A DECISION SUPPORT SYSTEM FOR APPROPRIATE TREATMENT TECHNOLOGY SELECTION FOR INTEGRATED WATER AND WASTEWATER MANAGEMENT

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By

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CHAPTER 5

SUMMARY AND CONCLUSIONS

5.1 Summary and Conclusions

Reclaimed water has emerged as a new potential resource in the wake of imminent water crisis. This study emphasises on bringing a shift in the human water cycle from a linear economy paradigm of take-make-dispose to a circular economy vision through reuse-focused integrated water and wastewater management (IWWM). In the present study a decision support system for integrated water and wastewater management (DSS_IWWM) has been developed to facilitate selection of appropriate wastewater treatment technology (WWTTs) and localised planning of reclaimed water around sewage treatment plants (STPs) to achieve the desired value of water. Thus, there were three primary objectives of this study,

i. identification of key factors affecting reuse of reclaimed water in IWWM,

ii. selection of reuse-focused appropriate wastewater treatment technologies (WWTTs), and

iii. localized planning around STPs in terms of reclaimed water demand identification, estimation, allocation, and sustainable pricing.

The application of developed DSS_IWWM has been validated using data from five cities of Uttar Pradesh (India). With justifiable results, finally, the application has been extended to seven more cities of India representing various socio economic and climatic conditions in the country. The summary of observations and recommendations have been presented.

As a part of the first objective, out of 22 potential factors obtained through literature review (Annexure II) for a reused focused IWWM, as 12 or lesser factors are considered most suitable for applying ISM (Attri et al., 2013), 12 key factors (i. Policy and Regulations, ii. Treatment Technology, iii. Demand for Treated Wastewater, iv. Land Requirement, v. Social Acceptance, vi. Post-Distribution Network, vii. Reuse Purpose, viii. Power Requirement, ix. Capital Cost, x. Operation and Maintenance Cost (O&M), xi. Water Pricing, and xii. By-Products and GHGs) were identified and finalized based on the rankings provided by the experts. Other ten factors (i. Material Requirement, ii. Nutrient Recovery, iii. Manpower Requirement, iv. Availability of Raw Wastewater, v. Ease of Operation, vi. Technical Durability, vii. Centralized or Decentralized WWTPs, viii. Value of Saved Water, ix. Funding Availability, and x. Weather and Climatic Conditions were not considered important to be included in the priority due to lower importance ratings given by the experts. Most of the excluded factors influence only the technical aspect of the reuse focused IWWM.

Next, Interpretive Structural Modelling (ISM) is used to develop a hierarchy of the 12 identified key factors. A total of 8 levels are obtained with the bottom-most level (Level VIII) depicting highest importance and top-most level (Level I) depicting least importance among the 12 factors. Further, the identified 12 key factors are classified into four categories namely, driving factors, dependent factors, linkage factors and autonomous factors, using Matrix of Cross Impact – Multiplications Applied to Classification (MICMAC) analysis. The classification highlights the influencing capacities of factors.

Following conclusions are drawn for the first object.tive of this study:

- Using ISM, two factors- Policy and Regulations and Social Acceptance, placed at the bottom-most level (level VIII) signify the factors of highest importance. These factors are important as they form the basis for a conducive environment for a reuse focused IWWM through acceptability and regulatory frameworks.

- Five factors including Reuse Purpose, Post-Distribution Network, Demand for Treated Wastewater, Power Requirement, and Treatment Technology fall in intermediate-levels (level IV, level V, level VI, and level VII) suggesting a significant role in the transfer of influence from higher levels to lower levels. These factors depict the relevance of technical and demand aspects of reclaimed water for an efficient IWWM.

- Five factors (Capital Cost, Operation and Maintenance Cost, Water Pricing, Land Requirement, and By-Products and GHGs, are found in top levels (level I, level II, and level III) signifying lower driving importance. However, these factors are significant as they purely refer to the treatment technology aspects of reuse focused IWWM.

