewater quality</td><td>BOD (mg/l)</td><td>COD (mg/l)</td><td colspan="2">TSS (mg/l)</td><td>TN (mg/l)</td><td>FC (MPN/l)</td></tr>
<tr><td>315</td><td>628</td><td colspan="2">336</td><td>20</td><td>$24x10^6$</td></tr>
<tr><td rowspan="2">Reuse Quality</td><td>BOD (mg/l)</td><td>COD (mg/l)</td><td colspan="2">TSS (mg/l)</td><td>TN (mg/l)</td><td>FC (MPN/l)</td></tr>
<tr><td>10</td><td>30</td><td colspan="2">10</td><td>10</td><td>200</td></tr>
<tr><td rowspan="2">Weightage</td><td>Land</td><td>Energy</td><td colspan="2">CC</td><td colspan="2">O&M</td></tr>
<tr><td>1</td><td>3</td><td colspan="2">2</td><td colspan="2">4</td></tr>
<tr><td colspan="2">Technology</td><td>Weighted Cost (Cr Rs.)</td><td>Land (ha)</td><td>Energy (MWh)</td><td>CC (Cr Rs.)</td><td>O&M per year (Cr Rs.)</td></tr>
<tr><td colspan="2">NEW: BIOFOR-F+WP+C-F-RSF</td><td>9.12</td><td>2.2</td><td>44.00</td><td>19.89</td><td>1.82</td></tr>
<tr><td colspan="2">UPGRADE: UASB+EA+WP+UF+RO</td><td>14.48</td><td>0.9</td><td>44.00</td><td>24.91</td><td>4.47</td></tr>
<tr><td colspan="2">SUPPLEMENT: UASB+EA+SBT+C-F-RSF</td><td>8.52</td><td>1.3</td><td>3.81</td><td>10.74</td><td>1.70</td></tr>
<tr><td colspan="3">Minimum Feasible Average Price</td><td colspan="4">Supplement: Rs. 10 per kl for recovery post 5th year</td></tr>
</table>

WEST REGION

Table 4.44. Appropriate WWTT suggestions using DSS_IWWM for non-potable reuse in Jaipur, Rajasthan

<table>
<tr><th colspan="7">Delawas STP, Jaipur (ASP-Based, 62.5 MLD)</th></tr>
<tr><td rowspan="2">Raw wastewater quality</td><td>BOD (mg/l)</td><td>COD (mg/l)</td><td colspan="2">TSS (mg/l)</td><td>TN (mg/l)</td><td>FC (MPN/l)</td></tr>
<tr><td>330</td><td>776</td><td colspan="2">620</td><td>56</td><td>$1x10^8$</td></tr>
<tr><td rowspan="2">Reuse
Quality</td><td>BOD (mg/l)</td><td>COD (mg/l)</td><td colspan="2">TSS (mg/l)</td><td>TN (mg/l)</td><td>FC (MPN/l)</td></tr>
<tr><td>10</td><td>30</td><td colspan="2">10</td><td>10</td><td>200</td></tr>
<tr><td rowspan="2">Weightage</td><td>Land</td><td>Energy</td><td colspan="2">CC</td><td colspan="2">O&M</td></tr>
<tr><td>1</td><td>3</td><td colspan="2">2</td><td colspan="2">4</td></tr>
<tr><td colspan="2">Technology</td><td>Weighted Cost (Cr Rs.)</td><td>Land (ha)</td><td>Energy (MWh)</td><td>CC (Cr Rs.)</td><td>O&M per year (Cr Rs.)</td></tr>
<tr><td colspan="2">NEW: A2O+UF+RO</td><td>79.8</td><td>6.56</td><td>20.62</td><td>195.87</td><td>8.71</td></tr>
<tr><td colspan="2">UPGRADE: NA</td><td>NA</td><td>NA</td><td>NA</td><td>NA</td><td>NA</td></tr>
<tr><td colspan="2">SUPPLEMENT: ASP+SBT+WP</td><td>34.6</td><td>4.34</td><td>25.94</td><td>87.79</td><td>6.35</td></tr>
<tr><td colspan="3">Minimum Feasible Average Price</td><td colspan="4">Supplement: Rs. 12 per kl for recovery post 5th year</td></tr>
</table>

