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SELECTION OF SEWAGE TREATMENT TECHNOLOGY FOR DELHI USING MULTI-CRITERIA DECISION-MAKING

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CANDIDATE'S DECLARATION

I MEGHA CHAISAR, ROLL No-2k19/PIE/06 student of M.Tech (Production Engineering), hereby declare that the project dissertation titled "Selection of Sewage Treatment Technology for Delhi using Multi-Criteria Decision-Making" which is submitted by me to the Department of Mechanical Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of the Master of technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition

Megha

Place: Delhi **(MEGHA CHAISAR)**

Date:1/08/2021

CERTIFICATE

I hereby certify that the project Dissertation titled “Selection of Sewage Treatment Technology for Delhi using Multi-Criteria Decision-Making” which is submitted by [MEGHA CHAISAR], Roll no 2k19/PIE/06 [Department of mechanical Engineering], Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this university or elsewhere.

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ABSTRACT

In India, untreated sewage is the primary polluter of water sources and rivers, resulting in a variety of illnesses, environmental degradation and agricultural pollution. The urban poor often residing near filthy drains and canal suffers due the mismanagement of sewage. The sewage systems in India's metropolitan cities, such as Delhi, are centralized, with underground pipelines, pumping stations, and treatment facilities. While a range of water treatment technologies are available, still the selection of the best technology among all alternative is a difficult job. The past study indicates that few Multi-Criteria Decision-Making (MCDM) method have been used to assess the performance of Sewage Treatment Technology (STT), but the negligence to take account of criteria such as Fecal Coliforms (FC) and other hazardous microorganisms has somewhere affected the reliability of results. This study attempts to help decision maker for selecting most appropriate STT by using Analytical Hierarchical Process (AHP) method of MCDM. Thirteen Sustainable criteria related to Social Acceptability, Suitability for Horticulture and Economical STP1ect were identified and analysed to evaluate the performance of STT. In this study four alternatives, namely STT1, STT2, STT3, STT4 were analysed STT2 with highest priority score (0.30) found to be most sustainable sewage treatment technology.

Key words: MCDM, AHP, Priority Vector, Critical Ratio

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SA	SOCIAL ACCEPTABILITY
EA	ECONOMICAL STP1ECT
SFH	SUITABILITY FOR HORTICULTURE
O	ODOUR
SH	SLUDGE HANDELING
WC	WATER CONSUMPTION
GC	GREEN COVER
MOC	MAINTENANCE & OPERATION COST
LC	LAND COST
CC	CAPITAL COST
UL	USEFUL LIFE
TDS	TOTAL DISSOLVED SOLIDS
BCD	BIOLOGICAL OXYGEN DEMAND & CHEMICAL OXYGEN DEMAND
E.COLI	ESCHERICHIA COLI
STP4	UP FLOW ANAEROBIC SLUDGE BLANKET
STP3	SEQUENCE BATCH REACTOR
STP1	ACTIVATED SLUDGE PROCESS
STP2	MESTP2ANE BIOREACTOR
AR	ALTERNATIVE RATING
PV	PRIORITY VECTOR
CR	CONSISTENCY RATIO
STT	SEWAGE TREATMENT TECHNOLOGY
PS	PRIORITY SCORE

Chapter 1

INTRODUCTION

1.1 Introduction

India is the second most populated country in the world with a population of 1.21billion as per 2011 census. It accounts for about 17.5% of the world population with land area of 3.287 million km2, which is only 2.5% of the total land area and only have 5 % share of the world’s water resources. Considering the 2011 census, the urban population of India is expected to increase from 31.2% in 2011 to 38.8% by 2026. Therefore, the demand for urban infrastructure is expected to increase dramatically in upcoming years, which represents a great challenge for policy makers and urban planners. There are 7935 towns/cities in India. Based on population, they are classified into class I to VI towns/cities as follows.

- Class-I cities- 414 cities with population of more than 100,000.
- Class-II cities- 489 cities with population between 50,000 and 100,000.
- Class-III to Class-V- Towns with population between 5000 and 49,999
- Class-VI- Towns with population less than 5000.

It should be noted that the minimum expected Sewage flow rate for Class- I cities is approximately 11 million litters per day (MLD), the water supply is 135 Lpcd for 100,000 people, and the sewage generation rate is 80%. This poses a challenge to sewage collection and treatment in towns and cities. The Central Pollution Control Board (CPCB), India’s leading pollution control organization, from an inventory of sewage generation and its disposal reported that in 2005, the Sewage generated in Class-I and II cities was 38,254 MLD, out of which only 30% of the sewage was collected and Only 20% of the collected sewage was treated in sewage treatment plants (STP). By 2051, the amount of sewage generated in urban areas in India is expected to exceed 120,000 MLD, and the respective STP capacity is expected to be between 0.5 MLD and 150 MLD, depending on water supply and population (CPCB 2007). Sewage containing biochemical oxygen demand (BOD), suspended solids (SS), and Fecal Coliforms (FC) can contaminate water, reduce water quality and the aesthetic characteristics of the water body, and can lead to outbreaks of water borne diseases. Considering the need to prevent water pollution and protect valuable water resources, the collection and treatment of sewage is ranked as the highest priority.

1.2 Sewage Generation in Delhi

In the past, sewage pollution in a city or state was less, but today it pollutes more. In any case, with the development of the population, urbanization and lifestyle, the quality and quantity of urban sewage have recently increased. Therefore, the correct treatment and management of sewage has become an important process to guarantee biological health and a good quality of life. Currently, sewage must be properly treated to ensure its safety before being discharged into the river or on the bank. Sewage treatment basically includes the expulsion of small-scale life forms, toxins or pollutants from wastewater. This is done using various technologies. For example, in Delhi, 35 sewage treatment plants (STPs) use 6 different types of technologies. As early as 1962, Delhi became one of the first Indian cities to propose an city development plan, Delhi has been identified as the top-priority city for the work to be done to combat the magnitude of pollution in the river's 22km stretch through the city. Therefore, to improve the status quo, this paper offers solutions to various problems in Delhi sewage treatment and disposal. India is a country with a rich and diverse heritage and huge cultural beliefs. It turned out that civilization originated on the banks of the river. Past civilizations, like Harappan, have historical evidence that civilizations thrived on banks of rivers. The past scenes of the river water quality have changed a lot from the current scenes. Rapid urbanization and industrialization have caused too many environmental problems, which have offset the benefits of modernization and development. Water, food and energy securities are becoming increasingly important and vital issues in India and the world. The current and future demand for fresh water can be met by improving water efficiency and demand management. Therefore, wastewater/poor quality water is becoming a potential source for demand management after necessary treatment. It is estimated that 38354 million litters per day (MLD) of sewage is generated in major cities in India every day, but the in-sewage treatment capacity is only 11786 MLD. Similarly, only 60% of industrial wastewater is treated which mainly includes large-scale industries. State-owned sewage treatment plants are used for municipal sewage treatment, and ordinary sewage treatment plants are used to treat small-scale industrial sewage, and they do not meet the prescribed standards. According to CPHEEO estimates, 70 to 80% of total household water consumption is generated as wastewater. The per capita wastewater generation by the class-I cities and class-II towns, representing 72% of urban population in India, has been estimated to be around 98 lpcd while that from the National Capital Territory-Delhi alone (discharging 3,663 MLD of wastewaters, 61% of which is treated) is over 220 lpcd (CPCB, 1999). In Delhi around 3296 MLD (Million Liters per day) of sewage is dumped in the river.

1.2.1 Water Demand

The water demand is proportional to the population, greater the population higher will be the water demand. It is also dependent on various other factors such as lifestyle of the individual, type and nature of the intake, size of the city, metering system etc. Based on the norms of 60 Gallon Per Capita per Day (GPCD) as per the Central Public Health and Environmental Engineering organization (CPHEEO), Ministry of Urban Development, Government of India norms. The total requirement of water in March in 2011 was found to be 1020 MGD. The water demand is calculated by multiplying the population with the per capita demand. The various types of water demand, which a city may have, may be broken down into various classes such as domestic demands, Industrial demands, Institutional demands, public use demands, Fire,

loss and theft demand.

The amount of domestic water consumption per person shall vary according to the living conditions of the consumers

Average rate of draft in litres per day per service= (V/365 * 1/ No of services)

Per capita demand (q) = [total yearly water requirement of the city in litres (V)/ 365 *population]

Where, V is total annual volume in litres or million litres. As per IS:1172-1993 the minimum domestic consumption of a town or city with full flushed system should be taken as 200l/h/d; although it can be reduced to 135l/h/d for economically weaker section and LIG colonies depending upon the prevailing condition. The Delhi development authority has taken a figure of 274 lpcd or 60 GPCD. The water demand is calculated by multiplying the water demand by the projected population. The requirement of water may keep varying decade to decade as it depends on various factors as mentioned above. A proper water supply plan must be adopted to meet the required deficit.

1.2.2 Wastewater generation

According to reports, 80-90% of water is converted into wastewater. Therefore, considering the percentage mentioned by CPHEEO, the calculated water demand is converted to wastewater. The amount of wastewater generated is estimated to be based on the amount of water needed in financial year 2050. Wastewater refers to liquid waste derived from domestic water. It includes wastewater, toilet discharges, urinals, wastewater generated by commercial establishments, institutions, and industrial establishments, as well as groundwater and rainwater that can enter sewers. Its decomposition will produce a large amount of malodorous gas, and contain many pathogenic bacteria, as well as high concentrations of organic matter and suspended solids. According to CPHEEO’s statement, almost 80% of water is wastewater. The water consumption in the years shown is predicted based on wastewater. As mentioned in the Delhi master plan, the value of water demand in 2021 is known, and various mathematical methods are used to predict the next few years. Therefore, the amount of wastewater produced is calculated as 80% of the given water demand.

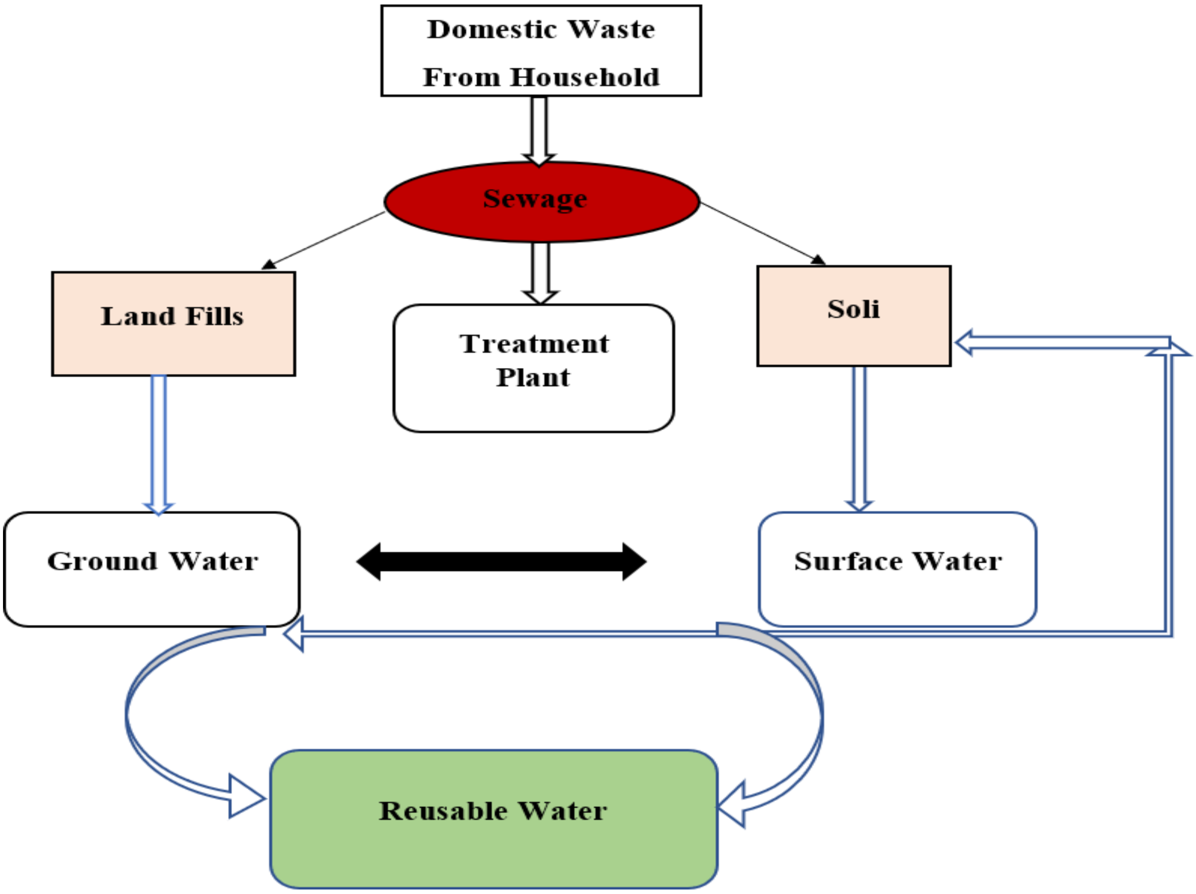

Fig 1. Lay out of domestic sewage circulation from house household to environment (Self)