- Using MICMAC analysis, five factors- Reuse Purpose, Post-Distribution Network, Social Acceptance, Treatment Technology, and Policy and Regulations are obtained as driving factors, suggesting criticality of these factors while implementing reuse focused IWWM.

- Demand for Treated Wastewater is obtained as the only autonomous factor, indicating its independent nature. This factor is driven by social acceptance and related policies and regulations.

- By-products and greenhouse gas emissions (GHGs) is found as linkage factors, depicting a high role in influence transfer between driving and dependent groups.

- Five factors including Power Requirement, Capital Cost, Operation and Maintenance Cost, Water Pricing, and Land Requirement are obtained as dependent factors. These factors are essential for water pricing.

- 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 DSS_IWWM using socio-economic methodology for reclaimed water demand allocation.

- Two factors, Policy and Regulations and By-products and GHGs have not been addressed in the developed DSS_IWWM at present. They are suggested in the future scope of this study.

Selection of reuse-focused appropriate wastewater treatment technologies (WWTTs) is the second objective of this study. Accordingly, fourteen reuse purposes have been identified and their critical quality parameters were enlisted. The reuse purposes include: i. Toilet Flushing, ii. Construction, iii. Road Cleaning, iv Landscape, v. Industrial Cooling, vi. Irrigation, vii. Vehicle Washing, viii. Inland Surface Water/Surface waters as a source of drinking water, ix. Fire Protection, x. Laundry Washing, xi. Dust Control, xii. Snow Making, xiii. Outdoor Bathing and xiv. Groundwater Recharge.

Next, 25 WWTTs, including 18 secondary treatment methods, 4 emerging technologies and 3 tertiary treatment technologies, are analyzed in 360 combinations to obtain a chain of treatment units that satisfy the effluent quality requirements for the desired reuse.

For ranking of appropriate WWTTs based on four decision criteria namely, land, energy, capital cost and O&M cost, a least-weighted cost methodology using FUCOM for weightage calculation and weighted sum method for converting the multi-criteria problem into a single point objective has been developed. The methodology is sensitive to local-resource scenarios and is user-friendly and flexible in nature. It uses all possible options in terms of secondary, tertiary, and emerging technologies, facilitating appropriate treatment technology selection for the identified and intended reuse in the vicinity of a STP.

Localized planning of reuse around the existing STPs in terms of water demand identification, estimation, allocation, and sustainable pricing is the third objective undertaken in the present study. A socio-economic methodology with proportionate pricing for various categories of users based on their income and cost recovery potentials is suggested to allocate water demand. With this approach, the cost burden from the public for basic utilisation of reclaimed water is reduced and appropriate contribution from commercial users are realised.

The DSS_IWWM is a user-friendly tool, developed using streamlit framework, written in Python language, and hosted on platform GitHub.

The DSS_IWWM has two modules: The first module gives the reuse focused selection of appropriate wastewater treatment technology combination. For application of this module, identification of possible reuses of reclaimed water in an area is the first step. From here, the desired effluent quality parameters are firmed up. The influent characteristics in terms of COD, BOD, TSS, TN and FC are provided as input. Rating of decision criteria, such as land, energy, capital cost and O&M cost is required to be given on 1-4 scale. With such inputs, the DSS_IWWM puts forth all WWTT combinations that satisfy the effluent quality requirements with sensitivity to local resource scenario.

The application of the first module of DSS_IWWM indicates that:

- The raw wastewater quality characteristics and intended reuse decide the degree of treatment to be given through WWTTs.
- With multiple reuse purposes, the DSS_IWWM suggest the chain of treatment units satisfying the most stringent criteria for the effluent quality.
- Reclaimed water of desired quality for selected reuse purpose(s) can be produced through either augmentation/supplementation with appropriate technologies to the existing STPs, or installation of a new STP with chosen chain of units.
- The DSS_IWWM gives output in the form of a list of prioritized combinations of treatment technology chain based on least weighted cost.
- The recommendation for appropriate WWTT combinations vary with changing

influent characteristics.