EAST REGION

Table 4.45. Appropriate WWTT suggestions for non-potable reuse in Patna, Bihar

Bihar: Patna (Saidpur STP, ASP-based, 45 MLD)						
Raw wastewater quality	**BOD (mg/l)**	**COD (mg/l)**	**TSS (mg/l)**		**TN (mg/l)**	**FC (MPN/l)**
	130	315	288		13	$2x10^9$
Reuse Quality	**BOD (mg/l)**	**COD (mg/l)**	**TSS (mg/l)**		**TN (mg/l)**	**FC (MPN/l)**
	10	30	10		10	200
Weightage	**Land**	**Energy**	**CC**		**O&M**	
	1	3	2		4	
Technology		**Weighted Cost (Cr Rs.)**	**Land (ha)**	**Energy (MWh)**	**CC (Cr Rs.)**	**O&M per year (Cr Rs.)**
NEW: BIOFOR-F+MF+RO		51.42	7.20	14.85	114.43	6.25
UPGRADE: -		-	-	-	-	-
SUPPLEMENT: OP+MF+RO		53.15	10.35	15.95	92.67	8.64
Minimum Feasible Average Price			**Supplement:** Rs. 16 per kl for recovery post 5th year			

4.7 Comparison of Appropriate WWTTs Obtained for Different Cities Towards Same Target Quality

In the Table 4.46, a comparison of appropriate WWTTs obtained for different cities towards same target quality was presented. The DSS_IWWM was applied to multiple cities with same decision criteria prioritization, land, and energy costs and varying influent wastewater characteristics. The appropriate treatment technology selection using DSS_IWWM in this case was performed to obtain reclaimed water suitable for defined non-potable reuse purposes, such as, toilet flushing, vehicle washing, laundry washing and horticulture and to draw comparison between the appropriate WWTTs obtained for the same quality criteria but varying input conditions. It was observed from the above table that the appropriate WWTT suggestions vary with the influent quality characteristics, decision criteria weightages, the desired quality criteria, and the existing technology at STPs. Complex combinations and costlier technologies (UF/MF+RO) were obtained for influents with very-high COD, TSS and FC concentrations. The raw wastewater in Patna exhibited very high faecal coliform concentration, due to this, new installation of BIOFOR-F+MF+RO was suggested as the most appropriate WWTT instead of upgrading or supplementing existing ASP technology. Since MF and RO are costly technologies, a higher average price of Rs. 16 per kl was imposed. Also, stricter the quality criteria, more complex is the technology combination suggested. It was also observed that inclusion of existing technologies can help considerably reduce the further expenditure required to obtain effluent of desired quality. This validates the observation that most of the suggestions for appropriate technology were for supplementation case. Higher the performance efficiency of existing technology at STP, lesser complex is the augmentation/supplementation requirements for a desired quality criterion. This is inferred from the appropriate technology suggestions obtained for SBR-based STPs at cities with highly polluted raw wastewaters, (high COD, TSS and FC) Varanasi, Lucknow, Patna, and Jaipur, where supplementation with relatively lower cost and high performing SBT technology is suggested to meet quality criteria at a price of Rs. 5 per kl, while for cities with lower BOD, COD, TSS, TN and FC concentrations in influents, such as in Allahabad, Agra, Hyderabad, Jalandhar and Goa, low-cost technology option such as oxidation pond is obtained at an average price of Rs. 4 per kl. In Madurai, due to very high COD, supplementation with high performing and costlier A2O technology at an average price of Rs. 7 per kl was obtained. However, to obtain the same quality from supplementation of conventional low-performing ASP or UASB+EA-based existing technologies, high-performing SBT in combination with emerging (WP, Rs. 12 per kl) or tertiary (C+F+RSF, Rs. 10 per kl) technologies were obtained for the concerned cities with larger energy requirements of existing technologies. Therefore, high performing technologies at existing STPs require relatively lower cost technology supplementations to produce effluent of desired quality. For UASB+EA-based technology at Kanpur, costlier supplementation with BIOFOR-F followed by C-F-RSF was obtained at an imposed average price of Rs. 11 per kl. For MBBR based existing STPs with low performance as observed at Lucknow, Prayagraj, and Jaipur (high influent COD, TSS, FC), supplementation with BIOFOR-F, BIOFOR-F, and BIOFOR-F + MLE respectively were obtained at higher prices. For traditional oxidation pond technology at Agra (moderate COD, TSS, FC in influent), supplementation with BIOFOR-F was obtained at an average price of Rs. 7 per kl. Substantial cost difference was seen between supplementation suggestions for existing advanced and conventional technologies, inferring that costlier technologies are required for supplementation to low performing conventional technologies and vice versa.

