018530 - SWITCH

Sustainable Water Management in the City of the Future

Integrated Project

Global Change and Ecosystems

D5.3.7: Design Criteria and guidelines for optimum treatment efficiency and resource recovery

Selection Tool for Natural Wastewater Treatment Systems

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SWITCH Deliverable Briefing Note Template

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Dissemination Level		
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SWITCH Document

Sah, L., Rousseau, D.P.L. and van der Steen, P. (2010)- Selection tool for natural wastewater treatment systems. UNESCO-IHE.

Audience

Urban planners, environmentalists, engineers, public works officials , managers of wastewater treatment plants and educators.

Objective

To develop selection tool exclusively for natural systems for wastewater treatment (SETNAWWAT),disposal and reuse with following sub-objectives:

- Useful for feasibility study.
- It should be comprehensive, yet transparent and easy to use.
- Planners, decision makers and communities should be able to use it.
- It should be suitable for teaching and training purposes.
- To use it, an engineering degree in wastewater treatment technologies should not be a prerequisite.

Background

Among various challenges regarding sustainable urban water management, the protection of water resources from quality deterioration by point and non-point sources, probably is the biggest challenge over the coming decades. Wastewater has been identified as the main land based point source pollutant causing contamination of the water resource in the world (UNEP/GPA, 2000).

Therefore, wastewater management requires a holistic approach which is incorporated in the SWITCH (Managing water in the city of future) framework. Within the 3SSA (3 Step Strategic Approach), the backbone of SWITCH, efficient use of water, treatment of wastewatwer before disposal and minimization of quantity of treated wastewater to be returned back into the urban water cycle by reuse has been given due attention. Due to recent shift in the reclamation strategies for wastewater from high-tech to environmentally sound, sustainable, cost effective technologies, natural systems have gained due popularity.

Although, there are several technologies for wastewater treatment available, the next biggest challenge is selection of appropriate technology and its successful implementation. In line with this there is need for development of software for selection of technolgy especially focussing on natural systems.

Outcome of the study

A selection tool has been developed in Microsoft Excel consisting of pre-defined treatment trains, incorporating units exclusively from natural systems. The model requires inputs defined by users via user forms developed in Excel VBA. Based on these inputs, the model evaluates the treatment trains depending upon defined set of criteria ranging from technical, economic and social criteria and ranks them in the order of preference.

Scope of the tool

- Evaluation of different options available within the natural systems for wastewater treatment. This model also gives the planners the oppurtunity of analyzing the feasibility of use of natural systems.
- Evaluation of alternatives for treatment of raw wastewater or treatment of secondary effluent from a wastewater treatment plant. .
- Flexibility of defining weight value to the indicators of selection criteria provides potential users to define preferences for the indicators which might inturn depend upon the discharge of effluent into surface waters or reuse possibility.
- Since the model requires few input parameters and contains pre-defined treatment trains, is easy for the users and no prerequisite for background in details of wastewater treatment technologies.
- Users with background in Excel and wastewater treatment technologies can also add new treatment trains to this model.

Limitations of the tool

- The selection of options for wastewater treatment is limited within the natural systems.
- The model cannot provide the actual values of the effluent concentrations, construction costs and opertaion and maintenance costs, rather provides comparative evaluation for assigning rank to each predefined treatment train.
- SETNAWWAT is not a dynamic program and does not analyze the response of a system to variable influent conditions. Sensitivity to variable influent conditions could be explored through multiple trials with different influent quality.
- Since, the costs and average removal efficiencies data used in model is derived from different sources and from different regions, the model calculated costs and effluent quality may not be true reflection of local conditions under study.

Selection Tool for Natural Wastewater Treatment Systems

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Abstract:

Among the challenges regarding urban water management (UWM), the deterioration of water quality by point and non point sources, probably is the biggest challenge in sustainable water resource management. Wastewater has been identified as the main land based point source pollutant causing contamination of the water resource in the world (UNEP/GPA, 2000). Therefore, wastewater management needs due attention and there is need for application of holistic approach where wastewater is linked to resource recovery. Hence, wastewater treatment for reuse becomes an important objective. There are several wastewater technologies available, with NSWWT (Natural systems for wastewater treatment) gaining increased acceptance.

Although there are several technologies prevalent, the next biggest challenge is the selection of appropriate technology for wastewater treatment and its successful implementation. In line with this, a technology selection tool SETNAWWAT(Selection tool for natural systems for wastewater reatment), exclusively for natural sytems have been developed. This support system is simple and have been developed in excel 2007 and excel Visual Basic Application (VBA) 2007. The model requires input of data by the users which is done via user friendly interface. After calculation in excel, the model displays the first five most feasible treatment trains with information about land requirement, costs, cummulative weight and warning signals.

The methodology behind this model is it contains a list of pre-defined treatment trains. These pre-defined trains have been built incorporating the most widely used natural system units for wastewater treatment such as units of waste stabilization ponds(without vegetation), constructed wetlands and aerated lagoons. The model calculates, in excel, effluent quality in terms of BOD, TN, TP, SS, FC, construction and O&M costs and land requirement, depending on the data provided by the user. Based on these calculations, the treatment trains are evaluated and ranked in the order of preference. The evaluation of treatment trains is done based on different screening criterias and indicators. Depending on this evaluation, each treatment train receives points. Finally, cummulative weight is calculated from the points received at previous step and is used to rank the treatment trains in the order of feasibility.

Key words: Aerated lagoons, constructed wetlands, excel VBA 2007, SETNAWWAT, technology selection tool, urban water management, wastestabilization ponds.

Abbreviations

AP	Anaerobic Pond
BOD	Biological Oxygen Demand
CW	Cumulative Weight
DSS	Decision Support System
FAL	Facultative Aerated Lagoon
FC	Faecal Coliforms
FP	Facultative Pond
FWSCW	Free Water Surface Constructed Wetland
HRT	Hydraulic Retention Time
HSSFCW	Horizontal Subsurface Flow Constructed Wetland
MP	Maturation Pond
NF	Non Feasible
NSWWT	Natural System for Wastewater Treatment
O&M	Operation and Maintenance
PT	Primary Treatment
SS	Suspended Solids
ST	Sedimentation Tank
TN	Total Nitrogen
TP	Total Phosphorus
SETNAWWAT	Selection Tool for Natural Wastewater Treatment Systems
UWM	Urban Water Management
VBA	Visual Basic for Applications
VSSFCW	Vertical Subsurface Flow Constructed Wetland

Chapter 1

Introduction

1.1 Background

Increasing global change pressures such as industrialization and urbanization coupled with population growth, escalating costs and other risks inherent to conventional urban water management (UWM) are causing cities to face ever increasing difficulties in efficiently managing scarcer and less reliable water resources. As well, satisfying water uses/services and wastewater disposal without creating environmental, social or economic damage is an increasingly difficult challenge.

Among the above mentioned challenges regarding UWM, the protection of water resources from quality deterioration by point and non point source pollution discharges probably is the biggest challenge in sustainable water resource management over the coming decades. Wastewater has been identified as the main land based point source pollutant causing contamination of the water resource in the world (UNEP/GPA, 2000). Approximately 95% of the generated wastewater in the world is released to the environment without treatment (Zimmo *et al.*, 2003), thereby adding to the problem of surface water pollution and aggravating water scarcity isuue.

In addition, Millennium Development Goals (MDGs), specifically number 7 (Environmental Sustainability) target 10 aims at improvement of the coverage for water supply and sanitation services. This goal presents two conflicting ambitions: Increasing water supply delivery will lead to increasing volumes of wastewater, which, without being properly managed will exacerbate the ongoing water resources destruction (Nhapi and Gijzen, 2005). The water quality crisis, however, will remain unsolved for quite some time to come if we do not drastically change the current practice of unrestricted water use, and the planning of pollution control interventions exclusively ‘at the end of the pipe’ (Nhapi and Gijzen, 2005). Hence proper wastewater treatment and reclamation needs due attention.

Therefore, wastewater management should be considered within the wider context of sustainable development. This means that a holistic approach must be followed where the management of wastewater is linked to that of resource recovery.

1.2 Urban Water Cycle and the three Step Strategic Approach (SSA)

Three Step Strategic approach is the backbone of SWITCH (Managing water for the city of the future) framework. SWITCH is the name of an action research programme, implemented and co-funded by the European Union and a cross-disciplinary team of 33 partners from 15 countries around the world. SWITCH aims to bring about a paradigm shift in urban water management away from existing ad hoc solutions to urban water management and towards a more coherent and integrated approach. The vision of SWITCH is for sustainable urban water management in the 'City of the Future' (http://www.switchurbanwater.eu/).