- For the same target reuse, mostly supplementation of existing technology is found to be more economical than installation of a new STP.

- Referring addition of emerging or tertiary technologies to the existing technology at STPs as upgradation and addition of secondary treatment technologies to the existing STPs as supplementation, it is observed that conventional technologies (such as ASP, OP, and UASB+EA) require upgradation or supplementation with advanced WWTT combinations (such as BIOFOR-F, SBR and A2O) incurring higher costs for producing desired quality reclaimed water.

- Advanced oxidation processes (AOP) based technologies (such as A2O, SBR, MBR, and BIOFOR-F) may require supplementation with relatively low-cost WWTTs (such as SBT and OP) to produce reclaimed water of required quality.

- As supplementing secondary treatment technology, Soil Biotechnology (SBT) is the most preferred option, primarily because of relatively lower costs and higher performance.

- As augmentation unit, emerging biological nutrient removal (BNR) technology based Wuhrmann Process (WP) is found as the most preferred WWTT option.

- In order to futher improve the reclaimed water quality for intended reuse, physico-chemical approach based treatment technology combinations such as coagulation, flocculation, rapid sand filtration (C+F+RSF), ultrafiltration, microfiltration, reverse osmosis (UF/MF + RO) are recommended to the biologically treated and denitrified effluent.

The second module of DSS_IWWM helps in localized planning for reuse of reclaimed water around STPs in terms of demand identification, estimation, allocation, and sustainable pricing. The reuse applications of reclaimed water are divided into five categories based on income potential from end-user consumptions: i. agriculture, ii. public utilities, iii. domestic demand, iv. industrial demand, and v. commercial demand. Proportional pricing of reclaimed water based on break-even point analysis has been used so that the demands of the socially prioritized users (such as agriculture and public utilities) are met while ensuring cost recovery from other end-use categories (such as domestic, industrial and commercial).

The application of the second module of DSS_IWWM indicates that:

- The Capital and O&M costs of WWTTs and the socio-economic prioritization of end-use categories play the most significant role in reclaimed water demand allocation and cost recovery.

- The socio-economic planning of reclaimed water is performed by ensuring allocation of minimum water demand to the prioritized categories (agriculture and public utilities).

- After satisfaction of socially prioritized demands, the allocation of reclaimed water to high revenue generating categories (domestic, industrial and commercial) is performed. This creates an opportunity for significant cost recovery.

- The break-even point approach is an effective tool for feasible cost recovery by the end of the desired year.

- The design period of the treatment facility is a critical factor for sustainable pricing. The longer the design period, the lower will be the feasible average price.
- If the reclaimed water demand in the vicinity of an STP is less than its installed capacity, the prices for the end-users are higher. If the reclaimed water demand matches the installed capacity, the price reduces.
- Generally higher unit prices of reclaimed water are required for new installations due to higher initial and operational costs..
- Reclaimed water from supplementation/augmentation of existing STPs based on conventional technologies (such as ASP, UASB) require higher average prices than advanced technology (such as SBR, A2O, BIOFOR-F) based existing STPs.

The results showed that the DSS_IWWM developed in the present study produce recommendations that are useful and justifiable for field application. Hence, DSS_IWWM can be used as a tool for decision-makers for reuse focused wastewater treatment technology selection and cost recovery, bringing full value of water as a part of circular economy.

5.2 Research Contribution to Existing Literature

Wastewater reclamation has been vividly studied by the scientific community. But in-depth exploration from the lens of integrated water and wastewater management to develop a circular economy is the need of the hour. This study augments the existing literature as:

- It identifies the key influencing factors that affect reuse focused IWWM and establishes the interrelationships between them using rational methodologies.

- It presents a reviewed repository of twenty-five wastewater treatment technologies.

- It employs a local-context approach, covering technical, social, as well as economic aspects for appropriate technology selection and reuse of reclaimed water around STPs.