Table 4.46. A comparison of appropriate WWTTs for non-potable reuses (TF+LW+VW+H)

City	Existing Technology	Capacity (MLD)	BOD (mg/l)	COD (mg/l)	TSS (mg/l)	TN (mg/l)	FC (MPN/l)	Suggestion	Appropriate Technology	Average Price (Rs/kl)	Comment
1. Kanpur	ASP	37	314	672	969	19.2	9.4×10^7	Supplement	SBT+WP	12	Costly and complex WWTTs due to high COD, TSS and FC and low-performing existing technology
	UASB+EA							Supplement	BIOFOR-F+C-F-RSF	11	
2. Varanasi	SBR	120	101	289	198	12	1×10^7	Supplement	SBT	5	Low-cost and high performing technology for advanced oxidation based existing technologies
	A2O							Supplement	SBT	5	
	ASP							Supplement	SBT	6	Higher price due to higher O&M of existing technology
3. Lucknow	SBR	37	122	515	260	18	5.49×10^7	Supplement	SBT	5	SBT to supplement high performing SBR
	UASB+EA							Supplement	SBT+C-F-RSF	10	Secondary followed by tertiary WWTTs due to high FC and COD
	FAB/MBBR							Supplement	BIOFOR-F	6	Costlier secondary technology due to poor influent quality and low performing existing technology
4. Prayagraj	ASP	80	86	176	147	16	9.4×10^7	Supplement	SBT+C-F-RSF	10	Secondary tech followed by tertiary due to high FC and low performing

											existing technology
	FAB/MBBR							Supplement	BIOFOR-F	6	Costlier secondary technology due to poor influent quality and low performing existing technology
	SBR							Supplement	OP	4	Low-cost, low-performing technology for desired effluent quality
	UASB+EA							Supplement	SBT+C-F-RSF	10	Secondary tech followed by tertiary due to high FC and low performing existing technology
5. Agra	OP	10	87.6	248.6	204	18	3.3 x 10^7	Supplement	BIOFOR-F	7	High performing costlier technology to supplement very low-performing existing technology
	UASB+EA							Supplement	SBT+C-F-RSF	10	Secondary tech followed by tertiary due to high FC and low performing existing technology
	SBR							Supplement	OP	4	Low-cost, low-performing technology OP sufficient to produce desired effluent quality since existing tech is SBR

6. Madurai	SBR	46	230	536	3940	20	2.0 x 10^7	Supplement	A2O	7	Due to very high COD, TSS and FC, high performing, costlier secondary technology
7.Hyderabad	UASB+EA	172	212	358	212	18	2.0 x 10^7	Supplement	SBT+C-F-RSF	10	Secondary tech followed by tertiary due to high FC and low performing existing technology
	ASP							Supplement	SBT	6	High performing secondary technology for low-performing existing tech
	SBR							Supplement	OP	4	Low-cost, low-performing technology OP sufficient to produce desired effluent quality since existing tech is SBR
8. Jalandhar	SBR	25	154	324	177	10	5.4 x 10^6	Supplement	OP	4	Low-cost, low-performing technology OP sufficient to produce desired effluent quality since existing tech is SBR
	UASB+EA							Supplement	SBT	6	High performing secondary technology for low-performing existing tech
9.Goa	SBR	12	140	340	204	21	2.0 x 10^8	Supplement	OP	4	Low-cost, low-performing