1.3 Sewage Treatment Technologies

The STP technology comprises a sequence of unit processes and operations arranged in numerous alternatives. Many technological advances for STP have emerged in recent years as a result of the adoption of environmental policies and laws. New directions and concerns are evident in several interrelated areas of sewage treatment such as utilization of biogas for power generation. The available and adopted STP technologies in India are:

- Waste Stabilization Ponds (WSP)
- Aerated Lagoon (AL),
- Activated sludge process (STP1),
- Extended Aeration Activated sludge process (ESTP1),
- Up flow Anaerobic Sludge Blanket (STP4)
- Sequencing Batch Reactor (STP3)
- Moving Bed Biofilm Reactor (MBBR)
- MeSTP2ane bioreactor (STP2)

1.3.1 Waste Stabilization Ponds (WSP)

WSP systems offer an economic solution for treatment of sewage, the only disadvantage being the need for very large tracts of land, which are very scarce in many cities.

1.3.2 Aerated Lagoon

Aerated lagoon system consists of a large earthen pond with hydraulic residence time of 3 to 5 days to hold sewage and mechanical surface aerators to maintain an aerobic environment and prevent settling of the suspended biomass. The energy input for aeration is sufficiently high to keep the solids in suspension with complete mixing besides meeting the oxygenation needs of the system. The land requirements of aerated lagoon are much higher than the ASP.

1.3.3 Activated Sludge Process (ASP)

ASP was the most adopted STP technology in Ganga Action Plan and Yamuna

Action Plan to restore Rivers Ganges and Yamuna respectively and more than 50% of the 269 STPs in India due to its small footprint compared to WSPs systems (TEC 2004; CPCB 2007). More than 80% of the existing STPs and plants under construction in Tamil Nadu are based on STP1 technology. was the most adopted STP technology in Ganga Action Plan and Yamuna Action Plan to restore Rivers Ganges and Yamuna respectively and more than 50% of the 269 STPs in India due to its small footprint compared to WSPs systems (TEC 2004; CPCB 2007). More than 80% of the existing STPs and plants under construction in Tamil Nadu are based on STP1 technology.

1.3.4 Extended Aeration Activated sludge process (EAASP)

ESTP1 technology is a variation of STP1 with a longer hydraulic retention time

(HRT) of 15 to 36 h, with no primary sedimentation tank and sludge digester, since the sludge is well stabilized in the aeration tank due to long aeration. Further the technology involves high power and land costs. The 5 technology is widely adopted for medium towns where biogas power is not envisaged.

1.3.5 Up-flow Anaerobic Sludge Blanket (UASB)

Performance of STP4 systems varies significantly due to overflow of bio-solids in the effluent as a result of the rise in sludge blanket and the inability of operators to monitor sludge blanket (TEC 2004). (Tare et al. 2003) have made a comparison of the performances of STP4 and STP1 technologies in treating tannery waste in India and found STP1 superior to STP4 in all respects. There has been emergence of new treatment technologies, such as STP3, MBBR and STP2 with the intention of reducing footprint in recent times.

1.3.6 Sequence Batch Reactor (SBR)

There has been emergence of new treatment technologies, such as SBR, MBBR and MBR with the intention of reducing footprint in recent times. SBR is a variation of the ASP with batch process in a single reactor in which wastewater is filled, aerated and settled to remove undesirable constituents and then the effluent decanted and discharged. SBR is being preferred now due to its several advantages including smaller footprint needed and a time bound batch process possible with pre-determined flow, automatic control of operation and energy input through a Program Logic Control (PLC) system compared to ASP, which is space oriented with wastewater flowing from one tank to another on continuous basis (Mahvi 2008). In India there are 32 STPs of 1.35 to 125 MLD capacities based on STP3 technology under operation and more than 100 STPs of 1 to 150 MLD capacities are under constructions.

1.3.7 Moving Bed Biofilm Reactor (MBBR)

MBBR technology employs thousands of polyethylene biofilm carriers operating in mixed motion within an aerated wastewater treatment basin. Each individual biocarrier increases productivity through providing protected surface area to support the growth of heterotrophic and autotrophic bacteria within its cells. It is this high-density population of bacteria that achieves high-rate biodegradation within the system, while also offering process reliability and ease of operation. This technology provides cost-effective treatment with minimal maintenance since MBBR processes self-maintain an optimum level of productive biofilm. Additionally, the biofilm attached to the mobile biocarriers within the system automatically responds to load fluctuations.

1.3.8 MEMBRANE BIO REACTOR (MBR)

An STP2, or MeSTP2ane Zone, can best be described as the initial step in a biological process where microbes are used to degrade pollutants that are then filtered by a series of submerged membranes (or membrane elements). The individual membranes are housed in units known as modules, cassettes, or racks and a combined series of these modules are referred to as a working membrane unit. Air is introduced through integral diffusers to continually scour membrane surfaces during filtration, facilitate mixing and in some cases, to contribute oxygen to the biological process. The benefits of MBR includes a reduced footprint, usually 30-50% smaller than an equivalent conventional active sludge facility with secondary clarifiers and media tertiary filtration. The process also produces exceptional effluent quality capable of meeting the most stringent water quality requirements, a modular schematic that allows for ease of expansion and configuration flexibility, a robust and reliable operation and reduced downstream disinfection requirements.

1.4 Evolution of the Analytic Hierarchy Process

Decision-making is a fundamental human action that is often performed so effortlessly that we are unaware we are doing it every minute of every day of every year of our life. This direct and imprecise method served us well when mankind was divided, and individuals and groups of people did what they pleased without much regard for others. Today's society has developed progressively, and the resources have become scarce and valuable, necessitating deliberate decision-making about our most critical courses of action. We must explain our acts not only to ourselves but also to others in order to live in peace with the least amount of conflict possible. Almost all of us were raised with the belief that rational, logical thinking is the only way to confront and resolve issues. We've all been taught that rational thinking is the only approach to confront and solve issues. But we know logical reasoning isn't natural to us. We need to practise for a long period before we become good at it. Because complicated issues contain so many variables, conventional reasoning typically leads to a convoluted sequence that makes finding the optimal solution difficult. We need a conceptual model to deal with the many variables that influence goal attainment and the consistency of the judgements we make to draw concrete conclusions. The new strategy should be justified and appeal to our knowledge and experiences. It should not be overly complicated that only educated individuals can utilise it. The lack of a comprehensive decision-making process is particularly troubling when our intuition alone cannot help us to decide which among the available alternatives is the most desired or least objectionable. Real-world issues need trade-offs to best serve the general interest. To be effective, this approach should also help to build agreement and achieve a sustainable solution. We need a method to judge weight of important alternative over others for short and long run objectives. The Analytic Hierarchy Process (AHP) was designed to cope with such issues. It includes breaking down the problem into segments such that one can only compare a pair of problems at a time. This avoids the problem's multiple elements being merged and the researcher not knowing what goes with what to arrive at the final solution. However, it requires a broad understanding of the people, their interests, and the four issues involved. Once the structure is established, it is easier to communicate the decision's influences.

The AHP appeals to managers and decision-makers at all levels. It enables one to include both the strength of feelings as needed to express the judgment and knowledge of the problems involved in the choice. It systematically integrates many assessments to get the optimum result or combination of actions. Finally, and most importantly, these results are obtained in a manner that is pleasing to human intuition and understanding, not imposed by technological means. This method may be implemented using simple software programmes, making decision-making simpler. In summary, the AHP helps solve complicated issues by organising criteria, sub-criteria, and alternatives and extracting judgements to establish priorities. It also predicts probable outcomes based on these assessments. A system's control may be achieved by assessing the outcome's sensitivity to changes in judgement and preparing for the anticipated and desired characteristics.

1.5 Analytic Hierarchy Process as MCDM method

The analytical hierarchy process (AHP) is the most successful and frequently used MCDM method in a wide range of research applications. AHP streamlines the process of judgment problem analysis. It is a method for evaluating subjective and objective functions in multicriteria decision-making and helping users in reaching mutually accepted conclusions. Another important feature of AHP is its ability for collective decision-making with consensus can direct decision makers toward making the best possible judgement for their problem, rather than toward obtaining "perfect" solutions. It establishes a broad and balanced hierarchical framework for addressing problems of decision-making that are constrained by a shared goal and related criteria. AHP is advantageous in several situations, including decision-making, ranking, prioritisation, and resource allocation. AHP assists in quantifying the weight of evaluated criteria on a numerical basis. The weight of each element's criterion indicates its relative significance in relation to the other components in the hierarchy. As a result, it assists decision-makers in identifying and prioritising important variables. Additionally, AHP's computation of the inconsistency index is a main feature. It enables decision makers to examine the consistency of their judgements. A higher inconsistency index value, more than 0.10, should not be deemed appropriate, and such computations should be revaluated.

Mahvi listed various applications of AHP in their classification of operation research into five major categories, which include operation strategy, process, product design, planning and scheduling resources, project management, and supply chain management.

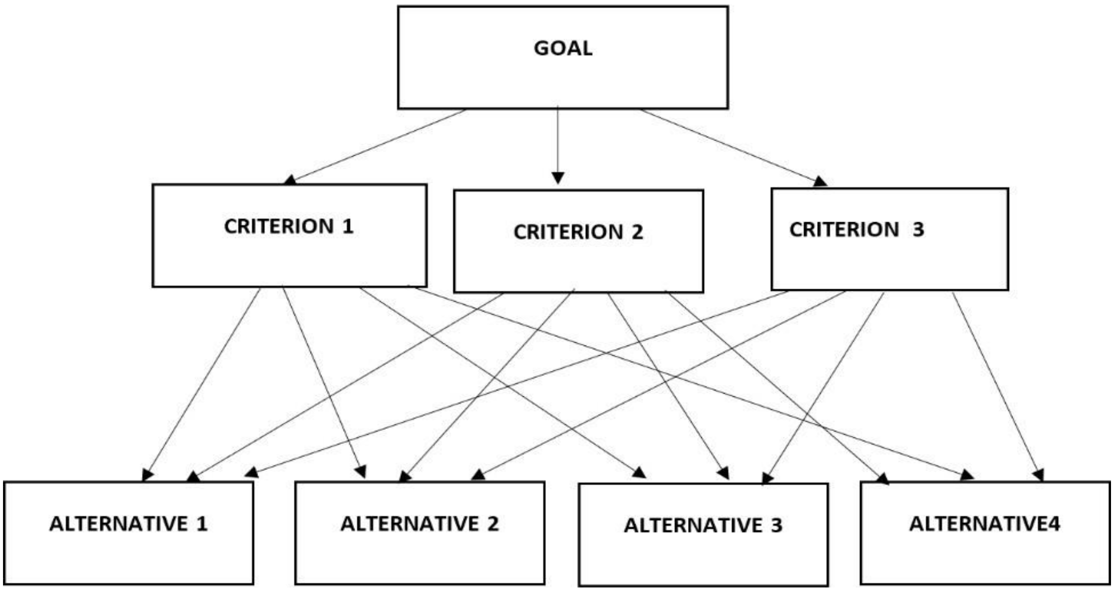

Fig 2. AHP diagram (Self)

1.6 Application areas of The Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP), since its origin, has been a tool at the hands of the decision makers and researchers and it is one of the most widely used Multiple Criteria Decision-Making techniques (MCDM). Various useful articles based on the AHP have been published; they include applications of the AHP in a variety of areas such as planning, alternative selection, resource allocation, dispute resolution, and optimization, as well as quantitative applications of the AHP. A careful examination of those research articles reveals that most of the AHP-related work falls into the following categories:

- Engineering and Selection,
- Social and Selection, and
- Personal and decision making.