The 3 Step Strategic approach, the backbone of SWITCH, include three steps: 1) prevention, 2) treatment for reuse, and 3) planned discharge with stimulation of self-purification capacity. The steps should be implemented in chronological order, and possible interventions under each step should be fully exhausted before moving on to the next step. This strategic approach is summarised in Figure 1.1 (Naphi and Gijzen, 2005). The concept of the first step is based on the application of Cleaner Urban Water Management principles (Siebel and Gijzen, 2002). These priciples are

Principle 1: Use a minimum input of resources per unit or product.

Principle 2: Do not use input material of a higher quality than strictly necessary.

Principle 3: Do not mix different waste flows.

Principle 4: Evaluate other functions of by-products before considering treatment and disposal.

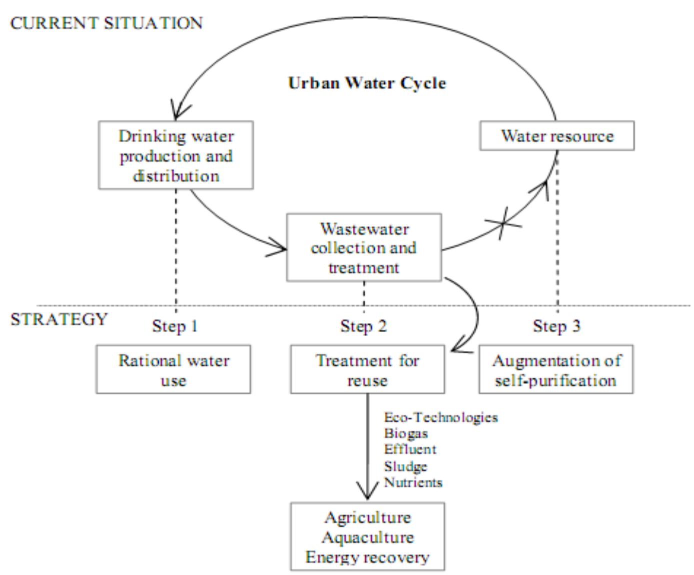

Figure 1.1: Schematic representation of the 3 step Strategic approach to wastewater management

Source: UNESCO-IHE and European Commision, 2007

Paradigm shift for the city of tomorrow

The paradigm shift represents a change in a set of scientific accomplishments that are "universally acknowledged", which during a certain time provides problem and solution models for the community. A change in paradigm generally implies a deep change of mentality regarding the time and values that form a specific vision of the reality, where the variable is the speed and depth of the change.

Knowledge and technological advancements have generated new proposals for water resource management in order to respond to environmental problems currently encountered. This progress promotes overturning the previous planning and water management paradigm to implement one in which human wellbeing and development is combined in a balanced manner with the environment.

The conventional water cycle that includes actual inefficiencies such as the use of high quality drinking water in large amounts for domestic use, human faeces transportation, loss of chemical substances, among others, requires a re-design. Even though the systems used 100 years ago faced the same inefficiencies, presently rapid population growth and higher water demand per capita, as well as higher industrial consumption and pollution load have caused these systems to not be able to naturally compensate the impacts, resulting in severe ecological damages (UNESCO-IHE and European Commission, 2007). The approach towards Urban Water Management (UWM) of the city of tomorrow should be based on sustainability in all its depth.

1.3 Pollution Control

As already mentioned, wastewater disposal is one of the biggest point source cause for pollution of natural water bodies, and within the 3SSA, efficient use of water, treatment of wastewatwer before disposal and minimization of quantity of treated wastewater to be returned back into the urban water cycle by reuse needs due attention.

1.3.1 Treatment for Reuse

Treated wastewater may be used beneficially in activities such as crop irrigation, industrial processes, cleansing or washing activities, protection of water resources, prevention of pollution, recovery of water and nutrients for agriculture, savings in clear water use and wastewater treatment costs, etc. (Capra and Scicolone, 2007). The reuse of wastewater may help satisfy the greater demands of water as long as there is an adequate treatment that ensures the appropriate quality for the assigned use. Additionally, wastewater reuse, being an additional source of water, represents environmental benefits such as the decrease in the amount of water used for sensitive ecosystem recreation activities and a decrease in wastewater discharges that reduce and prevent the contamination of water supply sources (EPA, 1998). Besides, sludge produced from wastewater treatment, may be used as crop fertilizers and the gases generated may be used as an energy generation source.

Within this context, it is thus important to find an appropriate alternative technology for wastewater treatment and reclamation, which is a major challenge. Furthermore, recent years have witnessed a major shift in the reclamation strategies for wastewater from high-tech to environmentally sound, sustainable, effective that provide low O&M cost (less dependency of external energy and chemicals), requires a minimum infrastructure level, provides flexibility in the operation and that allows recovery of energy, nutrients and water to address the increasing wastewater problems (Gijzen, 2001). In many cases they offer a more holistic alternative to improve the environmental quality.

The technologies that seem most suitable to achieve these goals are so called Natural Systems for wastewater treatment (NSWWT). This category includes wide range of technologies such as different variants of ponds (with or without plants), constructed wetlands, aerated lagoons, storage tanks, terrestial treatment methods like slow rate, overland flow or soil aquifer treatment. NSWWT are based on processes mediated naturally by microorganisms and are appropriate and economically feasible (von Sperling and Chernicharo, 2005). Furthermore, there is possibility of recovering energy, nutrients and water.

Although there are several technologies prevalent, the next biggest challenge is the selection of appropriate technology for wastewater treatment and its successful implementation. This selection process should integrate technical, environmental, social, cultural, economic, policy and regulatory aspects, allowing for a transition from the traditional approach to another of closed and efficient processes. The former views the environment as an inexhaustible source of resources and a recipient of waste generated by production and consumption processes whereas with the latter, environmental impact is lessened and water reuse is promoted.

In line with this there is need for development of technology selection tool or Decision Support System (DSS). This DSS should be simple, can be easily understood by the users, can be applied with skills locally available as much as possible and its role should be to facilitate the planning process rather than to replace human experts. It is in line with the definition of a DSS provided by Janssen (1990). A DSS is ‘a computer program that assists individuals or groups of individuals in their decision processes, supports rather than replaces judgement of these individuals, and improves the effectiveness rather than the efficiency of a decision process'.

1.3.2 Technology Selection Models

These are decision making tools for technology selection accompanied by methodological tools that facilitate the process, considering multiple aspects or criteria, from the technical, environmental, social and economic points of view, in order to guarantee the sustainability of the technology implemented. Horan and Parr (1994) classify technology selection methods into five categories: descriptive documents, checklists, selection matrices, algorithms and methods that include computer programmes (software).

Lately, models that include computer programmes such as PROSAB, SANEX, WAWTTAR and PROSEL, incorporates multi-criteria analysis and are in higher use. These models have a higher degree of complexity and involve a larger number of factors and variables, allowing a selection from a greater number of alternatives (Galvis,A.C., 2009). The common selection criteria for most authors can be classified into the following factors: treatment objectives, technological aspects, costs, operation and maintenance, wastewater characteristics, demographical and socio-cultural factors, site characteristics, climate factors, environmental impact, capacity and willingness to pay and construction aspects. The number of variables proposed by each author depended on the objectives for which each selection model was developed.

An indepth inspection of these computer based models reveals that most of these models were not exclusively designed for selection of wastewater technologies rather also includes water treatment systems or sanitation system for human excreta. Furthermore, these models are complicated with requirement of indepth background in wastewater treatment, distribution and reuse. Furthermore, they also require detailed data input by the end users of technology selection tool, the collection of which, makes it tedious for the users and also it does not exclusively considers natural systems.

A Decision Support System (DSS) exclusively for natural wastewater treatment systems, can assist in countering the scepticism about the feasibility of NSWWT by showing that under certain circumstances NSWWT are actually feasible. Also, natural systems for wastewater treatment is gaining due importance for wastewater treatment and reuse, hence, there is need for technology selection tool or also called DSS for natural wastewater treatment systems.

1.4 Objective

The present document focuses on development of selection tool exclusively for Natural systems for wastewater treatment, disposal and reuse with following sub-objectives:

- Useful for feasibility study.
- It should be comprehensive, yet transparent and easy to use.
- Planners, decision makers and communities must be able to use it.
- It should be suitable for teaching and training purposes.
- To use it, an engineering degree in wastewater treatment technologies should not be a prerequisite.

Chapter 2

General Guidelines

This chapter is intended to supply basic information about the operation of SETNAWWAT. It provides an overview of information display and editing conventions that have been adopted as well as the functions performed by each command. It is assumed that the user of this programme is familiar with MS-windows operating system and basic keyboard and mouse skills. This manual is not intended to be a tutorial for wastewater treatment technologies or MS-windows system.

2.1 Introduction to SETNAWWAT

SETNAWWAT is a decision support platform to assist planners and decision makers in screening possible options for natural systems for wastewater treatment. This system is best suited for planners who are exploring the possibility of implementation of natural system for wastewater treatment. It is hoped that SETNAWWAT will assist planners in improving sanitation coverage in the world.