											technology OP sufficient to produce desired effluent quality since existing tech is SBR
2. Patna	ASP	45	130	315	288	13	2.0 x 10^9	New	BIOFOR-F+MF+RO	16	Due to very high FC, augmenting/ supplementing existing technology is not economically feasible. Therefore, new, costlier WWTT suggested.
	SBR							Supplement	SBT	5	High performing secondary technology for high performing existing technology due to very high FC
3. Jaipur	SBR	62.5	330	776	620	56	1.0 x 10^8	Supplement	SBT	5	High performing secondary technology for high performing existing technology due to high COD, TSS and FC
	ASP							Supplement	SBT+WP	12	Costly and complex WWTT to augment low-performing existing technology, given very poor influent quality
	MBBR							Supplement	BIOFOR-F+MLE	11	
4. Delhi	UASB+EA	10	315	628	336	20	24 x 10^6	Supplement	SBT + C-F-RSF	10	Secondary tech followed by tertiary due to high FC and low performing

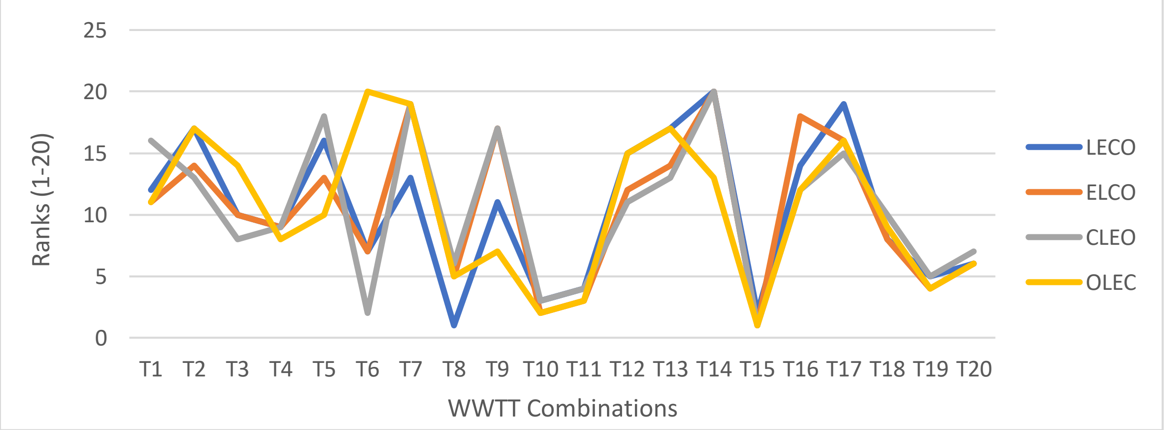
											existing technology
	BIOFOR							Supplement	SBT	5	High performing secondary technology due to high FC
	ASP							Supplement	SBT + C-F-RSF	10	Secondary tech followed by tertiary due to high FC and low performing existing technology

* TF: Toilet Flushing, LW: Laundry Washing, VW: Vehicle Washing, H: Horticulture

4.8 Sensitivity Analysis of Decision Criteria (Land, Energy, Capital Cost and O&M Cost)

Sensitivity analysis is performed to assess the reliability of results by observing the impact of changes in decision criteria weightages on suggested ranks (Hamby, 1994). Stevic et al. (2020) analysed the variations in the ranks by changing the primary dominant criteria while employing FUCOM-MARCOS model for traffic risk assessment (Castillo et al., 2017). In a study conducted by Biswas et al. (2021) FUCOM-CODAS model was employed to facilitate smartphone brand selection. The stability of results in this study was checked under fixed primary criteria condition and changing primary criteria. Erceg et al. (2019) employed ABC-FUCOM model for stock management and checked the reliability of results by varying primary criteria. In this study, both varying primary criterion and fixed primary criterion conditions are examined. The case of industrial cooling in Kanpur city is considered to demonstrate the stability of results while the decision criteria weightages are varied as per requirement. It is to be noted that primary criteria refer to the criteria that was rated most important by the decision makers.

The developed DSS_IWWM is based on four decision criteria (‘L’ depicts land, ‘E’ depicts energy, ‘C’ depicts capital cost and ‘O’ depicts O&M costs), therefore, a total of 20 different WWTT combinations (Depicted through T1-T20 here) of these decision criteria need to be



examined for establishing the reliability of the results. In Figure 4.24, the variations in the ranks of top 20 WWTT combinations with changing primary criterion are presented.