This demonstrates the AHP's usefulness as a decision-making tool in both the engineering and social sectors.

Again, different application areas of the AHP may be classified according to certain fields, as shown below:

- Selection
- Evaluation,
- Benefit-cost analysis,
- Allocation,
- Planning and development, and rank setting,
- Decision making,
- Forecasting and related fields.

Additionally, the AHP is mostly utilised in the selection and assessment topic area.

In terms of application, the AHP has been mostly used in the engineering, personal, and social sectors. The following application areas of AHP have been discovered by researchers in the field:

Economic/Management problems

- Database selection
- Design
- Architecture
- Finance
- Macro-economic
- forecasting
- Marketing
- Consumer choice
- Product design
- Portfolio selection
- Planning
- Facility location
- Forecasting
- Resource allocation
- Sequential decisions
- Policy/strategy making
- Transportation
- Water research
- Political problems
- Security assessment
- Education
- Environmental,
- Health
- Law
- Therapy selection

Chapter 2

LITERATURE REVIEW

2.1 Literature Review on AHP

A small number of papers on the MCDM technique have been published for assessing and select-ing ST alternatives. A Study of the literature review demonstrates that the Analytical Hierarchical Process (AHP) and its variations have proven to be effective ways for resolving the complexity associated with selecting STT options by incorporation of physical and intangible components into the evaluation process.

(Bottero, Comino, and Riggio 2011) reveals that AHP analysis is well-suited for dealing with complicated decision-making situations since it allows for the incorporation of several criteria which are systemically evaluated and compared.

(Kalbar, Karmakar, and Asolekar 2013) utilised an alternate MCDM method called Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) to the STT segment in India. This approach is based on the concept that the favoured option should be the one with the smallest geometric distance to the positive ideal solution and the greatest geometric distance to the negative ideal solution.

(Ren and Liang 2017) the study assisted decision-makers in selecting sustainable Water Treatment Plant among four chosen alternatives by developing a group multi-attribute decision analysis (MADA) technique based on intuitionistic fuzzy set (IFS) theory.

(Anaokar, Khambete, and Christian 2018) evaluated the perfor-mance index of WWT (wastewater treatment plant) using the TOSIS approach and monitoring the effi-ciency of the system by selecting appropriate criteria weights while comparing limits established by the Central Pollution Control Board of India.

(Chen, Yang, and Sheng 2009)) explains that AHP does not take into account the possibility of a negative scale, validity of the judgement matrix and available quantitative information. Additionally, AHP combines values and costs, which often results in cost being weighted more strongly than it should be, so exchanging a poor, sustainable performance for a lower cost.

However, despite all available techniques, the most often utilised MCDM strategy for the selec-tion of sewage treatment is the AHP and its variations. Sound judgment decision-making often uses the AHP because it integrates linguistic data (Ishizaka and Labib 2009).

The key steps in developing an AHP framework are hierarchy building, pairwise comparisons, calculating relative weights, consistency check-ing, and synthesising the results (Saaty and L.G.Vargas 1991).

((Tang 1994); (Ellis and Tang 1992); (Bottero et al. 2011); (Kalbar et al. 2013);(Srdjevic, Samardzic, and Srdjevic 2012); (Zorpas and Saranti 2016); (Hadipour et al. 2016); (Aydiner et al. 2016)) have simply used traditional AHP techniques to assess and select the best WWT technology for a variety of urban and industrial wastewater scenarios.

2.2 Literature Review on Sewage Treatment Technologies

Sewage from metropolitan cities and states used to be less filthy but has become a more serious issue in recent years. While population growth and urbanization have undeniably improved living circum-stances, but they have come at the cost of rising sewage. Sewage treatment and management have become a critical issue now. According to the Indian Constitution, water supply and sanitation are a state issue, and the states are responsible for the design, implementation, and cost recovery of water supply and sanitation projects (Tare, V., Bose 2009).

The main watercourse through Delhi is the Yamuna, which drains an area of approximately 1483 km2. The river has witnessed a decrease in the quality of its water over time. To enhance the quality of river water, the Delhi government launched the Yamuna action plan (YAP 2006a) in 1993, in which sewage treatment plant were both improved and built. At that time STPs were designed with the consideration of several factors like removal of TSS (Total Suspended Solids), BOD (Biochemical Oxygen Demand) and COD (Chemical Oxygen Demand) etc. while little consideration was given to the elimination of Fecal Coliforms (FC) and other harmful pathogens.

The Yamuna action plan incorporated energy-neutral and energy-recovery sewage treatment technologies in which a significant benefit was that building, operation, and maintenance costs were cheap, while energy usage was minimal. However, it was subsequently discovered that these plants produced effluent of extremely low quality with high concentration values for BOD5, COD and FC. Simultaneously, under the same scheme, new STPs were designed and older STPs were updated to control river water within the Delhi watershed. These plants made use of aerobic processes for sewage treatment. The efficiency in the eradication of these technologies remains uncertain. Traditionally, the adoption of sewage treatment technology has been driven by economic and technological considerations (Popovic et al. 2013).

To maintain the long-term sustainability of STP, environmental and social considerations should also be addressed in the decision-making process (Shrestha et al. 2017).

Choosing STP alternatives that eSTP2ace an integrated approach is a quite challenging and complex process, considering the diversity of objectives that are related, it is necessary to make sure that all parameters must be taken into consideration for the selection of appropriate STP. To address this issue, multi-criteria decision making (MCDM) has proven to be an effective tool for assisting decision-makers in the selection of the most appropriate STT from a range of alternatives since the approach is systematic and has a logical foundation.

Furthermore, MCDM has been successfully utilized to determine the optimal solution to a variety of environmental challenges, sustainable and renewable energy systems, transportation system, service quality check and energy management problems. Sewage treatment is the process of removing pollutants from wastewater, mostly sew-age from residential areas. Physical, synthetic, and natural methods are used to remove pollutants from wastewater, resulting in cleaner wastewater that is better for the environment.

Sewage sludge is a semi-solid waste or slurry that is produced as a by-product of the sewage treatment process. This sludge must be treated with assistance before its disposal to land or in water. The Delhi Jal Board supervises wastewater treatment and transmission through a competent system of about 7000 km of sewage pipes crosswise over Delhi.

2.3 Sewage Treatment Processes

2.3.1 Primary Treatment

In primary treatment, the unit operations include an inlet chamber for controlling the velocity of the sewage flow and ensuring smooth distribution to the screen channel, screens to remove large floating matter, grit chambers or detractors to remove inert inorganic solid particles, and primary clarifiers to remove settleable organic solids. There are two screen channels, one in use and one in reserve; each channel is equipped with a coarse screen that is manually cleaned before being replaced with a fine mesh screen that is mechanically cleaned. Maximum flow velocities through screens are 0.9 $m.s^{-1}$ and 1.8 $m.s^{-1}$, respectively, for normal flow and peak flow. Sewage that is free of floating materials will flow to the detractors, where heavy inert inorganic particles 0.15 mm in diameter and larger will be removed and cleaned using a mechanical scraper and classifier system. Grit-free sewage is then sent to the main clarifier, where it is treated to remove settleable organic materials as primary sludge. 30% of influent BOD and about 80% of suspended particles would be eliminated in the 12 main treatment stages.

2.3.2 Secondary Treatment

The secondary treatment is intended to remove unsettle able and soluble organic matter from the original wastewater using biological processes in order to significantly decrease the organic matter of the primary effluent. Biological processes are classified into two types: aerobic and anaerobic. Microorganisms need dissolved oxygen, which is supplied naturally or mechanically, and organic compounds are converted to non-hazardous products such as carbon dioxide, water, and cell tissues during the aerobic process. The oxygen requirement of microorganisms is met in anaerobic processes through the decomposition of complex organic substances such as sulphate and phosphates, and the organic substances are converted into hazardous gases such as methane, ammonia, and hydrogen sulphide, as well as carbon dioxide and cell tissues. The last stage of secondary treatment is to settle biomass as biological flocs and generate effluent with very low levels of organic matter in terms of BOD and suspended particles in order to satisfy the effluent criteria for discharge into surface waterways. After disinfection, the effluent is discharged into the environment, while the settled biomass or secondary sludge is treated further in sludge management facilities.

2.3.3 Tertiary Treatment

Tertiary treatment is required to remove undesired dissolved particles from secondary effluent in order to recover water for agriculture, industrial usage, and non-consumptive residential use. Coagulation and flocculation, adsorption on activated carbon, nitrification and denitrification, and ion exchange or reverse osmosis 15 are the most often employed tertiary treatment processes. In most cases, tertiary treatment is utilised in water reclamation facilities. Recycled sewage, often known as reclaimed water, is useful for agricultural, groundwater replenishment, and non-consumptive household purposes. In Israel, about 42% of recovered water is utilised for agriculture and 30% for groundwater recharge, and a cost-benefit study determined that reclaimed water is an extremely low-cost water supply in those nations, which are experiencing a severe water shortage (Hidalgo et al 2004).

(Metcalf and Eddy 2003) stated that the Knosset's Interior and Environment Protection Committee had adopted rules limiting BOD and SS concentrations in recovered water used for agriculture to 10 mg L–1. In Israel, the agricultural sector now uses recycled water for irrigation at a rate of more than 50% of total water use. While primary and secondary treatment are adequate to satisfy effluent requirements, in certain cases, tertiary treatment including further suspended particles and nutrient removal may be needed (Peavy et al 2013).

2.4 Sewage Treatment Technologies

The STP technology is composed of a series of comparable and dissimilar unit processes and activities that are organised according to the desired effluent quality (USEPA 1976).

The Waste Stabilization Ponds (WSP), the Activated Sludge Process (ASP), Up flow Anaerobic Sludge Blanket (UASB), and the Sequencing Batch Reactor (SBR) are the most widely adopted technologies in India. In this section we have discussed the unique characteristics of different sewage technologies chosen alternatives for our case study.

2.4.1 Activated Sludge Process

The method uses bacteria (to breakdown the biodegradable organics) and air to cleanse sewage and wastewater generally known as effluent (Oxygen for respiration) (Metcalf and Eddy 2003) The main components of an activated sludge process are:

- Primary Clarifier: Separate solids from sewage/ effluent in primary clarifier
- Liquid-Solid Separator: A reactor in which the microorganisms are kept in suspension, aerated, and in contact with the waste they are treating) liquid-solid separation.
- An Active Sludge Recycling System: returning activated sludge back to the beginning of the process.