This support system is simple and has been developed in Excel 2007 and excel Visual Basic Application (VBA) 2007. The input of data by the users is done via user friendly interface and users are not expected to work directly on the worksheet. The selection between different wastewater technologies is done from a list of pre-defined treatment trains. The list of pre-defined trains is given in chapter 3, table 3.1. These predefined trains have been built incorporating most widely used natural system units for wastewater treatment technologies such as different variants and combinations of ponds (without vegetation), different types of constructed wetlands and facultative aerated lagoons. The treatment trains does not include preliminary treatment step, hence it is recommended that these treatment trains be used for wastewater which has already undergone preliminary treatment that includes screening, grit removal and oil & grease removal.

2.2 Getting started with SETNAWWAT

2.2.1 Starting Excel (version 2007)

- Start Microsoft Excel programme on your computer from the main menu. If you can not see developer tab in the ribbon, install it from office button.
- Click office button, go to Excel options.
- In the Excel option dialog box, click the Show Developer tab in the ribbon check box.

- Click OK to close the dialog box. Now you can see developer tab in the ribbon at the top.
- From the ribbon click developer tab and then click Macro security.
- In the macro security dialog box, under the macro security section, click Enable all macros (not recommended; potentially dangerous code can run) option.
- Click OK to close the dialog box.
- Now open the Excel file for this programme.

2.2.2 Open SETNAWWAT model

Click The "SETNAWWAT" tab on the screen to run the macro which will start the SETNAWWAT Model. Alternatively from developer tab in the ribbon, click macros, select macro named "Show front page" and click run. This will show the front screen of the model as below

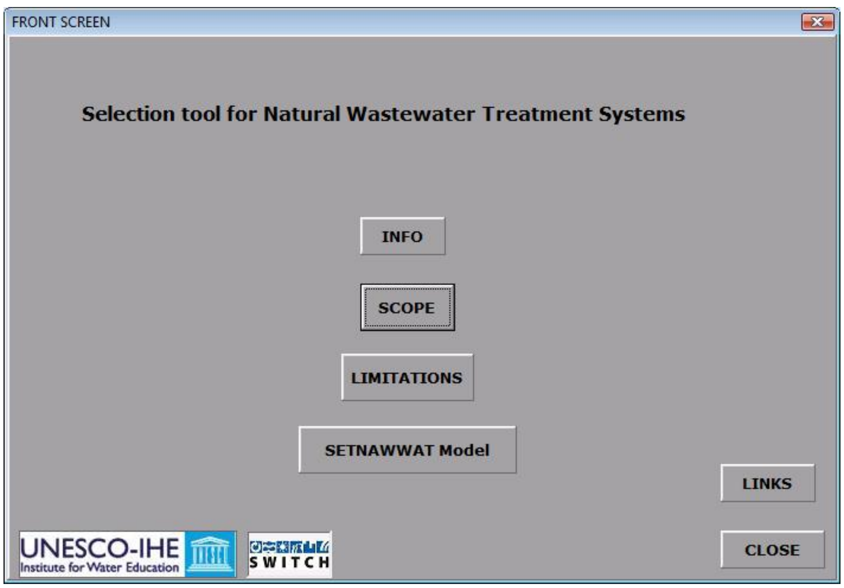

Figure 2.1: Front screen of the SETNAWWAT Model

2.2.3 Defining input for the model

Next step is getting into the model and providing required information. For this click SETNAWWAT tab and you will see a screen as shown in figure 2.2. Now you can click and enter each module to define the required data. The input data required for the model has been categorised into broad categories namely Hydro-meteorological data, demographic data, wastewater characteristics, technical and economic aspects, topographic data and socio-cultural aspects. The details of data under each category is given in table 2.1. As the name suggests CLOSE button at the bottom right of the form closes the respective window and brings back to previous screen. For reference, the screens for different modules are shown in figures 2.3 - 2.8. From this figure it is evident that the data can be easily entered by clicking each data entry boxes or these can be also accessed using "Enter" or "Tab" key on the keyboard. A blinking cursor in the box indicates that the textbox is ready for data entry. It is important for the users to realize the importance of units of data entered. Users are strictly advised to enter data in the same unit as prescribed in the model. For example in figure 2.3, population growth rate should be enetered in %, so the user should enter the value as 3 if growth rate is 3% and not as 0.03 or 3%. Data entered should only be the value and not the unit itself, else it might lead to calculation errors.

Table 2.1: List of input parameters required for SETNAWWAT

Modules	Parameters	Unit
Demographic data	Present population	#
	Population growth rate	%
	Base year	year
	Design period	# of years
Hydro-meteorological data	Average monthly temperature of coldest month	Degree celcius
	Average annual precipitation	mm/year
	Average annual evaporation	mm/year
Wastewater characteristics	Average flow rate	m^3/d
	Influent cBOD	mg/l
	Total nitrogen (TN)	mg/l
	Total suspended solids (TSS)	mg/l
	Total phosphorus (TP)	mg/l
	Faecal coliforms	#/100ml
	Select the possibility of reuse option	Select from options (surface discharge/ use for irrigation/ use for aquaculture)
	Select the type of wastewater	Select from options (Raw

Modules	Parameters	Unit
	to be treated	wastewater/ effluent from secondary treatment)
	Effluent standard for cBOD	mg/l
	Effluent standard for TSS	mg/l
	Effluent standard for TN	mg/l
	Effluent standard for TP	mg/l
	Effluent standard for faecal coliforms	#/100ml
Technical and economic aspects	Availibility of construction materials(Sand, gravel and Liners)	Yes/ No
	Availibility of continuous supply of electricity	Yes/No
	Available land area	m^2
Topographic data	Soil type	Sandy/ clay/ loamy/ silty
	Percolation rate	cm/d
Socio-cultural aspects	Location of planned site within 0.5 km	Yes/No
	Prevalence of mosquito borne diseases	Yes/No
	Weight for each indicator mentioned below	0 - 2, value cannot be zero
	Ability to meet effluent cBOD standard	
	Ability to meet TN and TP standard	

Modules	Parameters	Unit
	Ability to meet faecal coliforms removal	
	Land requirement	
	Construction costs	
	Operation and maintenance costs	
	Noise	
	Odor	
	malaria	
	Local availibility of materials	