Fig. 4.24 Variations in ranks of WWTT combinations under changing primary criteria (Land, energy, capital cost, and O&M cost)

Significant variations in the ranking of WWTTs can be observed in the above figure. It is seen that most of the technologies experience a change in rank with change in weights for different primary criteria. Therefore, it can be inferred that the developed DSS_IWWM is sensitive to variations in weightages for decision criteria (Erceg et al., 2021; Stevic and Brkovic, 2020).

Futher, the variations in the rankings of WWTTs with fixed primary criteria and varying other criteria are examined as shown in Figures 4.25-4.28.

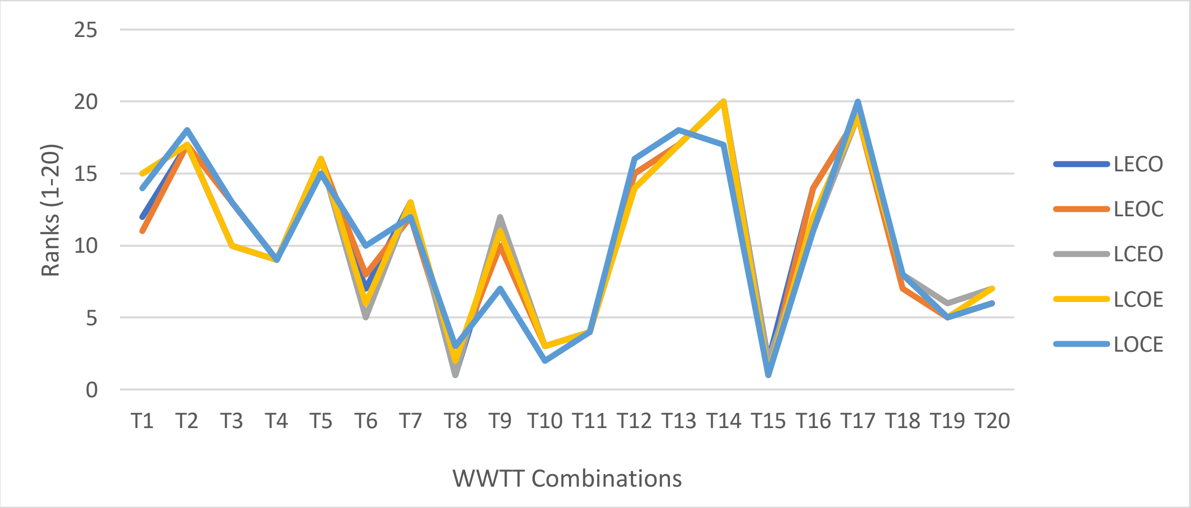


Fig. 4.25 Variations in ranks of WWTT combinations with land as primary criterion and varying weightages of remaining criteria (energy, capital cost and O&M cost)