When designed and managed correctly, activated sludge effectively removes BOD, COD, and nutrients. The method itself is adaptable and may be adapted to needs (e.g., for nitrogen removal). It's a combination of microbiology and biochemistry involving numerous microorganisms. Bacteria in the ASP produce sticky compounds that encapsulate sewage particles. The particles create gel-like flocs that sustain microorganisms (Peavy et al 2013). The activated sludge is aerated to dissolve oxygen, allowing bacteria to use the organic matter (BOD). Organic stuff (food) adheres to activated sludge and enables bacteria to use it and convert ammonia to nitrate. The tank should be large enough to enable adequate contact time between the sewage and the activated sludge for all chemical reactions to occur.

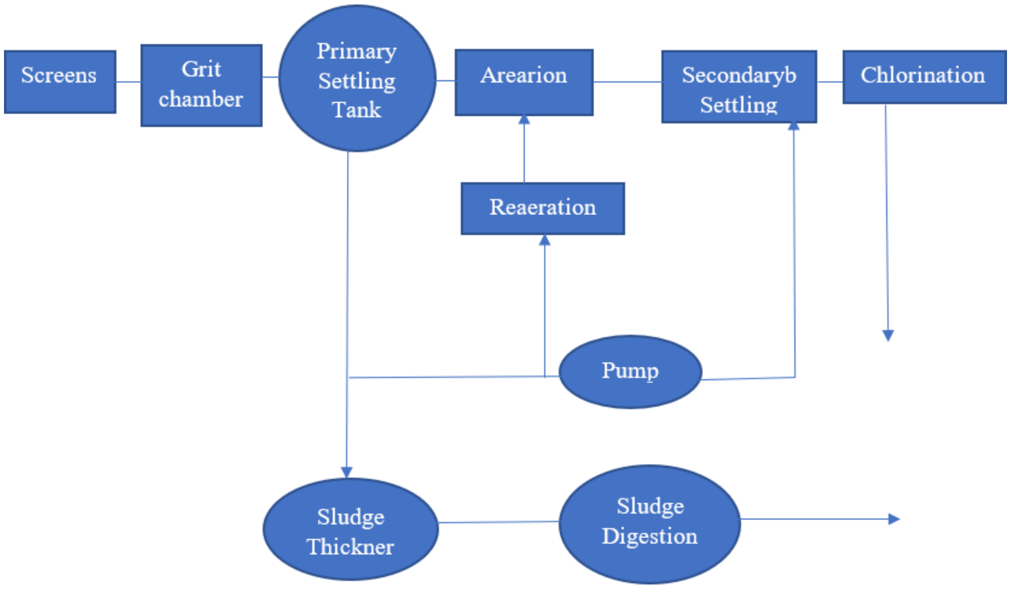

Fig 3. Flow Diagram for ASP Process (Self)

2.4.2 Sequencing Batch Reactor

The sequencing batch reactor (SBR) is a variant of the ASP for sewage treatment with a batch (fill-and-draw) process and includes five stages in an operating cycle; fill, react, settle, decant, and idle carried out in succession in a single reactor as stated below and illustrated in figure 2.2.

The sequencing batch reactor (SBR) is a variant of the ASP for sewage treatment with a batch (fill-and-draw) process and includes five stages in an operating cycle; fill, react, 23 settle, decant, and idle carried out in succession in a single reactor as stated below and illustrated in Figure 2.2

- During the fill phase, raw sewage enters the tank and is combined with settled biomass from the previous cycle. Some aeration may occur during this phase to encourage biological interactions with the influent sewage.

- During the react phase, the sewage is aerated using high-efficiency fine bubble non-clog diffusers, which allows the biomass to absorb substrate in a regulated environment.
- Aeration and mixing are suspended during the settled phase, and solids are allowed to settle in a quiescent state, resulting in a cleared liquid.
- The clarified liquid is removed during the decant process by drawing it through a floating or adjustable weir decanter. The idle phase allows the multi-tank system to transition to the fill phase. Because the idle phase is not required, it is sometimes skipped.

Typically, conventional screening and grit removal are performed as a preparatory step. Reactors are generally round, square, or rectangular concrete tanks. Hydraulic volumes are usually up to 30% of the volume of the top water level, and the total basin depth is normally between 5 and 7 metres. The amount of liquid at the bottom water level is calculated to produce a enough quantity of activated sludge for the biological treatment procedures to be completed. In SBR systems, fine bubble diffusers with the greatest oxygen transfer efficiency are utilised (Metcalf and Eddy 2003).

Extended aeration helps biodegrade organics in sewage. Because air is provided to STP3 only during the fill and react phases, a cycle requiring 50% aeration requires process air to be supplied to the SBR tank during a 12-hour period each day. This translates into continuous blower operation for the whole system in the case of a two-tank system, with each tank equipped with an aeration grid capable of handling the overall airflow. Simultaneous nitrification and denitrification may be accomplished by turning on and off the air during the filling and reacting stages and adjusting the aeration strength to maintain anoxic conditions inside the activated sludge flocs (Munch et al 1996; Roe et al 1999).

Biological phosphorus removal is generally accomplished by incorporating an anaerobic phase into the process cycle, usually at the start during the filling of the selector zone at the reactor's front end, where anoxic/anaerobic conditions are maintained, and microorganisms encounter high BOD and low DO concentrations. Additionally, the reactor's waste is recycled through the selection (Mahvi 2008).

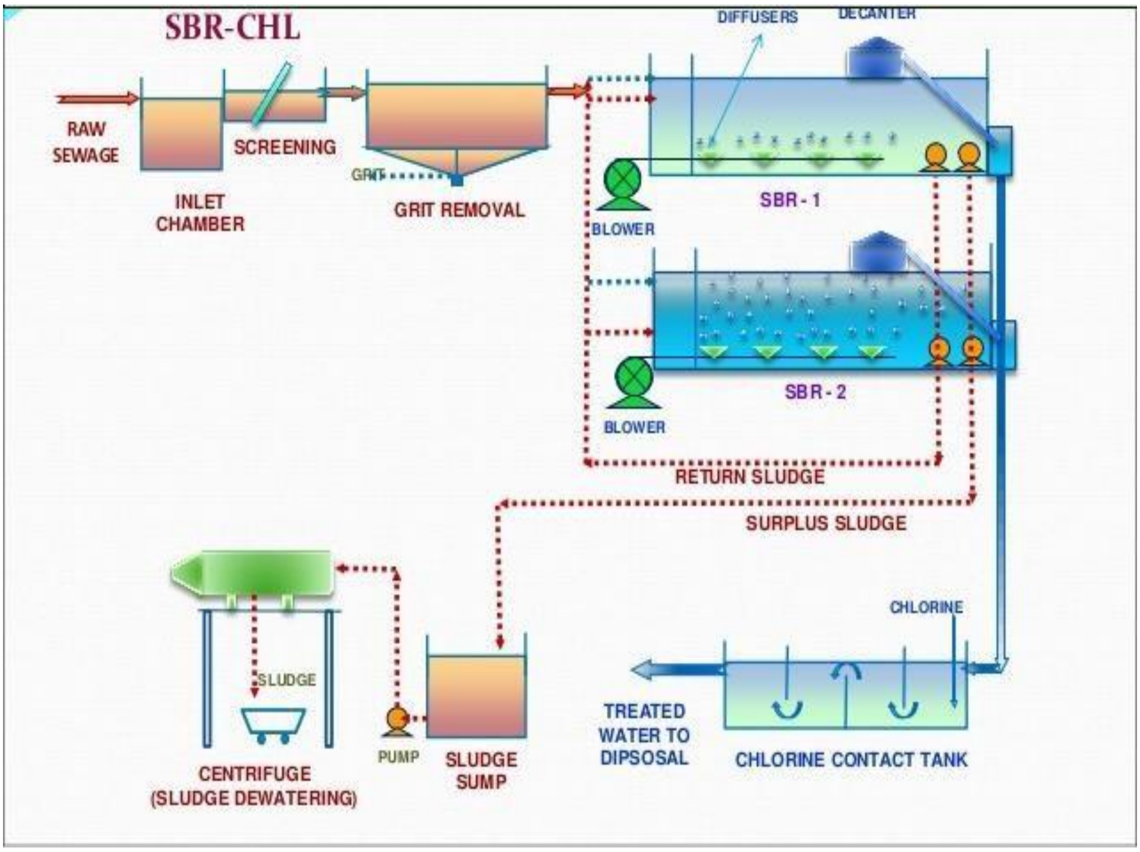

Fig 4. Flow diagram for SBR (https://5.imimg.com/data5/FE/NT/MY-35572/sequencing-batch-reactors-500x500.png)

2.4.3 Up flow Anaerobic Sludge Blanket (UASB)

UASB operates in an anaerobic environment, generating a blanket of granular sludge that suspends in the tank. Wastewater is drawn upward and digested (degraded) by anaerobic bacteria. The upward flow, coupled with gravity's settling action, suspends the blanket using flocculants. Around three months after planting, the blanket matures. Small sludge particles begin to develop, their surface area coated with bacterial aggregations (Metcalf and Eddy 2003). Without a support matrix, the flow conditions produce a selective environment in which only bacteria capable of adhering to other microorganisms survive and multiply. As a by-product, biogas with a high concentration of methane is generated. This methane may be collected and utilised as an energy source to create electricity for export and to operate the facility (Stamatelatou, K & Tsagarikas 2015).

When used, the technique requires continuous monitoring to ensure that the sludge blanket is maintained and not washed away (thereby losing the effect). Heat generated as a by-product of power production may be used to heat the digestion tanks (Peavy et al 2013).. The blanketing of the sludge allows the digesters to retain both solids and hydraulic (liquid) matter. Solids that need extensive digestion may stay in the reactors for up to 90 days. Sugars dissolved in the liquid waste stream can be transformed rapidly into gas in the liquid phase, which can leave the system in less than a day UASB reactors are usually used to treat diluted wastewater (3 percent TSS with a particle size greater than 0.75mm).

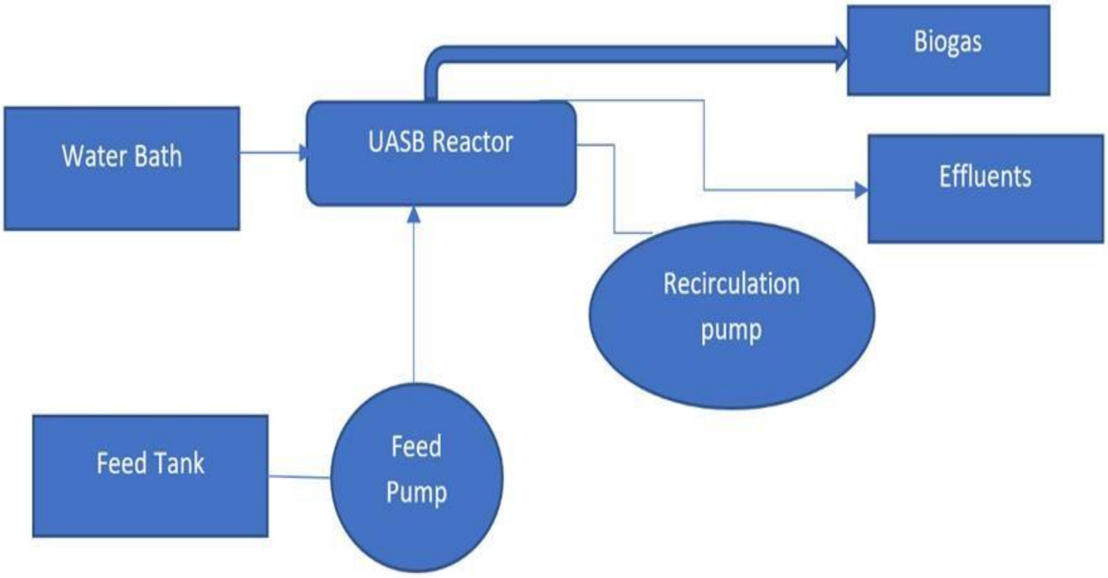

Fig 5. Flow diagram for STP4 (Self)

2.4.4 Membrane Bio Reactor

Membrane Bio Reactor (MBR) technology has developed rapidly over the past two decades due to the benefits it provides over traditional treatment methods, including a smaller footprint, superior effluent quality, and improved process control (Metcalf and Eddy 2003). Need for MBR systems is anticipated to continue growing at a rate of more than double digits per year for the next decade, owing to more strict regulations and the enormous demand for water reuse applications. MBR are already widely used in some parts of the globe as the primary technology for protecting and enhancing vulnerable surface waters (the United States and Europe) or for water reuse (Middle East).