- It suggests a proportional pricing approach for balancing the burden of capital and O&M costs recovery from different end-use consumption categories such as agriculture, public utilities, domestic, industrial and commercial.

5.3 Implications for Practice

This study is beneficial as it identifies the underlying interrelationships between the relevant factors influencing reuse focused IWWM and points out the type of influences such as driving or depending, and the importance hierarchy between them. This study could be helpful for designers, planners, and policymakers to plan, implement, and promote an efficient reuse focused IWWM system. The study also has following implications for practice:

- This study supports selection of technologies that incur lower capital expenditure for producing the reclaimed water for the desired reuse.

- It leads to development of circular economy in wastewater management, moving from wastewater treatment and disposal to cost recovery and revenue generation giving value to water.

- It will attract private players to become stakeholders in IWWM, STP construction and reclaimed water management.

- Application of DSS_IWWM will lead to pollution prevention of water bodies and conservation of freshwater.

5.4 Implication of Research for Policy Formulation

As per MoJS (2021), urban local bodies are required to allocate 20-25% of treated used water (TUW) for reutilisation to reduce freshwater usage. The mandated reuse percentage should increase in subsequent phases. The adoption of reuse focused appropriate treatment technology selection, as illustrated by DSS_IWWM can help ULBs achieve the desired target with scientific and rational planning. The DSS_IWWM emphasises localised reuse of reclaimed water around existing STPs. Hence, this study will enable the government to formulate policies for identification of possible reuse purpose, definition of reuse quality criteria, formulation of guidelines to estimate reclaimed water demand, procedure to allocate reclaimed water quantity, select appropriate technology and sustainable pricing mechanism for cost recovery.

As per CPCB (2009), more than 300 STPs were installed across the country under the Ganga Action Plan and Yamuna Action Plan (GAP-I and YAP-I). These STPs were largely designed to reduce the pollution load on the river with the help of conventional technologies such as ASP and UASB. With the new objective of reclaimed water reuse, augmentation and supplementation of existing STPs can be done with the help of this study. Therefore, the DSS_IWWM can help government take necessary action to improve the performance of existing STPs and setting up of new STPs, with economically feasible options. The DSS_IWWM can act as a scientific support to government’s phased intervention planning.

5.5 Limitations

The present study identified twelve key factors out of the twenty-two potential factors. From them, ten key factors (reuse purpose, demand for treated wastewater, water pricing, post distribution network, treatment technology, land requirement, energy requirement, capital cost and O&M cost) have been considered in the present study. The remaining two key factors (Policy and Regulations and By-products and GHGs) have been suggested as the future scope of the study.

This study only identifies the critical influencing factors and establishes interrelationships, but the strength of the relationship between the factors cannot be obtained using ISM since they use only binary inputs.

The quality criteria for different reuse purposes have been taken from review of literature across the world. These quality criteria may vary under different climatic conditions.

The DSS_IWWM is based on five quality parameters such as BOD, COD, TSS, TN and FC. More quality parameters such has TDS, Boron, electrical conductivity, etc. may be considered and used.

The DSS_IWWM is based on 25 identified WWTTs. The performance efficiencies have been taken as reported in the studies. These may vary with changing influent characteristics and climatic conditions.

5.6 Scope for Future Studies

Following studies can be undertaken to enhance the universal application and efficiency of the developed DSS_IWWM:

- The factor- By-products and greenhouse gas emissions (GHGs) can be included in the further study to enhance the environmental sustainability of the DSS_IWWM for carbon emission reduction.

- The study considered five quality parameters- BOD, COD, TSS, TN and FC. More quality parameters such as total dissolved solids (TDS), turbidity, boron, etc. can be included.

- Other treatment technologies such as, soil aquifer treatment (SAT), Electrocoagulation, Biofilters, Carbon filters, Rotating Biological Contacters (RBC) etc. may be included and evaluated for appropriate treatment technology selection.