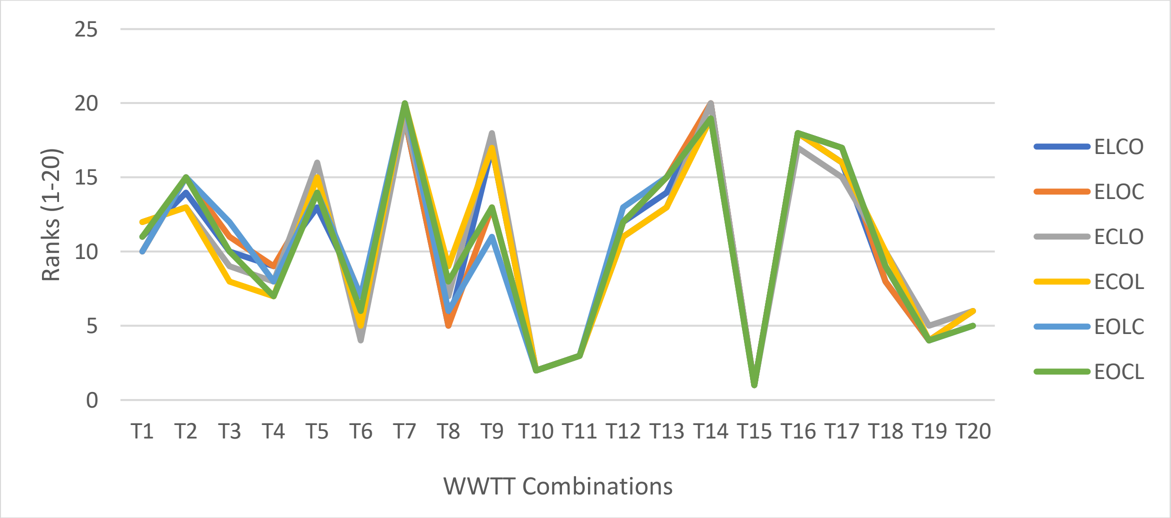


Fig. 4.26 Variations in ranks of WWTT combinations with energy as primary criterion and varying weightages of remaining criteria (land, capital cost and O&M cost)

Similarly, it can be seen in Figures 4.25 and 4.26, that the graphs follow a common pattern and a few variations in the rankings are obtained, indicating stability of the results. The closeness of the graph indicates the sensitivity of result under given primary criterion (Blagojevic et al., 2021).

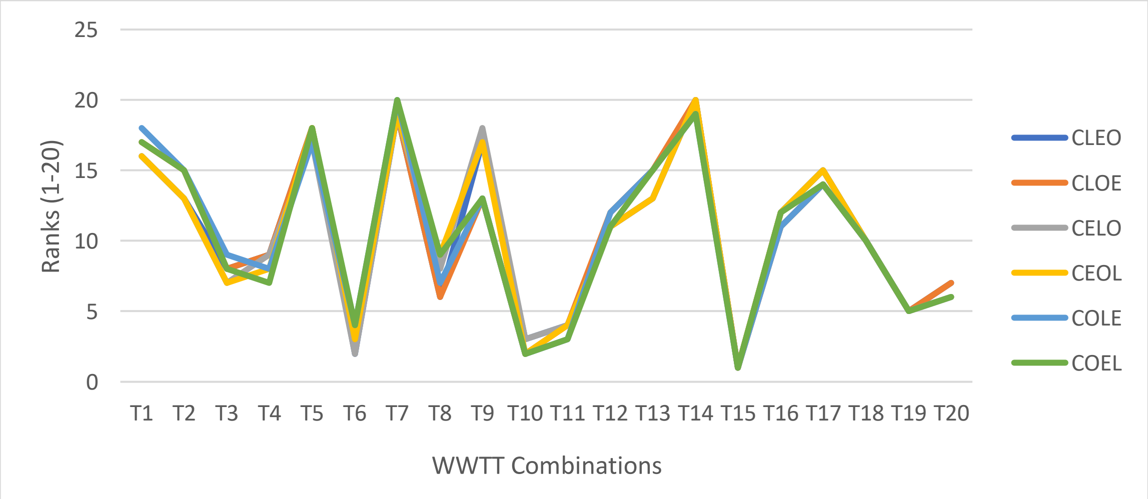
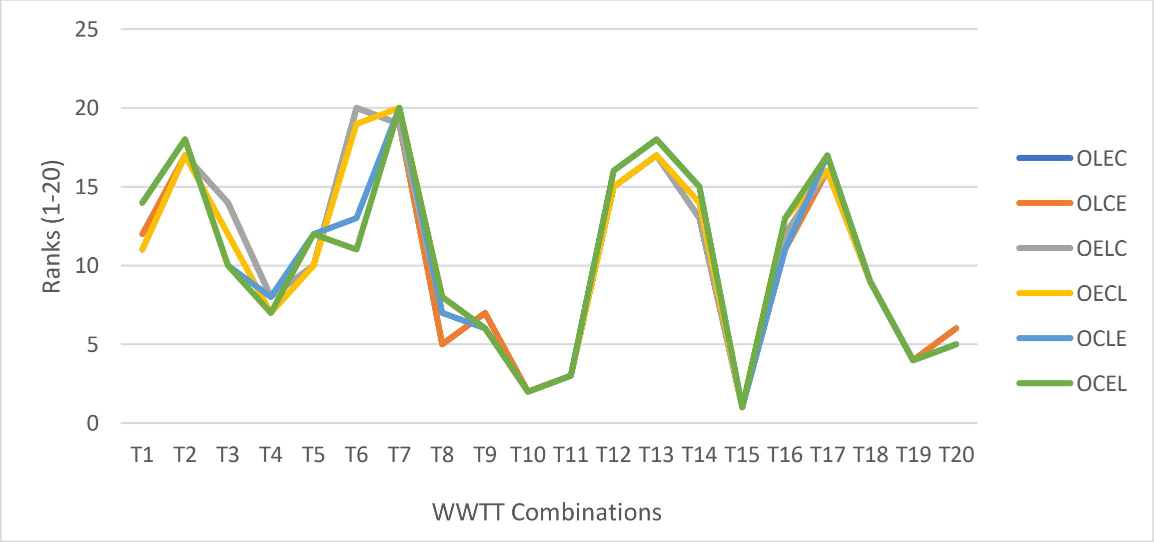