Microfiltration (MF) or ultrafiltration (UF) membranes are often used in meSTP2ane bioreactors to treat wastewater. Membranes are used to separate solids and liquids. STP2 systems may be vacuum (or gravity) or pressure driven. Immersed vacuum or gravity systems use hollow fibre or flat sheet membranes in either the bioreactors or a membrane tank. whereas External pressure driven systems are in-pipe cartridge systems (Peavy et al 2013).

An “MBR System” is a full and integrated membrane unit (sub-systems) with associated components required to run the process. An MBR system typically has ten or eleven sub-systems, including fine screening (headworks), the Membrane Zone, and post-disinfection processes (Stamatelatou, K & Tsagarikas 2015).

An MBR, or Membrane Zone, can best be described as first stage of a biological process where microorganisms breakdown contaminants that are subsequently filtered by a succession of submerged membranes (or membrane elements). Individual membranes are contained in modules, cassettes, or racks. a functioning membrane unit is a collection of these modules. MBR has a lower footprint than traditional active sludge facilities with secondary clarifiers and medium tertiary filtering.

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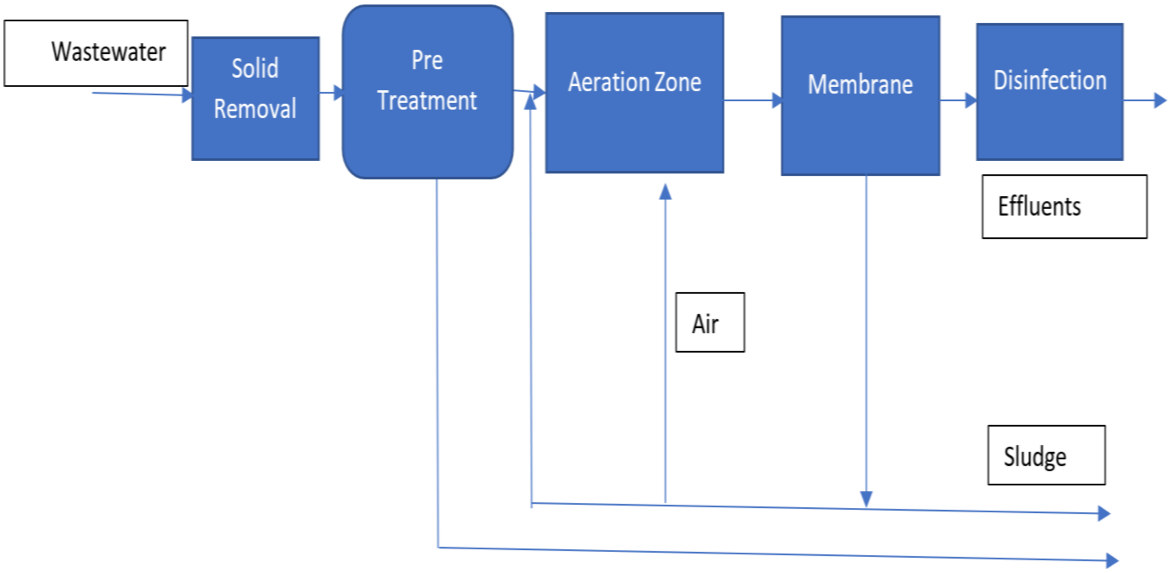

Fig 6. Flow diagram for MBR (Self)

A case study is performed in this research to determine the best sewage treatment technique for Delhi. Expert opinion and extensive literature study are used to establish relevant criteria for possible alternatives .Using the AHP method, data was assimilated and analysed to determine the most appropriate sewage treatment system.

Chapter 3

METHODOLOGY

3.1 AHP Method

For decision making procedure in a wide variety, AHP is utilised. However, a need arises for hav-ing at least two distinct choices for decision making using this method. Instead of subjective division, AHP uses objective and quantitative weighing of each criterion. According to study, the AHP method's global popularity as a decision making tool is because of its ability to rapidly adjust to fixed variables such as pricing, delivery time, personal experience, and perhaps even intuition. The following four methods are adopted by decision-makers using AHP method. These steps are:

Step 1:Construction of Hierarchy

Being the foundation of AHP, forming a Hierarchical structure uses a top-down approach that comprises various levels. Each hierarchical level is kept on the same single-unit scale and magnitude. Components at the same hierarchy level and their associated factors in a structure need to be correlated. The AHP hierarchy begins with the highest goal and moves toward the lowest deci-sion criteria.

Step2: Decision matrix formation

After the construction of hierarchy, the relative significance of main-criteria and sub-criteria is determined by comparing both in form of pairs. This stage is highly significant hence is known as the spine of AHP. Throughout this process, elements in each set of the hierarchy are compared with their respective group members. Saaty nine-point scale is used (Table 1) to assess the rela-tive importance of the elements. The intensity of scale varies from one and nine (Saaty and Vargas,1991).

Intensity of Importance	**Definition**
1	Equal importance
2	Weak or slight
3	Moderate importance
4	Moderate plus
5	Strong importance
6	Strong plus
7	Very strong
8	Very very strong
9	Extreme importance

Table 3.1. Saaty scale used in AHP (Self)

$$A = \begin{bmatrix} a_{11} & a_{11} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \tag{1}$$

Matrix “A” represents the opinions or relative importance of alternatives as n × n matrix, where “n” is the number of items being evaluated.

The entries of matrix “A,” i.e. $a_{11} = 1 \leftrightarrow i = j$ **(2)**

where, a_{ij} can also be written as, $a_{ij} = \frac{1}{a_{ji}}$ **(3)**

where, w_i shows the relative weight of the alternative i.

$$a_{ij} = \frac{w_i}{w_j} \tag{4}$$

Step 3: Normalised decision matrix and Priority Vector

In this step, relative weights for each of the decision hierarchy's criteria and sub criteria are calculated. Saaty (1991), a pioneer of AHP, developed the eigenvector technique from matrix theory to assign relatives weights to these criteria. Using this approach, the weights associated with decision elements are calculated by comparing the normalised eigenvalue to the principal eigenvalue (Saaty and L.G.Vargas 1991). As per equations (4), the matrix "A" in equation (1) can be represented as

$$\begin{array}{c|cccc}
C & A_1 & A_1 & A_1 & A_1 \\
\hline
A_1 & \frac{w_1}{w_1} & \frac{w_1}{w_2} & \ldots.. & \frac{w_1}{w_n} \\
A_1 & \frac{w_2}{w_1} & \frac{w_2}{w_2} & \ldots.. & \frac{w_2}{w_n} \\
A_1 & \vdots & \vdots & \ldots.. & \vdots \\
A_n & \frac{w_n}{w_1} & \frac{w_n}{w_2} & \ldots.. & \frac{w_n}{w_n}
\end{array}$$

Figure 8. Normalised decision matrix (Self)

Here, the objective is to evaluate eigen vector "w,"

$$w = (w_1, w_2, w_3, w_4, \ldots\ldots, w_n) \qquad \textbf{(5)}$$

where "w" is the eigenvector (Priority Vectors) and a column matrix.

Step 4: Checking the Consistency Ratio

The measure of "Consistency Ratio" (CR) is an important STP1ect of AHP. Its value mostly determines the optimum decision-making in pairwise comparison. This step acts as a checkpoint for consistency and inconsistency of the decision matrix. Generally, pairwise comparisons are evaluated using cardinal and ordinal consistency tests. According to Ordinal consistency if a > b and b > c, then a > c. However, cardinal consistency states that a stronger correlation between the variables being assessed is needed, if a is twice as essential as b and b is three times as important as c, then a should be six times as essential as c. An index measuring the consistency of weights was formulated to compute the consistency ratio. In this case, CR should be equal to or less than 0.10. However, if CR is higher than this threshold value, a pairwise comparison must be revised (Saaty and L.G.Vargas 1991).

Step 5: Synthesizing Results

In the last phase, the relative values assigned to each set of alternatives across all the hierarchy levels are added at starting. These numbers are added together to get the total score, or weight assigned to each alternative. The following equation illustrates a simple mathematical approach for aggregating criteria weights at various hierarchical levels (Saaty and Vargas, 1991).

$$\text{Final Weight of Criteria} = \sum[(\text{Weight of alternative w. r. t criteria}) \times (\text{importance of criteria})] \qquad \textbf{(6)}$$

3.2 Sustainable criteria for selection of Sewage Treatment Technologies

According to (WCED 1987) and (Othman et al. 2010), the criteria for assessing the sustainability of sew-age treatment plants are often based on the three aspects of sustainability (namely, economics, environment, and society). However, there is no universally accepted criteria system for measuring sustainability since various decision-makers have different requirements. As a result, in this study, three factors, including social acceptability, economic viability, and appropriateness for horticulture are analysed while determining the optimum sewage treatment technology for Delhi. Three main criteria and nine sub-criteria are used to measure the performance of various processes based on literature studies and expert suggestions. These criteria are as follows:

3.2.1 Social acceptability (SA)

Social acceptability includes criteria in four asects: odour, sludge handling, green cover, and water consumption. The social acceptability of treated wastewater is determined by how receptive customers are to the process and the resultant product quality (Ren and Liang 2017).

3.2.2 Odour (O)

The anaerobic breakdown of organic substances causes common odours to persist in and nearby treatment plant. Hydrogen sulphide is a natural by-product of anaerobic digestion (H2S) re-sponsible for odour. Amines and mercaptans are two additional odour causing substances found in sewer-age systems. As a result, the acceptability of the odour producing environment in which the works are working and the public, mainly the people living nearby the plant, should be adequate.

3.2.3 Sludge Handling (SH)

It includes sludge disposal, transportation, handling, and re-use for energy production.

3.2.4 Green Cover (GC)

It has to do with the appropriateness of treated water for use in horticultural applications.

3.2.5 Water Consumption (WC)

It is concerned with the recycling of wastewater and the subsequent use of recycled water for horticulture.

3.2.6 Economical Aspect (EA)

There are four economic criteria, namely, capital cost, operation & maintenance cost, land cost and useful life.

3.2.7 Maintenance & Operation Costs (MOC)

It includes the expenses associated with the maintenance and repair of equipment and components that are used during the operation in the plant (Meerholz and Brent, 2013).

3.2.8 Useful life (UL)

The reliability of ST systems refers to the robustness against breakdowns in different wastewater treatment processes.

3.2.9 Capital Cost (CC)

The capital cost reflects the total facility investment for ST processes. (Sadr et al. 2015) noted that the initial investment costs substantially affect the execution of ST-related projects.

3.2.10 Land cost (LC)

This criterion refers to the total amount of cost related to land occupied as a result of the implementation of ST processes, i.e., the land used to construct the ST plant and the land used to develop supplementary infrastructure. Especially city like Delhi where land availability is a problem, a high weightage should be given to this criterion for the selection process.

3.2.11 Suitability for Horticulture (SFH):

The reliability of a treatment technology meeting specified effluent quality requirements at any time or over extended periods despite varying flow rates and influent water quality. The treated water characteristics suited for horticulture should have permissible level, BOD & COD, pH, NH3, TDS and E. coli.