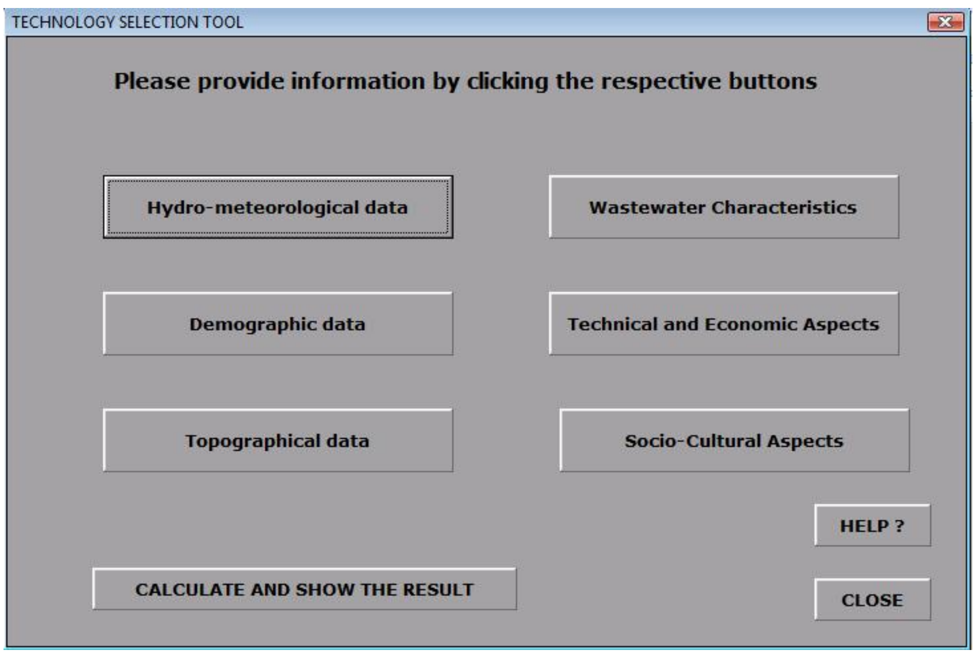

Figure 2.2: Screen showing different modules of the SETNAWWAT Model

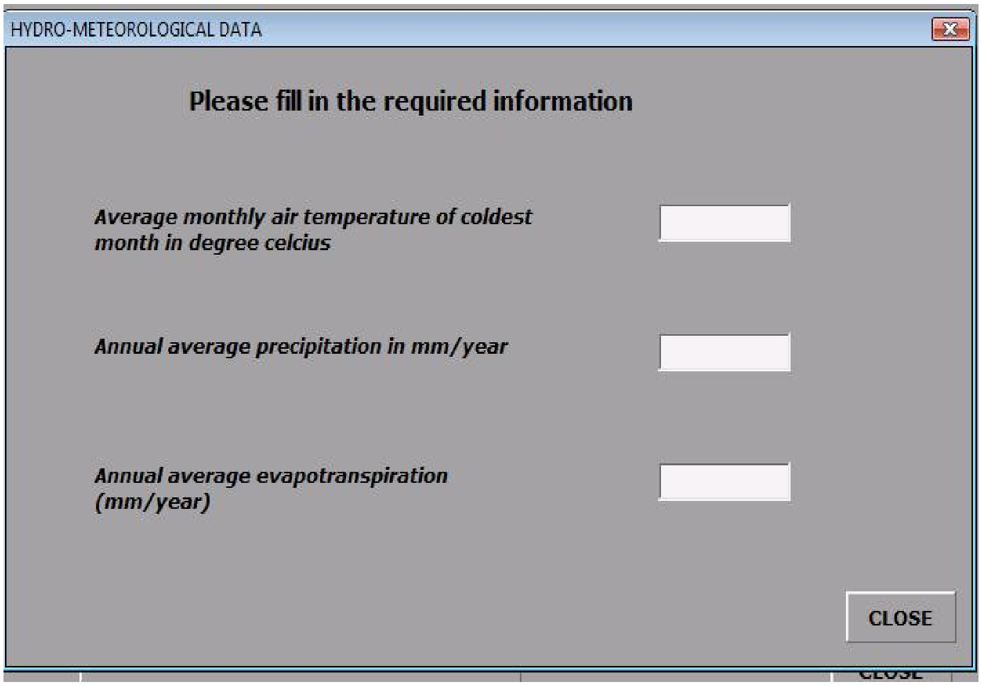

Figure 2.3: Screen showing the Hydro-meteorological Data

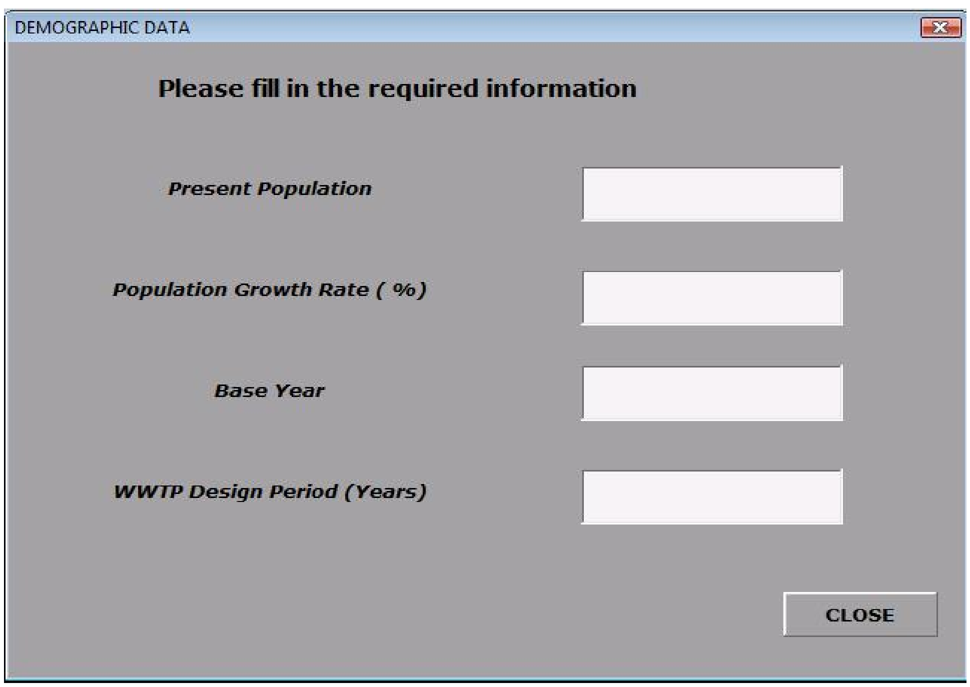

Figure 2.4: Screen showing the Demographic Data

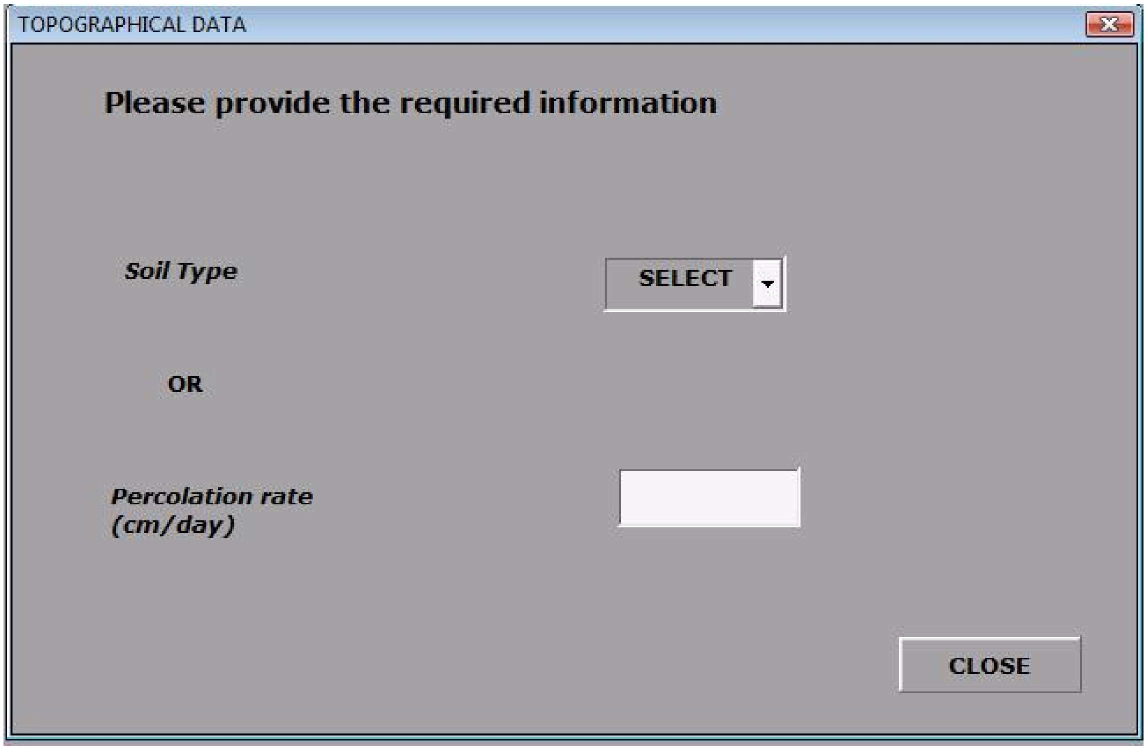

Figure 2.5: Screen showing Topographic Data

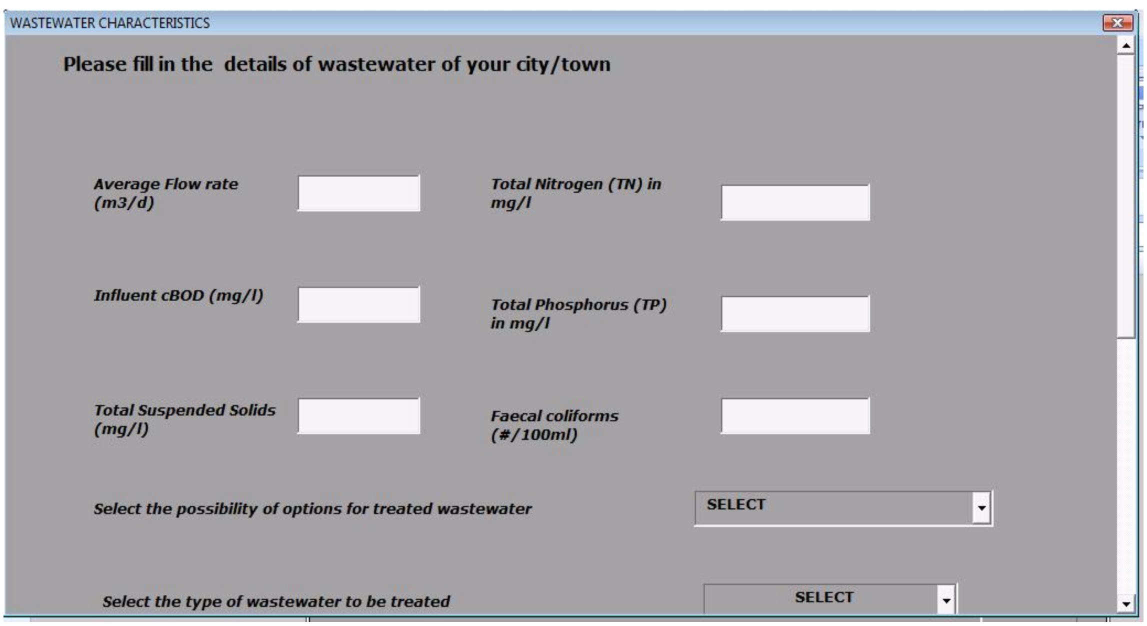

Figure 2.6: Screen showing wastewater characteristics Data

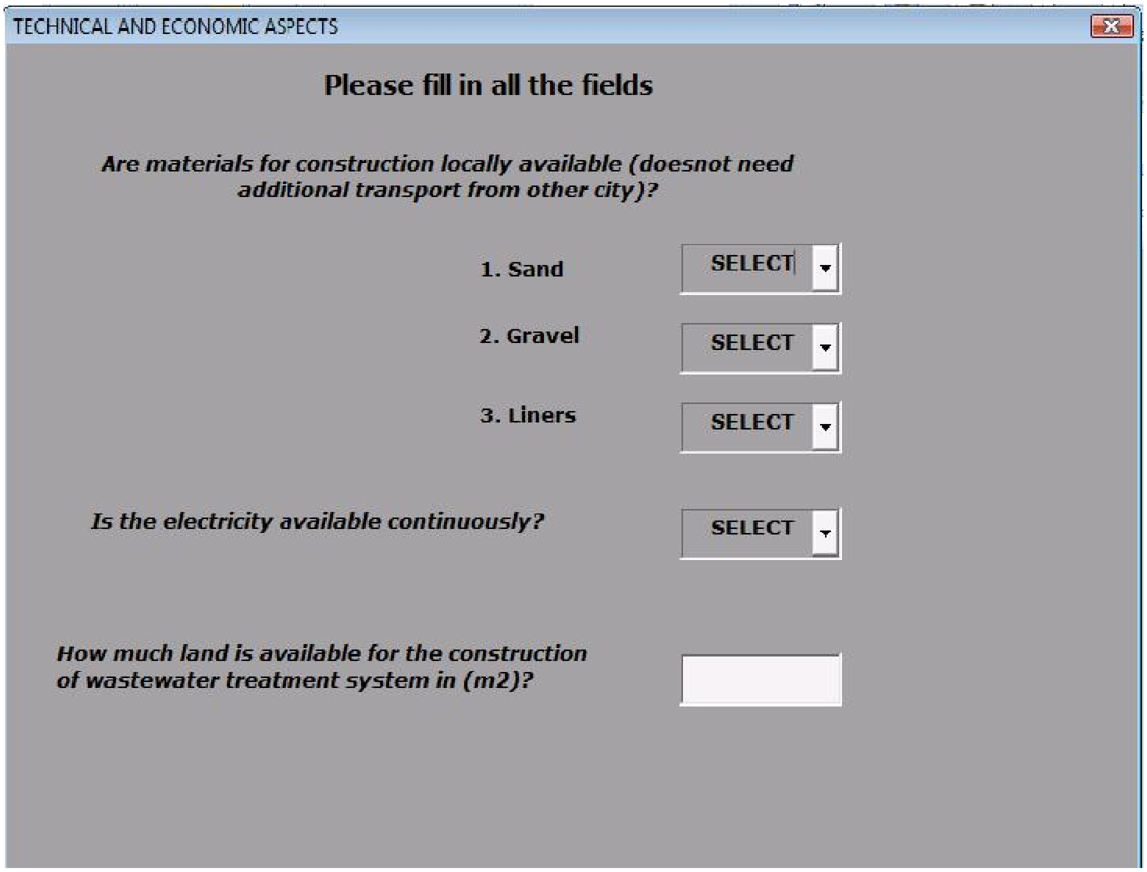

Figure 2.7: Screen showing Technical-economic aspect Data