Fig. 4.27 Variations in ranks of WWTT combinations with capital cost as primary criterion and varying weightages of remaining criteria (land, energy and O&M cost)

Fig. 4.28 Variations in ranks of WWTT combinations with O&M cost as primary criterion and varying weightages of remaining criteria (land, energy, and capital cost)

In Figures 4.27 and 4.28, a common pattern can be observed in each of the graphs with capital cost and O&M cost as fixed primary criteria. In these two cases, the graphs are closely spaced indicating sensitivity of results to primary criteria capital cost and O&M cost (Mijajlovic et al., 2020).

A common pattern in ranks of WWTTs is observed, indicating stability of results subject to primary criteria considerations and high individual value of resources. The results show adequate variations with changing primary criteria, hence, indicating sensitivity of DSS_IWWM.



4.9 Observations from the Application of DSS_IWWM on Indian Cities:

For validation of the DSS_IWWM, it is first applied to five cities in the state of Uttar Pradesh (Kanpur, Lucknow, Varanasi, Prayagraj and Agra), and finally after getting justifiable results, the application was extended to seven additional cities from other states depicting varying resource and reuse options under differing socio-economic and climatic conditions in the country.

i. Kanpur city:

- For the city of Kanpur, two case studies are considered, the first around Bingawan STP (UASB+ EA) targeting reuse of treated water for industrial cooling at Panki Thermal Power Station and, the second around Sajari STP (ASP) intending non-potable reuse (Toilet flushing, lawndry washing, road cleaning, horticulture, and outdoor bathing).
- The application of DSS_IWWM suggests that the effluent quality from Bingawan STP needs to be improved through addition of Wuhrmann process (WP) followed by tertiary treatment technologies, including ultrafiltration (UF) and reverse osmosis (RO) to the existing treatment system to produce reclaimed water suitable for industrial cooling purpose.
- The effluent quality from Sajari STP (ASP) is suggested to be improved through supplementation with Soil Biotechnology (SBT) followed by WP to produce effluent suitable for non-potable reuses, such as toilet flushing, laundry washing, road cleaning and horticulture.

ii. Varanasi city:

- For Varanasi city, three reuse purposes- i. railway (platform, apron, coaches) washing from DLW (ASP-based) STP, ii. e-flow augmentation to river Assi from Ramna (SBR-based) STP and iii. non-potable reuse (road cleaning, toilet flushing, landscape, horticulture) around Goithaha (SBR-based) STP are considered.

- The application of DSS_IWWM suggests that for the intended reuse in railway washing from the reclaimed water of DLW STP, a new installation based on BIOFOR-F technology is the most appropriate. Alternatively, it also suggests supplementation of existing ASP-based STP with Soil BioTechnology or BIOFOR-F or A2O for producing reclaimed water suitable for railway washing purposes. However, these supplementation options are costlier than the new installation of BIOFOR-F of the same capacity in a lifecycle of 15 years.
- For e-flow augmentation of river Assi from SBR based Ramna STP, it is obtained from application of DSS_IWWM that the reclaimed water from SBR itself can satisfy desired quality for river flow augmentation. However, as a new installation, Soil BioTechnology is suggested as the most appropriate WWTT due to lower cost in a design life of 15 years.
- For the non-potable reuse demand around the Goithaha (120 MLD) STP, addition of Modified Ludzack Ettinger (MLE) process to the existing SBR-based technology is obtained as the most appropriate WWTT combination.
- For meeting additional reclaimed water demand, new installation BIOFOR-F followed by WP is suggested as the most appropriate WWTT combination. As supplementation to the existing SBR-based STP, SBT is found to produce reclaimed water satisfying non-potable reuse quality requirements.