3.2.12 BOD & COD (BCD)

The biochemical oxygen demand (BOD) is the quantity of oxygen used by bacteria and other microorganisms during the decomposition of organic matter under aerobic (oxygen-containing) conditions at a given temperature.

3.2.13 pH

pH is a critical parameter for determining the quality of water. It is defined as the negative logarithm of the hydrogen ion concentration. pH of water is a measure of its acidity/basicity. The pH is a commonly used measurement indicator for irrigation water quality.

3.2.14 NH_3

Ammonia, nitrite, nitrate, and Kjeldahl nitrogen are all nitrogen molecules of environmental significance that are commonly analysed in wastewater. Water makes up most of the plants, trees, and crops. A large discharge of ammonia will likely burn the adjacent downwind vegetation and not recommend for horticulture purpose.

3.2.15 TOTAL DISSOLVED SOLIDS (TDS)

The total dissolved solids (TDS) may pass through a filter. TDS measures the quantity of dissolved material in water. This may contain carbonate, bicarbonate, chloride, sulphate, phosphate, nitrate, calcium, magnesium, sodium, and other ions. These ions are required for aquatic life. Changes in TDS concentrations may be detrimental because water density affects water movement into and out of an organism's cells.

3.2.16 E. coli

E. coli is a kind of faecal coliform bacteria frequently seen in animals and people' intestines. Its presence could be harmful to humans and aquatic life.

3.3 Case study

This study examined an illustrative scenario of selecting the best alternative from four Alternatives, namely STP1, STP2, STP3, STP4.The criteria were identified and prioritized after interviewing professionals from industry and academics. The inputs for the pair-wise comparison matrix were obtained from the

opinions of experts and further aggregated by taking their average values.

Three main criteria (Social acceptability, Suitability for horticulture and Economic Aspects) including nine sub-criteria Odour, Sludge Handling, Water Consumption, Green Cover, Bod & COD removal efficiency, TDS removal efficiency, NH3 concentration, E. coli presence, Operation and Maintenance Cost, Capital Cost, Land Cost and Useful Life were considered for sustainability measurement of these alternatives.

A comprehensive study and detailed examination of the literature is conducted on these four alternatives, and their relative merits and demerits in terms of appropriateness for adoption in Delhi are thoroughly analysed using the AHP method. The methodology explained in previous section 3.1 is adapted to assign weights and ranking to the alternatives. The hierarchy for the selection of Sewage technology is shown in Fig 3.1

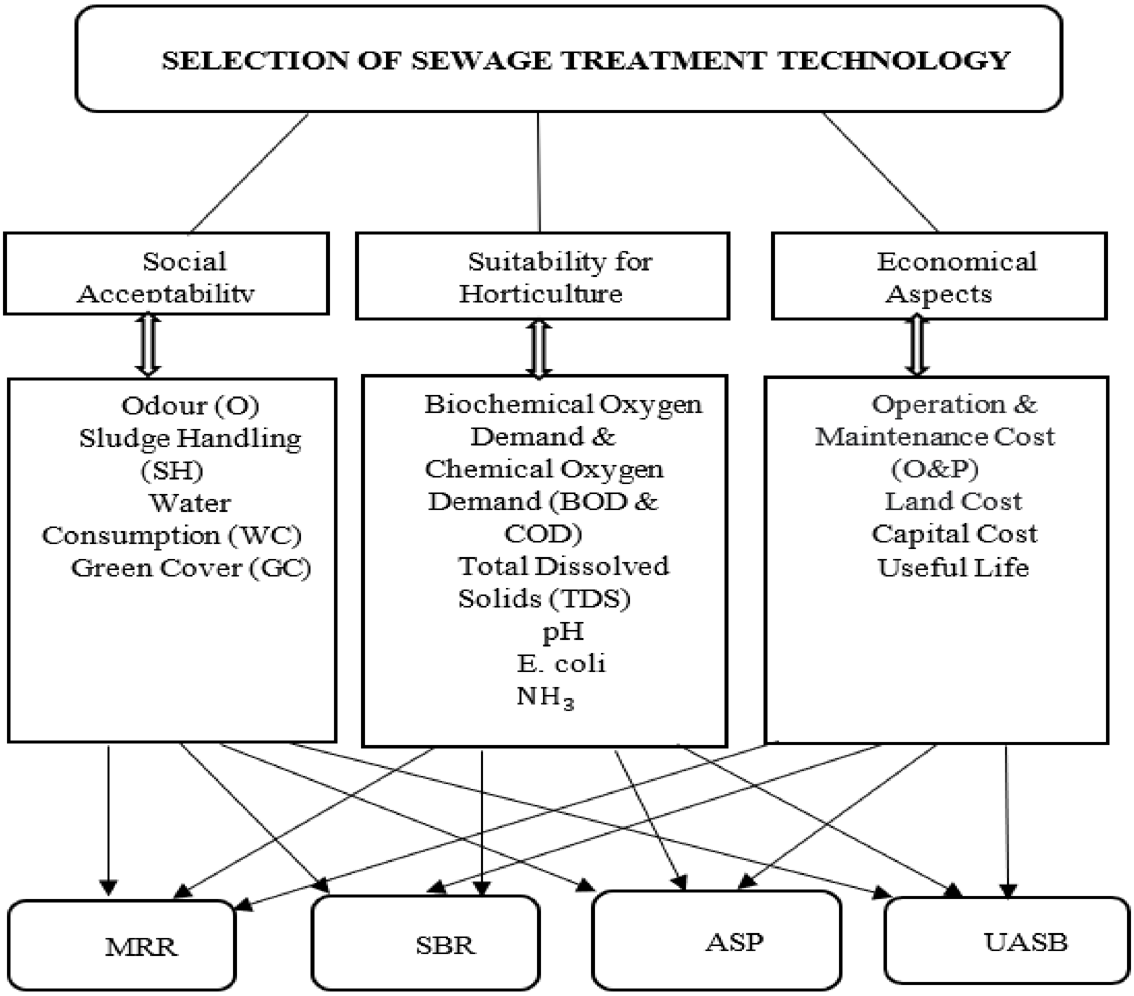

Figure 9. AHP model for sewage treatment technology selection (Self)

Chapter 4

Results and Discussions

4.1 Formation of decision matrix for Main Criteria and Sub Criteria

The four respondents' assessments were listed in the comparison matrix and then verified for consistency test. According to Saaty and Vargas, the judgments were approved if the Consistency Ratio (CR) is equal to or less than 0.10. After receiving consistent judgments from all the respondents, pair wise comparison was performed to form decision matrices and the aggregated results listed in table 4.1, 4.2, 4.3, 4.4, which show decision matrices for Main Criteria and tables 4.5, 4.6, 4.7, 4.8, 4.9, 4.10, 4.11, 4.12, 4.13, 4.15, 4.16, and 4.17 show the decision matrices for Sub Criteria with respect to alternatives. The diagonal values of the matrix are equal to 1 which shows that the weight of criteria with respect to itself is always 1.

Decision matrices for Main Criteria and Sub Criteria are as shown below in tables

Table 4.1. Decision matrix for main criteria

	SA	**SH**	**EA**
SA	1.00	6.00	3.00
SH	0.17	1.00	0.25
EA	0.33	4.00	1.00

Table 4.2. Decision matrix for sub criteria (Social Acceptability)

.	**O**	**SH**	**WC**	**GC**
O	1.00	5.00	4.00	6.00
SH	0.20	1.00	3.00	4.00
WC	0.25	0.33	1.00	3.00
GC	0.17	0.25	0.33	1.00

Table 4.3. Decision matrix for sub criteria (Economic Aspects)

	MOC	**LC**	**CC**	**UL**
MOC	1.00	0.33	4.00	5.00
LC	3.00	1.00	5.00	6.00
CC	0.25	0.20	1.00	3.00
UL	0.20	0.17	0.33	1.00

Table 4.4. Decision matrix for sub criteria (Suitability for Horticulture)

	PH	**TDS**	**BCD**	**NH_3**	**E.coli**
PH	1.00	0.50	0.30	0.60	0.40
TDS	1.90	1.00	0.80	0.60	0.70
BCD	2.90	1.30	1.00	1.00	1.00
NH_3	1.80	1.70	1.00	1.00	0.70
E.coli	2.60	1.40	1.00	1.40	1.00

Table 4.5. Decision matrix for Order w.r.t. alternatives

O	**STP1**	**STP2**	**STP3**	**STP4**
STP1	1.00	0.50	0.33	0.25
STP2	2.00	1.00	0.50	0.33
STP3	3.00	2.00	1.00	0.50
STP4	4.00	3.00	2.00	1.00

Table 4.6. Decision matrix for Sludge Handling w.r.t. alternatives

SH	**STP1**	**STP2**	**STP3**	**STP4**
STP1	1.00	0.20	0.33	2.00
STP2	5.00	1.00	3.00	7.00
STP3	3.00	0.33	1.00	5.00
STP4	0.50	0.14	0.20	1.00

Table 4.7. Decision matrix for Water Consumption w.r.t. alternatives

WC	**STP1**	**STP2**	**STP3**	**STP4**
STP1	1.00	0.25	0.33	2.00
STP2	4.00	1.00	0.50	2.00
STP3	3.00	2.00	1.00	4.00
STP4	0.50	0.50	0.25	1.00

Table 4.8. Decision matrix for Green Cover w.r.t. alternatives

GC	STP1	STP2	STP3	STP4
STP1	1.00	0.25	0.33	2.00
STP2	4.00	1.00	0.50	2.00
STP3	3.00	2.00	1.00	4.00
STP4	0.50	0.50	0.25	1.00

Table 4.9. Decision matrix for Maintenance and operation cost w.r.t. alternatives

MOC	STP1	STP2	STP3	STP4
STP1	1.00	5.00	3.00	0.50
STP2	0.20	1.00	0.20	0.14
STP3	0.33	5.00	1.00	0.25
STP4	2.00	7.00	4.00	1.00

Table 4.10. Decision matrix for Land Cost w.r.t. alternatives

LC	STP1	STP2	STP3	STP4
STP1	1.00	0.14	0.17	0.33
STP2	7.00	1.00	3.00	5.00
STP3	6.00	0.33	1.00	4.00
STP4	3.00	0.20	0.25	1.00

Table 4.11. Decision matrix for Capital Cost w.r.t. alternatives

CC	STP1	MRB	STP3	STP4
STP1	1.00	1.00	0.20	0.25
STP2	1.00	1.00	0.20	0.25
STP3	5.00	5.00	1.00	3.00
STP4	4.00	4.00	0.33	1.00

Table 4.12. Decision matrix for Useful Life w.r.t. alternatives

UL	STP1	STP2	STP3	STP4
STP1	1.00	6.00	0.33	5.00
STP2	0.17	1.00	0.14	0.50
STP3	3.00	7.00	1.00	5.00
STP4	0.20	2.00	0.20	1.00

Table 4.13. Decision matrix for pH w.r.t. alternatives

pH	**STP1**	**STP2**	**STP3**	**STP4**
STP1	1.00	0.50	0.20	3.00
STP2	2.00	1.00	0.33	5.00
STP3	5.00	3.00	1.00	7.00
STP4	0.33	0.20	0.14	1.00

Table 4.14. Decision matrix for Biochemical and Chemical Oxygen Demand w.r.t. alternatives

BCD	**STP1**	**STP2**	**STP3**	**STP4**
STP1	1.00	0.13	0.17	0.33
STP2	8.00	1.00	3.00	5.00
STP3	6.00	0.33	1.00	4.00
STP4	3.00	0.20	0.25	1.00

Table 4.15. Decision matrix for Total Dissolved Solids w.r.t. alternatives

TDS	**STP1**	**STP2**	**STP3**	**STP4**
STP1	1	1	1	1
STP2	1	1	1	1
STP3	1	1	1	1
STP4	1	1	1	1

Table 4.16. Decision matrix for NH_3 w.r.t. Alternatives

NH_3	**STP1**	**STP2**	**STP3**	**STP4**
STP1	1.00	0.33	0.33	1.00
STP2	3.00	1.00	1.00	3.00
STP3	3.00	1.00	1.00	3.00
STP4	1.00	0.33	0.33	1.00

Table 4.17. Decision matrix for E.coli w.r.t. alternatives

E.coli	**STP1**	**STP2**	**STP3**	**STP4**
STP1	1.00	0.20	1.00	1.00
STP2	5.00	1.00	5.00	5.00
STP3	1.00	0.20	1.00	1.00
STP4	1.00	0.20	1.00	1.00

4.2 Formation of Normalised decision matrix for Main Criteria and Sub Criteria:

After obtaining Decision matrices for the Main Criteria and Sub Criteria Normalised decision matrices are evaluated as described in section 3.1. Tables 4.18, 4.19, 4.20, 4.21, 4.22, 4.23, 4.24, 4.25, 4.26, 4.27, 4.28, 4.29, 4.30, 4.31, 4.32 and 4.33 show the decision matrices for each of the 12 sub-criteria with respect to the main criteria. Moreover, CR values in all matrices satisfy the Saaty consistency test, indicating that the judgments for the comparison matrices are reliable. Among all sub-criteria Odour (PS, 0.537) and land cost (PS, 0.537) have the highest value of Priority Vector. The Priority Vector for land cost is even justified by the unavailability of land in a metropolis city like Delhi.