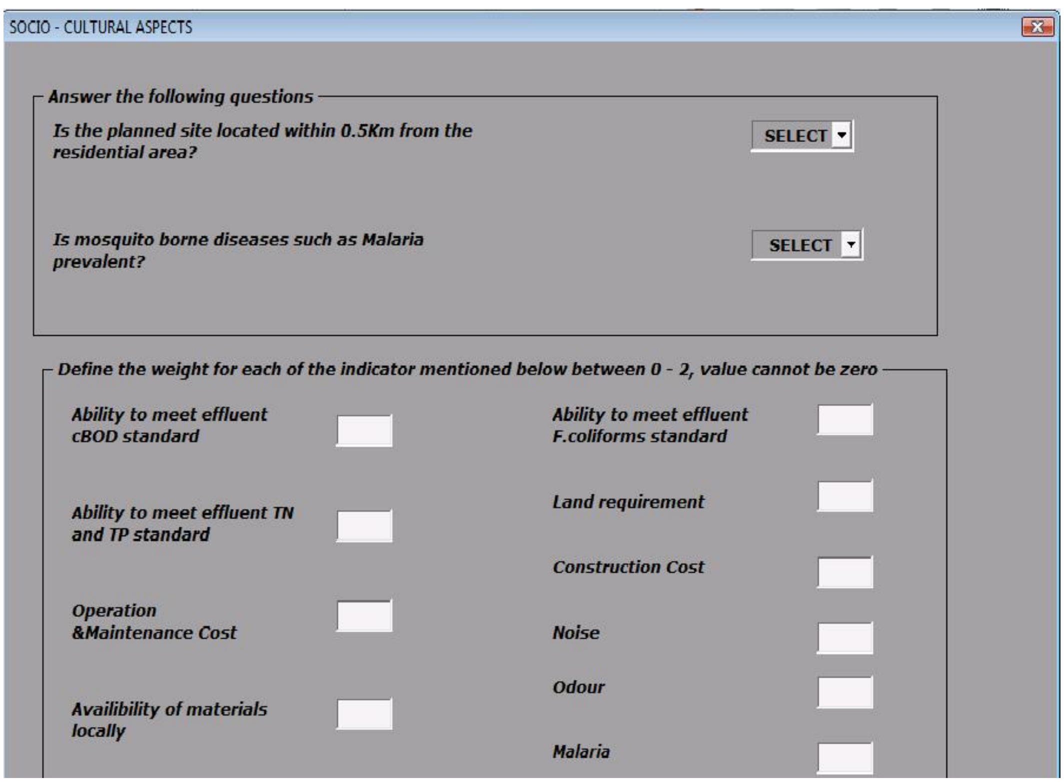

Figure 2.8: Screen showing socio-cultural aspects Data

2.2.4 Calculating and displaying results

Once all the data in each module is provided the Excel calculates and ranks each treatment train. To display the results click the button marked "Calculate and Show the Result". The screen for the result is shown below in figure 2.9. The result shows the treatment train number, name of the treatment train, cummulative weight, rank, land requirement, Construction costs and warning signals. The screening criteria is described elaborately in chapter 3.