iii. Lucknow city:

- For Lucknow city, seven possible non-potable reuses (Landscape, e-flow augmentation, vehicle washing, toilet flushing, fire protection, laundry washing, road cleaning) are identified in the vicinity of Awas Vikas Parishad STP (37.5 MLD, SBR-based).
- The DSS_IWWM suggests that for supplementation of existing STP (SBR-based) at Awas Vikas Parishad, SBT is the most appropriate WWTT option to meet the reclaimed water quality criteria for non-potable reuse.
- For meeting additional reclaimed water demand, new installation of BIOFOR-F followed by ultrafiltration and reverse osmosis processes is obtained as most appropriate WWTT combination for a design period of 15 years.

iv. Prayagraj city:

- For Prayagraj city, six possible non-potable reuses Landscape, toilet flushing, horticulture, outdoor bathing, vehicle washing, and road cleaning) are identified in the vicinity of Naini STP (ASP, 80 MLD).
- The DSS_IWWM suggests that supplementation of the existing ASP-based with SBT followed by coagulation, flocculation and rapid sand filtration processes is the most appropriate WWTT combination to produce reclaimed water satisfying the non-potable reuse quality requirments.
- For meeting additional reclaimed water demand, new installation of BIOFOR-F followed by microfiltration and reverse osmosis is obtained as most suitable WWTT combination for meeting the desired quality expectations for a design period of 15 years.

v. Agra city:

- For Agra city, six possible non-potable reuses (vehicle washing, e-flow augmentation, landscape, horticulture, toilet flushing and road cleaning) are identified in the vicinity of Peelakhar STP (10 MLD-Oxidation Pond).
- The DSS_IWWM suggests that supplementation of existing oxidation pond based STP, with BIOFOR-F is the most appropriate WWTT combination to produce reclaimed water satisfying the non-potable reuse quality criteria.
- For meeting additional reclaimed water demand, new installation of BIOFOR-F followed by coagulation, flocculation and rapid sand filtration is most suitable WWTT combination for meeting the desired quality expectations for a design period of 15 years.

vi. Other Cities from Different Regions of India (South Region- Madurai, Hyderabad, Panjim, **North Region-** Jalandhar, Delhi, **West Region-** Jaipur **and East Region-** Patna**)**

- Four possible non-potable reuses (Toilet flushing, lawndry washing, vehicle washing and horticulture) have been considered.
- For cities with SBR-based STPs and highly polluted raw wastewaters (such as Patna and Jaipur) with high COD, TSS and FC, supplementation with low-cost, and high-performing SBT is obtained as the most appropriate WWTT combination for producing reclaimed water suitable for non-potable reuse quality criteria.

- For SBR-based STPs at cities such as Hyderabad, Jalandhar and Goa with low COD, TSS and FC concentrations in influents, relatively lower-cost, and low-performing WWTT such as oxidation pond is obtained as th most appropriate. In Madurai, due to very high COD, high performing and costlier A2O technology is obtained as the most appropriate suggestion for supplementing SBR-based STP.
- For MBBR based STPs with lower observed performance such as at Jaipur because of high COD, TSS, FC concentrations in the influent, supplementation with BIOFOR-F + MLE are obtained as most appropriate.

vii. Sensitivity analysis

- The appropriate WWTT combinations suggested by the DSS_IWWM application are sensitive to changing primary decision criteria (land, energy, capital cost and O&M cost) as significant variations in WWTT rankings are observed.
- A common pattern in WWTT rankings is observed under each individual primary criterion, depicting stability of the results suggested by DSS_IWWM.