Normalised decision matrices for Main Criteria and Sub Criteria

Table 4.18. Normalised decision and Priority Vector matrix for main criteria

	SA	**SH**	**EA**	**PV**
SA	0.667	0.545	0.706	0.639
SH	0.111	0.091	0.059	0.087
EA	0.222	0.364	0.235	0.274

Table 4.19. Normalised decision matrix and Priority Vector for sub criteria (Social Acceptability)

	O	**SH**	**WC**	**GC**	**PV**
O	0.619	0.759	0.48	0.428	0.572
SH	0.124	0.152	0.36	0.286	0.230
WC	0.155	0.050	0.12	0.214	0.135
GC	0.103	0.038	0.04	0.072	0.063

Table 4.20. Normalised decision and Priority Vector matrix for sub criteria (Economic aspect)

	MOC	**LC**	**CC**	**UL**	**PV**
MOC	0.225	0.196	0.387	0.333	0.285
LC	0.674	0.588	0.484	0.4	0.536
CC	0.056	0.118	0.097	0.2	0.117
UL	0.045	0.098	0.032	0.067	0.060

Table 4.21. Normalised decision matrix and Priority Vector for sub criteria (Suitability for Horticulture)

	PH	**TDS**	**BCD**	**NH_3**	**E.coli**	**PV**
PH	0.098	0.085	0.073	0.130	0.105	0.098
TDS	0.186	0.169	0.195	0.130	0.184	0.173
BCD	0.284	0.220	0.244	0.217	0.2631	0.245
NH_3	0.176	0.288	0.244	0.217	0.1842	0.222
E.coli	0.255	0.237	0.244	0.304	0.263	0.261

Table 4.22. Normalised decision matrix and for Order w.r.t. alternatives

O	**STP1**	**STP2**	**STP3**	**STP4**	**PV**
STP1	0.100	0.077	0.087	0.120	0.096
STP2	0.200	0.154	0.130	0.160	0.161
STP3	0.300	0.308	0.260	0.240	0.277

Table 4.23. Normalised Decision matrix and Priority Vector for Sludge Handling w.r.t. alternatives

SH	**STP1**	**STP2**	**STP3**	**STP4**	**PV**
STP1	0.105	0.119	0.073	0.133	0.108
STP2	0.526	0.596	0.662	0.467	0.563
STP3	0.316	0.199	0.221	0.333	0.267

Table 4.24. Normalised decision matrix and Priority Vector for Water Consumption w.r.t. alternatives

WC	**STP1**	**STP2**	**STP3**	**STP4**	**PV**
STP1	0.117	0.067	0.160	0.222	0.142
STP2	0.470	0.267	0.240	0.222	0.299
STP3	0.353	0.533	0.480	0.444	0.452
STP4	0.058	0.133	0.120	0.111	0.106

Table 4.25. Normalised decision matrix and Priority Vector for Green Cover w.r.t. alternatives

GC	**STP1**	**STP2**	**STP3**	**STP4**	**PV**
STP1	0.118	0.067	0.160	0.222	0.142
STP2	0.470	0.267	0.240	0.222	0.299
STP3	0.353	0.533	0.480	0.445	0.452
STP4	0.058	0.133	0.120	0.111	0.105

Table 4.26. Normalised decision matrix and Priority Vector for Order w.r.t. alternatives

MOC	STP1	STP2	STP3	STP4	PV
STP1	0.283	0.278	0.366	0.264	0.298
STP2	0.057	0.055	0.024	0.075	0.053
STP3	0.094	0.278	0.122	0.132	0.156
STP4	0.566	0.389	0.488	0.528	0.493

Table 4.27. Normalised decision matrix and Priority Vector for Capital Cost w.r.t. alternatives

CC	STP1	MRB	STP3	STP4	PV
STP1	0.091	0.091	0.115	0.055	0.089
STP2	0.091	0.091	0.115	0.055	0.088
STP3	0.454	0.454	0.577	0.667	0.538
STP4	0.364	0.363	0.192	0.222	0.286

Table 4.28. Normalised decision matrix and Priority Vector for Useful Life w.r.t. alternatives

UL	STP1	STP2	STP3	STP4	PV
STP1	0.229	0.375	0.198	0.435	0.309
STP2	0.038	0.062	0.085	0.043	0.057
STP3	0.687	0.437	0.596	0.435	0.539
STP4	0.045	0.125	0.119	0.087	0.094

Table 4.29. Normalised decision matrix and Priority Vector for pH w.r.t. alternatives

pH	STP1	STP2	STP3	STP4	PV
STP1	0.12	0.106	0.119	0.187	0.133
STP2	0.24	0.213	0.198	0.312	0.241
STP3	0.6	0.638	0.597	0.437	0.568
STP4	0.04	0.043	0.085	0.062	0.057

Table 4.30. Normalised decision matrix and Priority Vector for Biochemical and Chemical Demand w.r.t. alternatives

BCD	STP1	STP2	STP3	STP4	PV
STP1	0.0555	0.075	0.038	0.032	0.050
STP2	0.445	0.603	0.679	0.484	0.553
STP3	0.333	0.201	0.226	0.387	0.287
STP4	0.167	0.120	0.056	0.097	0.110

Table 4.31. Normalised decision matrix and Priority Vector for Total Dissolved Solid w.r.t. alternatives

TDS	**STP1**	**STP2**	**STP3**	**STP4**	**PV**
STP1	0.25	0.25	0.25	0.25	0.25
STP2	0.25	0.25	0.25	0.25	0.25
STP3	0.25	0.25	0.25	0.25	0.25
STP4	0.25	0.25	0.25	0.25	0.25

Table 4.32. Normalised decision matrix and Priority Vector for NH_3 w.r.t. alternatives

NH_3	**STP1**	**R**	**STP3**	**STP4**	**PV**
STP1	0.125	0.125	0.125	0.125	0.125
STP2	0.375	0.375	0.375	0.375	0.375
STP3	0.375	0.375	0.375	0.375	0.375
STP4	0.125	0.125	0.125	0.125	0.125

Table 4.33. Normalised decision matrix and Priority Vector for E. coli w.r.t. alternatives

E. coli	**STP1**	**STP2**	**STP3**	**STP4**	**PV**
STP1	0.125	0.125	0.125	0.125	0.125
STP2	0.625	0.625	0.625	0.625	0.625
STP3	0.125	0.125	0.125	0.125	0.125
STP4	0.125	0.125	0.125	0.125	0.125

Weighted Sum Value (WSV) And Critical Ratio (CR)

Tables 4.34 – 4.50 show the WSV and CR for all main criteria and sub criteria As the CR value in each table is below 1, it clearly indicated that the judgements made are consistent.

Table 4.34. Weighted Sum Value and Critical Ratio for main criteria

	O	**SH**	**EA**	**WSV**	**CR**
SA	0.64	0.523	0.821	0.982	0.046
SH	0.106	0.087	0.068	0.262	
EA	0.213	0.348	0.274	0.835	

Table 4.35. Weighted Sum Value and Critical Ratio for main criteria (Social Acceptability)

	O	SH	WC	GC	WSV	CR
O	0.571	1.152	0.539	0.379	2.642	0.105
SH	0.114	0.230	0.405	0.252	1.002	
WC	0.143	0.077	0.135	0.189	0.544	
GC	0.095	0.057	0.0445	0.063	0.260	

Table 4.36. Weighted Sum Value and Critical Ratio for main criteria (Economic STP1ect)

	MOC	LC	CC	UL	WSV	CR
MOC	0.285	0.178	0.470	0.302	1.237	0.077
LC	0.856	0.537	0.588	0.362	2.343	
CC	0.071	0.107	0.118	0.181	0.478	
UL	0.057	0.089	0.039	0.060	0.246	

Table 4.37. Weighted Sum Value and Critical Ratio for main criteria (Suitability for Horticulture)

	PH	TDS	BCD	NH_3	E. coli	WSV	CR
PH	0.098	0.086	0.0737	0.133	0.104	0.496	0.009
TDS	0.187	0.173	0.197	0.133	0.182	0.872	
BCD	0.285	0.225	0.245	0.222	0.260	1.239	
NH_3	0.177	0.294	0.246	0.222	0.182	1.122	
E. coli	0.256	0.242	0.246	0.310	0.260	1.315	

Table 4.38. Weighted Sum Value and Critical Ratio for Order w.r.t. alternatives

O	STP1	STP2	STP3	STP4	WSV	CR
STP1	0.096	0.080	0.092	0.116	0.385	0.011
STP2	0.192	0.161	0.138	0.156	0.647	
STP3	0.288	0.322	0.278	0.233	1.120	
STP4	0.384	0.483	0.555	0.466	1.887	

Table 4.39. Weighted Sum Value and Critical Ratio for Sludge Handling w.r.t. alternatives

SH	STP1	STP2	STP3	STP4	WSV	CR
STP1	0.107	0.113	0.089	0.124	0.433	0.025
STP2	0.539	0.563	0.801	0.435	2.338	
STP3	0.323	0.187	0.267	0.310	1.088	
STP4	0.054	0.080	0.053	0.062	0.249	

Table 4.40. Weighted Sum Value and Critical Ratio for Water Consumption w.r.t. alternatives

WC	STP1	STP2	STP3	STP4	WSV	CR
STP1	0.141	0.075	0.151	0.212	0.579	0.073
STP2	0.567	0.299	0.226	0.212	1.304	
STP3	0.425	0.599	0.452	0.423	1.900	
STP4	0.071	0.149	0.113	0.106	0.439	

Table 4.41. Weighted Sum Value and Critical Ratio for Green Cover w.r.t. alternatives

GC	STP1	STP2	STP3	STP4	WSV	CR
STP1	0.142	0.075	0.151	0.212	0.579	0.073
STP2	0.566	0.299	0.226	0.212	1.304	
STP3	0.425	0.599	0.453	0.423	1.900	
STP4	0.070	0.149	0.113	0.105	0.439	

Table 4.42. Weighted Sum Value and Critical Ratio for Maintenance and Operation Cost w.r.t. alternatives

MOC	STP1	STP2	STP3	STP4	WSV	CR
STP1	0.298	0.265	0.469	0.246	1.278	0.063
STP2	0.059	0.0530	0.031	0.070	0.214	
STP3	0.099	0.265	0.156	0.123	0.644	
STP4	0.595	0.371	0.626	0.492	2.085	