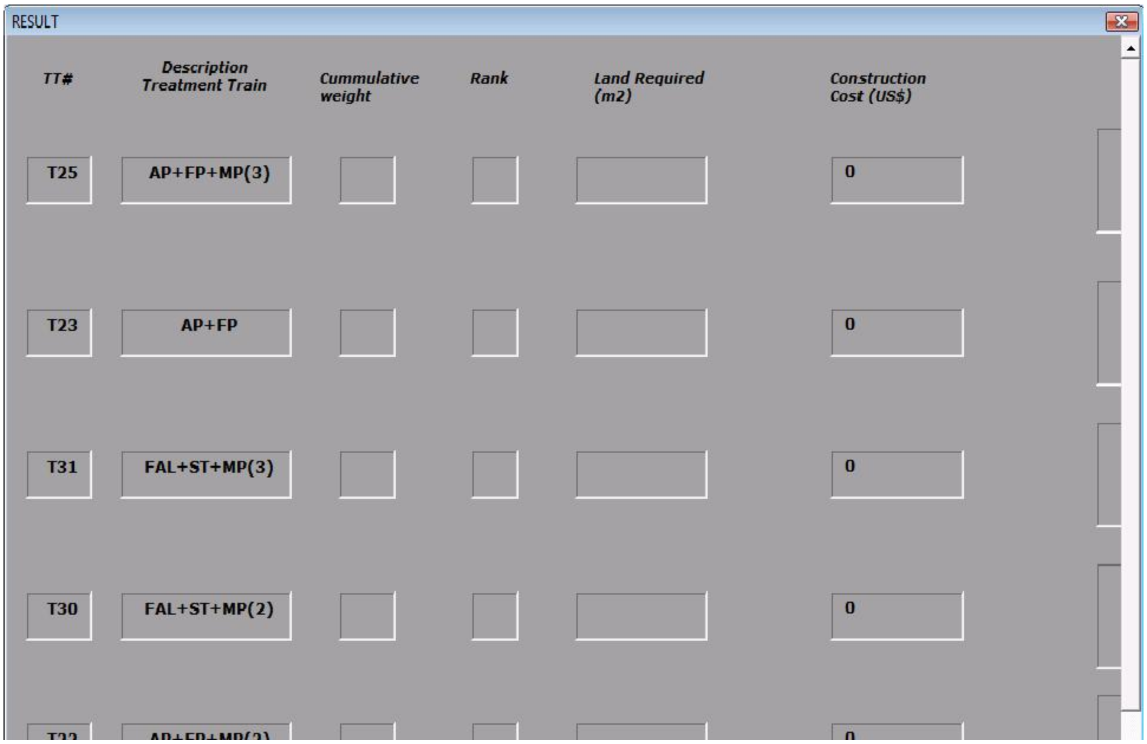

Figure 2.9: Screen showing result

2.2.5 Interpretationn of results

The results are displayed in table format with the left column showing the treatment train number, the second column displays the description of the treatment train including the order of arrangement of each treatment unit. The abbreviations for each treatment train is given at the beginning of the document. The third column in the result table shows the rank of the respective treatment train. The ranking order is such that treatment train with lowest rank is the most feasible. Furthermore, the result screen also shows the actual land required and construction costs, as calculated by the model, for first five treatment trains. Additionally, warning signals are displayed for the treatment trains.

2.3 Scope of the SETNAWWAT Model

SETNAWWAT is a decision support system designed to assist in the evaluation of infrastructure investment for wastewater treatment. The target audience of this tool includes planners, environmentalists, engineers, public works officials , managers of wastewater treatment plants and educators. This tool is exclusively designed for Natural sytems for wastewater treatment. This tool can be useful for

- Planners who have decided the construction of natural wastewater treatment facility due to either socio-economic reasons, reuse options or aesthetic reasons. This tool can help them in evaluation of different options available within the natural systems for wastewater treatment.
- This model is not only limited to planners who have already decided the use of Natural systems but also for planners who are in dilemma of selection between conventional and natural system. This model gives them the oppurtunity of analyzing about the feasibility of use of natural systems.
- Evaluation of alternatives for treatment of raw wastewater or treatment of an effluent from secondary treatment by conventional system or natural systems.
- Flexibility of defining weight value to the indicators of selection criteria provides potential users to define preferences for the indicators which might inturn depend upon the discharge of effluent into surface waters or reuse possibility.
- Since the model requires few input parameters and contains predefined treatment trains, is easy for the users and no prerequisite for background in details of wastewater treatment technologies.
- Users with background in excel and wastewater treatment technologies can add new treatment trains to this model.

2.4 Limitations of the SETNAWWAT Model

The use of this tool is limited to

- The selection of options for wastewater treatment limited within the Natural systems.
- The model cannot provide the actual values of the effluent concentrations, construction costs and opertaion and maintenance costs, rather provides comparative evaluation for assigning rank to each predefined treatment train.
- SETNAWWAT is not a dynamic program and does not analyze the response of a system to variable influent conditions. Sensitivity to variable influent conditions could be explored through multiple trials with different influent quality.

- Since, the costs and average removal efficiencies data used in the model is derived from different sources and from different regions, the model calculated costs and effluent quality may not be true reflection of local conditions under study.
- Hence, the authors are not liable for any discrepancies in costs or removal efficiencies.

Chapter 3

SETNAWWAT Details

This chapter focusses on the methodology adopted to develop the SETNAWWAT model as well as the mathematical model behind it. As already mentioned this model was developed in excel (2007) and user interface was developed using excel VBA (2007). It's main objective is to serve as a platform for technology selection exclusively for natural systems. This tool is more useful for the feasibility study during planning process. Further details about the model is described in upcomig sections.

3.1 Overview of SETNAWWAT operation

SETNAWWAT is a model for technology selection for natural systems of wastewater treatment. This model is simple to use, needs only few inputs by the users and a strong background in wastewater treatment is not essential.

How does it operate?

The model database has an inventory of predefined treatment trains. Each treatment train has two or three treatment units so as to include primary, secondary and tertiary treatment. Few treatment trains contain only one unit for tertiary treatment making the model flexible to be used as selection tool for polishing stage of the secondary effluent. Based on the userdefined data, model calculates, in Excel, effluent quality in terms of BOD, TN, TP, SS, FC, construction and O&M costs and land requirement. Based on this, these treatment trains are evaluated and ranked in the order of preference. The evaluation of treatment trains is done based on different screening criterias and indicators described in section3.4. The first step is testing the criteria for technical feasibility, through indicator, the availability of land. If the model calculated land requirement for a train is higher than the land available defined by the user, than the model marks that train as not feasible(NF) else the treatment train receives a point. Further screening involves fulfilling other criterias mentioned in section 3.4. Each treatment train receives a positive point for fulfilling an indicator for the criteria. Next step is calculation of cummulative weight which is based on the values received at testing stage of criteria and these values are adjusted depending upon the weight provided by users for each screening indicators. Finally, this cummulative weight is used to rank the treatment trains in the order of feasibility. The cummulative weight(CW) is calculated only when the indicator land availibility is met. Besides, the model also provides warning signals for each treatment trains in the output.

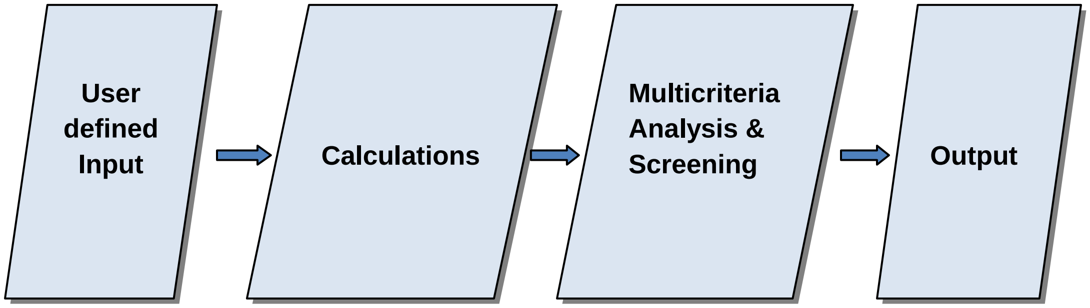

Figure 3.1: Schematic representation of screening of treatment trains

3.2 Methodology for model development

Model development started with

- Literature review and preparing inventory of possible treatment technologies. Besides, data for decay constants, construction and operation costs and removal efficiencies related to each treatment technology was also collected as an input to the model. The other set of data required by the model is provided by the user through user freindly interface developed in excel VBA.
- Following this, possible treatment trains were defined based on the information in the literature. The list of these pre-defined treatment trains is given in table 3.1. These treatment trains were defined in excel sheet and mathematical model were defined for each unit of the treatment train to calculate the effluent standards for BOD, TN, TP, SS and FC.
- Furthermore, mathematical equation for calculation of Construction costs, O&M costs, land requirement and water loss from the surface were also defined for each unit of the treatment train. Details of the mathematical model is dealt with seperately in section3.3.
- Next step is analysis of treatment trains for fulfilling different indicators associated with each criteria. First screening step consists of screening the treatment trains for indicator land availibility. If the criteria is met, the train gets a point between -1 to 1 depending upon the actual land area calculated by the model.
- Other screening tests includes the fulfillment of other indicators such as meeting the effluent standards, availibility of construction materials locally, contruction and O&M costs, odour, noise and malaria prevalence issues, and loss of water from surface.
- This screening stage provides points for each indicator to each treatment train. These points are then used to calculate the cummulative weight.
- The individual points for each indicator is adjusted depending upon the weightage provided by the users for each criteria.
- The treatment trains are finally ranked based on their cummulative points. And the model displays the first five most feasible options of treatment trains.

- The model also displays warning signals for each treatment trains based on the criteria met.

Table 3.1: List of pre-defined treatment trains used in SETNAWWAT

Treatment train number	Description of treatment train
T1	PT+FWSCW
T2	PT+SSHFCW
T3	PT+SSVFCW
T4	PT+SSVFCW+SSHFCW
T5	PT+SSHFCW+SSVFCW
T6	PT+FWSCW+SSHFCW
T7	PT+SSHFCW+FWSCW
T8	PT+FWSCW+SSVFCW
T9	PT+SSVFCW+FWSCW
T10	AP+FWSCW
T11	AP+SSHFCW
T12	AP+SSVFCW
T13	FP+FWSCW
T14	FP+SSHFCW
T15	FP+SSVFCW
T16	FP+MP(2)+FWSCW
T17	FP+MP(2)+SSHFCW
T18	FP+MP(2)+SSVFCW
T19	FWSCW
T20	SSHFCW
T21	SSVFCW

Treatment train number	Description of treatment train
T22	AP+FP+MP(2)
T23	AP+FP
T24	FP+MP(2)
T25	AP+FP+MP(3)
T26	FP+MP(3)
T27	FP+MP(3)+FWSCW
T28	FP+MP(3)+SSHFCW
T29	FP+MP(3)+SSVFCW
T30	FAL+ST+MP(2)
T31	FAL+ST+MP(3)
T32	MP(2)
T33	MP(3)

3.3 Mathematical model

This section provides an overview of the mathematical model used for calculations in the technology selection tool model. The treatment trains in the present selection model consists of different combinations of primary treatment, sedimentation tank, constructed wetlands wastestabilization ponds and facultative aerated lagoons. The treatment efficiency, land requirement and construction, O&M costs have been calculated using different design approach available in the literature.

For convenience, the description of mathematical model has been divided into several sub topics:

3.3.1 Constructed wetlands

Land requirement

For all the three types of constructed wetlands, calculation of land requiremnet is based on the hydraulic loading rate(q) which is calculated using the latest design equation, the PKC* model as given by (Kadlec and Wallace, 2009). Since, meeting effluent standard, is an important criteria for the screening of treatment trains, the effluent concentration from constructed wetland is assumed to be same as the standard provided by the user.

Equation PKC model (*Kadlec and Wallace, 2009)*:*

$$\left(\frac{C - C^*}{C_i - C^*}\right) = \frac{1}{\left(1 + \frac{k}{Pq}\right)^P} \quad \text{..........Eq.(3.1)}$$

Where, C is the effluent concentration(mg/l), C_i is influent concentration(mg/l), C^* is background concentration(mg/l), k is decay constant(m/d), P is apparent number of tanks in series(TIS); always $P \leq N$ (number of tanks in series as described by the tracer test) and q is the hydraulic loading rate (m/d).

The hydraulic loading rate (q) derived from above equation was used to calculate land requirement using the following equation:

$$Q = A * q \quad \text{..........Eq. (3.2)}$$

where Q is the flow rate (m^3/d) defined by the user, A is the area (m^2) of the wetland.

The above methodology was used to calculate land requirement for BOD removal. This is used for the evaluation based on land at the first screening stage.

In treatment trains with two units of different kind of constructed wetlands, the effluent concentration from the second constructed wetland was set at the standard defined by the user and for the first constructed wetland, the effluent standard was calculated assuming 75% of the total removal to happen in the first constructed wetland. This assumption is based on the concept of weathering.

The total land requirement for a treatment train is calculated by adding the land requirement for each unit in the treatment train.

Total nitrogen (TN), Total phosphorus (TP), Total Suspended Solids (TSS) and faecal coliforms (FC) removal

In the absence of elaborate data for the values of k, P and C* for TP and TSS removal, needed in PKC* model, the effluent concentration in terms of TP and SS was calculated based on average % removal data available in literature. Furthermore, for consistency in the model with regards to land requirement calculations for other types of treatment units, TN and FC effluent concentrations were also based on average % removal efficiency values. These values are given in table 3.1.

Construction, operation and maintenance (O&M) costs

In the absence of elaborate data on construction and O&M costs, present selection tool uses costs/P.E (costs per population equivalent, found in literature) data to calculate construction and O&M costs for different treatment units. These values are given in table 3.1. As mentioned by Kadlec(2009); the cost of FWSCW is 0.3 times of HSSFCW, the construction cost for FWSCW was accordingly extrapolated from the cost of HSSFCW. Similarly, comparison of cost breakdown for HSSFCW and VSSFCW as mentioned by Chen et al.(2008) and Vymazal (2002); the cost of VSSFCW was assumed to be 15% higher than that of HSSFCW. For O & M costs, assumption was made for 20% lower than HSSFCW in FWSCW and 20% higher in VSSFCW. The total costs for a treatment train is calculated by adding the costs for each unit in the treatment train.

Table 3.2: List of parameter values used for constructed wetlands

<table>
<tr><th>Treatment Unit</th><th>Parameter</th><th>Symbol</th><th colspan="2">Value</th><th>Unit</th><th>Source</th></tr>
<tr><td rowspan="15">FWSCW</td><td>Apparent number of TIS for BOD</td><td>P</td><td colspan="2">1</td><td>[-]</td><td>Kadlec and Wallace (2009)</td></tr>
<tr><td rowspan="5">Background concentration for BOD</td><td rowspan="5">$C*$</td><td>BOD (mg/l)</td><td>Value</td><td rowspan="5">mg/l</td><td rowspan="5">Kadlec and Wallace (2009)</td></tr>
<tr><td>0 - 30</td><td>2</td></tr>
<tr><td>30 - 100</td><td>5</td></tr>
<tr><td>100 - 200</td><td>10</td></tr>
<tr><td>>200</td><td>20</td></tr>
<tr><td rowspan="5">Apparent TIS rate constant for BOD</td><td rowspan="5">k</td><td>BOD(mg/l)</td><td>Value</td><td rowspan="5">m/year</td><td rowspan="5">Kadlec and Wallace (2009)</td></tr>
<tr><td>0 - 30</td><td>79, 195</td></tr>
<tr><td>30 - 100</td><td>67, 295</td></tr>
<tr><td>100 - 200</td><td>112, 411</td></tr>
<tr><td>>200</td><td>439, 827</td></tr>
<tr><td>Construction Costs</td><td></td><td colspan="2">12.6</td><td>US$/P.E</td><td>Extrapolated from cost of HSSFCW based on info in Kadlec (2009)</td></tr>
<tr><td>O & M Costs</td><td></td><td colspan="2">3.76</td><td>US$/P.E</td><td>Extrapolated from</td></tr>
</table>

<table>
<tr><th>Treatment Unit</th><th>Parameter</th><th>Symbol</th><th colspan="2">Value</th><th>Unit</th><th>Source</th></tr>
<tr><td rowspan="5"></td><td></td><td></td><td colspan="2"></td><td></td><td>cost of HSSFCW based on info in Kadlec (2009)</td></tr>
<tr><td>TP removal</td><td></td><td colspan="2">20</td><td>%</td><td>UNESCO-IHE SWITCH deliverable D 5.3.1</td></tr>
<tr><td>TN removal</td><td></td><td colspan="2">20</td><td>%</td><td>UNESCO-IHE SWITCH deliverable D 5.3.1</td></tr>
<tr><td>TSS removal</td><td></td><td colspan="2">75</td><td>%</td><td>UNESCO-IHE SWITCH deliverable D 5.3.1</td></tr>
<tr><td>FC removal</td><td></td><td colspan="2">99</td><td>%</td><td>UNESCO-IHE SWITCH deliverable D 5.3.1</td></tr>
<tr><td rowspan="13">HSSFCW</td><td>Apparent number of TIS for BOD</td><td>P</td><td colspan="2">3</td><td>[-]</td><td>Kadlec and Wallace (2009)</td></tr>
<tr><td rowspan="5">Background concentration for BOD</td><td rowspan="5">$C*$</td><td>BOD(mg/l)</td><td>Value</td><td rowspan="5">mg/l</td><td rowspan="5">Kadlec and Wallace (2009)</td></tr>
<tr><td>0 - 30</td><td>1</td></tr>
<tr><td>30 - 100</td><td>5</td></tr>
<tr><td>100 - 200</td><td>10</td></tr>
<tr><td>>200</td><td>15</td></tr>
<tr><td rowspan="5">Apparent TIS rate constant for BOD</td><td rowspan="5">k</td><td>BOD(mg/l)</td><td>value</td><td rowspan="5">m/year</td><td rowspan="5">Kadlec and Wallace (2009)</td></tr>
<tr><td>0 -30</td><td>224, 458</td></tr>
<tr><td>30 - 100</td><td>44, 167</td></tr>
<tr><td>100 - 200</td><td>44, 107</td></tr>
<tr><td>>200</td><td>114, 378</td></tr>
<tr><td>Construction Costs</td><td></td><td colspan="2">42</td><td>US$/P.E</td><td>Rousseau (2008)</td></tr>
</table>

Treatment Unit	Parameter	Symbol	Value	Unit	Source
	Operation and Maintenance Costs		4.7	US$/P.E	Rousseau (2008)
	TP removal		20	%	UNESCO-IHE SWITCH deliverable D 5.3.1
	TN removal		20	%	UNESCO-IHE SWITCH deliverable D 5.3.1
	TSS removal		75	%	UNESCO-IHE SWITCH deliverable D 5.3.1
	FC removal		99	%	UNESCO-IHE SWITCH deliverable D 5.3.1
VSSFCW	Apparent number of TIS for BOD	P	6	[-]	Kadlec and Wallace (2009)
	Background concentration for BOD	$C*$	0	mg/l	Kadlec and Wallace (2009)
	Apparent TIS rate constant for BOD	k	BOD(mg/l): value 0 - 30: 105 30 - 100: 79 100 - 200: 122 >200: 93	m/year	Kadlec and Wallace (2009)
	Construction Costs		48.3	US$/P.E	Extrapolated from cost of HSSFCW based on info in Kadlec (2009)
	O & M Costs		5.64	US$/P.E	Extrapolated from cost of HSSFCW based on info in Kadlec (2009)
	TP removal		65	%	UNESCO-IHE