Table 4.43. Weighted Sum Value and Critical Ratio for Land Cost w.r.t. alternatives

LC	STP1	STP2	STP3	STP4	WSV	CR
STP1	0.053	0.077	0.048	0.037	0.217	0.065
STP2	0.374	0.543	0.874	0.561	2.353	
STP3	0.321	0.181	0.291	0.449	1.242	
STP4	0.160	0.108	0.072	0.112	0.454	

Table 4.44. Weighted Sum Value and Critical Ratio for Capital Cost w.r.t. alternatives

CC	STP1	MRB	STP3	STP4	WSV	CR
STP1	0.088	0.088	0.108	0.071	0.355	0.036
STP2	0.088	0.088	0.108	0.071	0.355	
STP3	0.440	0.441	0.538	0.856	2.276	
STP4	0.352	0.353	0.179	0.285	1.170	

Table 4.45. Weighted Sum Value and Critical Ratio Useful Life w.r.t. alternatives

UL	STP1		STP2	STP3	STP4	WSV	CR
STP1	0.309		0.344	0.179	0.471	1.304	0.059
STP2	0.051		0.057	0.077	0.047	0.233	
STP3	0.928		0.401	0.539	0.471	2.339	
STP4	0.062		0.114	0.108	0.094	0.378	

Table 4.46. Weighted Sum Value and Critical Ratio for pH w.r.t. alternatives

pH	STP1	STP2	STP3	STP4	WSV	CR
STP1	0.133	0.120	0.112	0.172	0.540	0.029
STP2	0.267	0.241	0.189	0.287	0.985	
STP3	0.667	0.723	0.568	0.403	2.360	
STP4	0.044	0.048	0.081	0.057	0.231	

Table 4.47. Weighted Sum Value and Critical Ratio for Biochemical and Chemical Oxygen Demand w.r.t. alternatives

BCD	STP1	STP2	STP3	STP4	WSV	CR
STP1	0.050	0.069	0.047	0.036	0.203	0.008
BSTP2	0.402	0.553	0.860	0.550	2.366	
STP3	0.301	0.184	0.287	0.440	1.213	
STP4	0.150	0.110	0.071	0.110	0.443	

Table 4.48. Weighted Sum Value and Critical Ratio for Total Dissolved Solids w.r.t. alternatives

TDS	STP1	STP2	STP3	STP4	WSV	CR
STP1	0.25	0.25	0.25	0.25	1	0
STP2	0.25	0.25	0.25	0.25	1	
STP3	0.25	0.25	0.25	0.25	1	
STP4	0.25	0.25	0.25	0.25	1	

Table 4.49. Weighted Sum Value and Critical Ratio for NH_3 w.r.t. alternatives

NH_3	STP1	STP2	STP3	STP4	WSV	CR
STP1	0.25	0.08	0.08	0.25	0.67	0
STP2	0.75	0.25	0.25	0.75	2	
STP3	0.75	0.25	0.25	0.75	2	
STP4	0.25	0.08	0.083	0.25	0.67	

Table 4.50. Weighted Sum Value and Critical Ratio for E.coli w.r.t. alternatives

E.coli	STP1	STP2	STP3	STP4	WSV	CR
STP1	0.125	0.125	0.125	0.125	0.5	0
STP2	0.625	0.625	0.625	0.625	2.5	
STP3	0.125	0.125	0.125	0.125	0.5	
STP4	0.125	0.125	0.125	0.125	0.5	

4.3 Discussion

It is evident from the results tabulated in Table 4.51, which are based on the AHP methodology, that out of four available alternatives, the sewage treatment technology “STP2” has attained the highest priority score of (PS,0.322) and thus judged as sustainable treatment technology among all. This judgment of the “STP2 being most suitable and sustainable sewage technology is based on the fact that it has performed well on the majority of the sustainability criteria of this study.

The “STP2” technology has scored a maxi-mum for sub criteria under the head “Suitability for Horticulture (PS, 0.115) and “Economical STP1ect” (PS, 0.30). Additionally, it also exhibits favourable results for sub-criteria like LC (PS, 0.025), SH (PS, 0.083), O (PS, 0.058), BOD & COD (PS, 0.037), and E. coli (PS, 0.045).

The second highest alternative “STP3” (PS, 0.294) is also worth consideration as its tops the Priority Vector for social acceptability. “STP4” (PS, 0.258) and STP1 (PS, 0.124) have lower performance on the sustainability criteria compared to the STP2 & STP3, as such ranked as third and fourth best alternatives respectively.

Though “STP4” has ranked 3rd in the list of alternatives, but it has scored well for O (PS, 0.170) which is one of the most concerning criteria for Sewage Treatment Plant. These results are significant for the research's methodology and sustainability needs

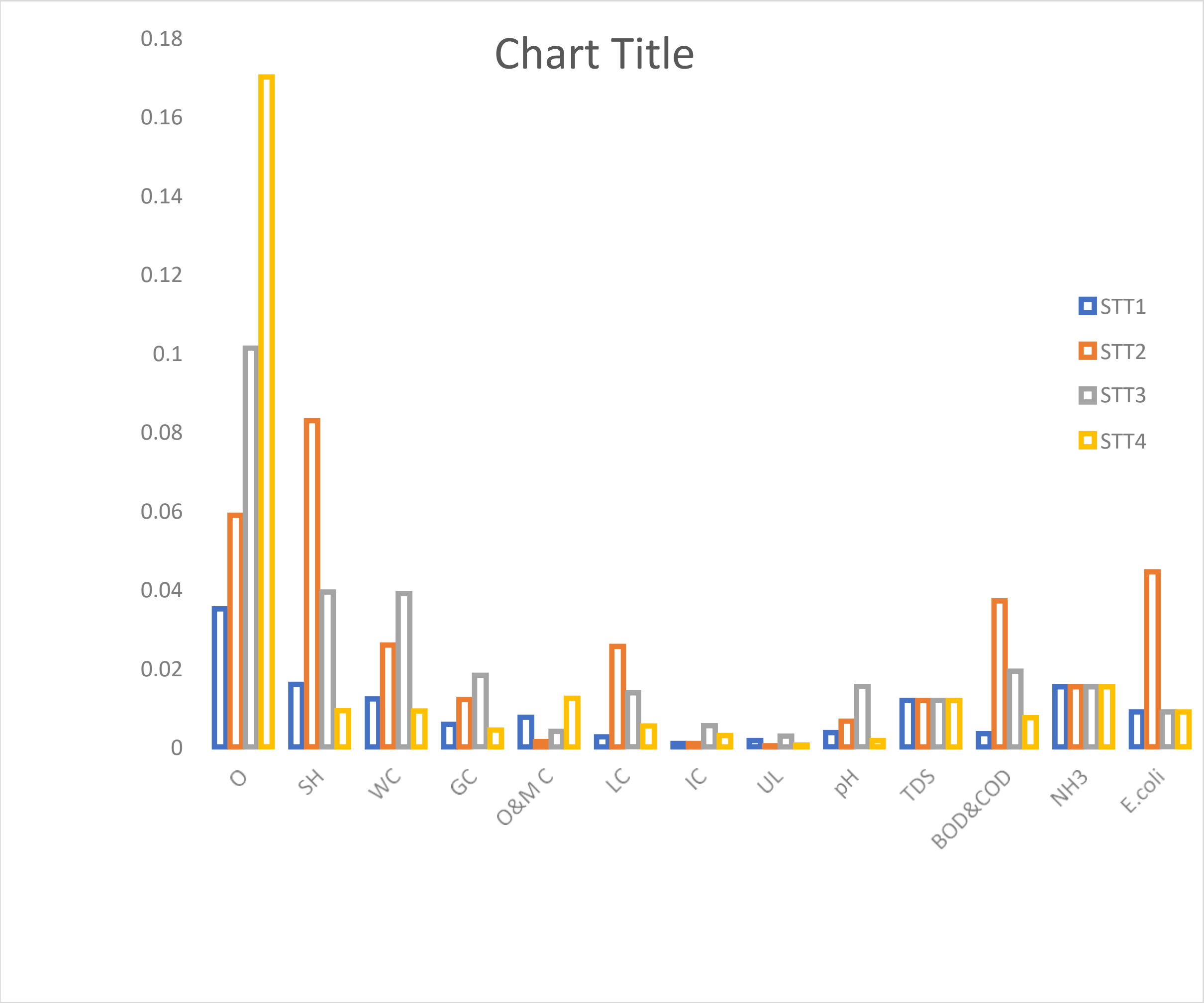

Figure 10. Global weights of alternative

Table 4. 51Overall rating of sustainable criteria and alternative

Main criteria	Local weight	Sub Criteria	Local weight	Global weight	Local weight of alternative				Global weight of alternative			
	1		2	3	STP1	STP2	STP3	STP4	STP1	STP2	STP3	STP4
SA	0.639	O	0.572	0.365	0.096	0.161	0.277	0.466	0.035	0.058	0.101	0.170
		SH	0.230	0.147	0.108	0.563	0.267	0.062	0.016	0.083	0.039	0.009
		WC	0.134	0.086	0.141	0.299	0.453	0.106	0.012	0.026	0.039	0.009
		GC	0.063	0.040	0.142	0.299	0.453	0.106	0.006	0.012	0.018	0.004
EA	0.087	MOC	0.285	0.025	0.298	0.053	0.157	0.493	0.007	0.001	0.004	0.012
		LC	0.536	0.047	0.054	0.543	0.291	0.112	0.002	0.025	0.014	0.005
		CC	0.1178	0.010	0.0882	0.088	0.538	0.285	0.001	0.001	0.006	0.003
		UL	0.060	0.005	0.309	0.057	0.538	0.094	0.002	0.003	0.003	0.001
SFH	0.274	pH	0.098	0.027	0.133	0.241	0.568	0.057	0.004	0.006	0.015	0.002
		TDS	0.173	0.047	0.25	0.25	0.25	0.25	0.012	0.012	0.012	0.012
		BCD	0.246	0.067	0.050	0.552	0.287	0.110	0.003	0.037	0.019	0.007
		NH3	0.222	0.061	0.25	0.25	0.25	0.25	0.015	0.015	0.015	0.0152
		E.COLI	0.261	0.071	0.125	0.625	0.125	0.125	0.008	0.045	0.008	0.008
AR									0.124	0.322	0.294	0.258
Ranking									4	1	2	3

Chapter 5

CONCLUSION

This study discusses the challenge of selecting the most appropriate STT alternative based on a variety of criteria (social acceptability, economical Aspects, and suitability for horticulture). More precisely, the paper explains how to use the AHP method logy of multicriteria decision making to determine the most suitable STT for Delhi. As the capacity and operating process of each alternatives differ, it be-comes quite challenging to rate the sewage treatment technologies by the traditional input-out efficiency method. Even statistical efficiency evaluation, which is entirely qualitative, lags in providing satisfactory decision-making. Whereas AHP allows for both descriptive and analytical assessment as the relative significance of each criterion is represented in terms of weight in this approach. Moreover, consistency check eliminates biased decision making in AHP. The method also has the measurable feature that it de-composes problems into their constituent components and constructs hierarchies of criteria so that the significance of each criterion becomes evident. We evaluated 4 STT alternatives in our study; the characteristics of these alternatives were used to determine the relative importance of all main criteria and sub-criteria. Pairwise comparison matrices are formulated to calculate the weights of criteria and alternatives based on the eigenvector method. Results show that out of four available alternatives, the sewage treatment technology “STP2” has attained the highest priority score of (priority score, 0.322) and thus judged as the most sustainable sewage treatment technology among all. This judgment of the “STP2 being most suitable and sustainable sewage technology is based on the fact that it has performed well on the majority of sustainability criteria of this study.

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