Treatment Unit	Parameter	Symbol	Value	Unit	Source
					SWITCH deliverable D 5.3.1
	TN removal		55	%	UNESCO-IHE SWITCH deliverable D 5.3.1
	TSS removal		75	%	UNESCO-IHE SWITCH deliverable D 5.3.1
	FC removal		99	%	UNESCO-IHE SWITCH deliverable D 5.3.1

3.3.2 Anaerobic pond (AP)

Land requirement

The required land for the construction of AP was calculated based on the design equation of volumetric loading rate described by Shilton (2005).

$$V = \frac{BOD_{in} * Q}{\lambda_v}$$ **...Eq. (3.3)**

V is the volume of AP in (m^3), Q is the flow rate described by the user (m^3/d) and λ_v is the the volumetric loading rate (Kg BOD/m^3/day). The volumetric loading rate depends on the average minimum temperature.

From this equation area of the AP is calculated by

$$V = A * d$$ **...Eq. (3.4)**

Where V is the volume of AP in (m^3); A is the area of AP in (m^2) and d is the average depth of AP in (m) mentioned in literature.

The total land requirement for a treatment train is calculated by adding the land requirement for each unit in the treatment train.

BOD removal

For AP's, BOD removal was calculated using the % removal efficiency defined by Shilton (2005) which is a function of volumetric loading rate as described in table 3.2.

Table 3.3: Volumetric loading rate and BOD removal as function of temperature

Minimum month average air temperature (^oC)	Volumetric loading rate ($KgBOD/m^3/day$)	BOD removal efficiency (%)
<10	0.10	40
10 - 20	0.02 * temperature - 0.10	2 * temperature + 20
>20	0.30	60

TN, TP, TSS and FC removal

In the absence of any design equation for TP,TN, TSS and FC removal, the effluent concentration in terms of TN, TP, TSS and FC was calculated based on average % removal data available in literature.The values are given in Table 3.3.

Construction, operation and maintenance (O&M) costs

In the absence of elaborate data on construction and O&M costs, present selection tool uses costs/P.E data to calculate construction and O&M costs for different treatment units. The values are given in table 3.3. The construction costs and O&M cost values were extrapolated from values for FP given by von sperling, (2007).

The total costs for a treatment train is calculated by adding the costs for each unit in the treatment train.

Table 3.4: List of parameter values used for anaerobic pond

Treatment Unit	Parameter	Symbol	Value	Unit	Source
AP	Average depth of the pond	d	4	m	Shilton (2005)
	Construction Costs		19.5	US$/P.E	von Sperling (2007)
	O & M Costs		0.8	US$/P.E	von Sperling (2007)
	TN removal		40	%	UNESCO-IHE SWITCH deliverable 5.3.1
	TP removal		40	%	
	SS removal		60	%	
	FC removal		90	%	

3.3.3 Facultative ponds (FP)

Land requirement

The requirement of land for FP was calculated based on organic surface load which is a function of average air temperature of coldest month. Area is given by

$$A = \frac{BOD_{in} * Q}{\lambda_0}$$ **..............................Eq. (3.5)**

where A is area of FP (hactares), BOD_{in} (mg/l) converted into Kg/m^3, Q flow rate (m^3/day) and λ_0 organic surface load (KgBOD/ha/day). Hactare of land is converted into m^2.

According to Mara et al., (1992), the relationship between temperature and organic surface load is given by

$$\lambda_o = 350(1.107 - 0.002T)^{T-25}$$ **..............................Eq. (3.6)**

where λ_0 is surface loading rate (Kg BOD/ha/day) and T is average air temperature of coldest month (degree celcius).

The total land requirement for a treatment train is calculated by adding the land requirement for each unit in the treatment train.

BOD removal

For FP's, BOD removal was calculated using the removal rate as described by Mara et al., (1995) cited by Ellis and Rodrigues (1995) which is a function of organic surface loading rate.

$$\lambda_r = 0.79 * \lambda_0 + 2$$ **..............................Eq. (3.7)**

where λ_r is BOD removal in Kg BOD/ha/day which is converted into percent and used in the calculation for the final effluent BOD from FP.

TN, TP, TSS, FC removal

In the absence of any design equation for TP, TN, TSS and FC removal, the effluent concentration in terms of TN, TP, TSS and FC was calculated based on average % removal data available in literature. The values are mentioned in table 3.4.

Construction, operation and maintenance (O&M) costs

In the absence of elaborate data on construction and O&M costs, present selection tool uses costs/P.E data to calculate construction and O&M costs for different treatment units. The values are mentioned in table 3.4.

The total costs for a treatment train is calculated by adding the costs for each unit in the treatment train.

Table 3.5: List of values used for FP

Treatment Unit	Parameter	Value	Unit
FP	Construction Costs	22.5	US$/P.E
	O & M Costs	1.15	US$/P.E
	TN removal	40	%
	TP removal	40	%
	TSS removal	80	%
	FC removal	80	%

Source: von Sperling (2007)

3.3.4 Maturation ponds (MP's)

In general design of MP's is governed by the required FC removal and assumes the existence of a series of completely mixed ponds as described by Shilton, 2005.

Land requirement

This was calculated using the equation for a series of completely mixed ponds which is given by

$$\frac{N_e}{N_i} = \frac{1}{\left(1 + k_T \frac{HRT}{n}\right)^n} \quad \textbf{...Eq.(3.8)}$$

where, N_e is the number of FC (#/100ml) in the effluent, N_i is the number of FC in the influent (#/100ml), K_T is the decay constant (d^{-1}) at temperature T (^0C), HRT is the hydraulic retention time (days) and n is the number of completely mixed ponds in series.

The equation for K_T is given by

$$K_T = K_{20} * \theta^{T-20} \quad \textbf{...Eq. (3.9)}$$

Where, K_{20} is decay constant (d^{-1}) at temperature 20^0C, θ is temperature co-efficient (-), T is the temperature (^0C).

Using equation **(3.8)**, HRT was calculated, assuming the effluent FC concentration to be the standard FC concentration provided by the user. Area was calculated by the following equation:

$$A = \frac{HRT * Q}{d}$$ **..........Eq. (3.10)**

where, A is the area (m^2) of MP, Q is the user defined flow rate (m^3/day), d is the average depth of MP (m) as described in the literature. Refer table 3.5 for values.

The total land requirement for a treatment train is calculated by adding the land requirement for each unit in the treatment train.

Removal of BOD, TN, TP and TSS

In the absence of any design equation for BOD, TP,TN and TSS removal, the effluent concentration in terms of BOD, TN, TP and TSS was calculated based on average % removal data available in literature. The values are given in table 3.5.

Construction, operation and maintenance (O&M) costs

In the absence of elaborate data on construction and O&M costs, present selection tool uses costs/P.E data to calculate construction and O&M costs for different treatment units. The consruction and O&M costs were extrapolated from costs for FP given by von Sperling, (2007). The values are given in table 3.5.

The total costs for a treatment train is calculated by adding the costs for each unit in the treatment train.

Table 3.6: List of values used in MP

Treatment Unit	Parameter	Symbol	Value	Unit	Source
MP	Decay constant at 20^{0}C	K_{20}	2.6	d^{-1}	Marais (1974)
	Temperature coefficient	θ	1.19	[-]	Marais (1974)
	Average depth	d	1.5	m	Shilton (2005)
	Construction Costs		27.5	US$/P.E	von Sperling (2007)
	O & M Costs		1.5	US$/P.E	von Sperling (2007)

Treatment Unit	Parameter	Symbol	Value	Unit	Source
	BOD removal		70	%	UNESCO-IHE SWITCH deliverable D 5.3.1
	TN removal		50	%	UNESCO-IHE SWITCH deliverable D 5.3.1
	TP removal		0	%	UNESCO-IHE SWITCH deliverable D 5.3.1
	TSS removal		20	%	UNESCO-IHE SWITCH deliverable D 5.3.1

3.3.5 Facultative aerated lagoon (FAL)

The design of FAL is based on the assumption of completely mixed flow conditions in the pond.

Land requirement

Calculation of land requirement for FAL is based on the calculation of HRT, which inturn is calculated based on the equation for calculation of effluent concentration assuming completely mixed flow conditions. The equation is as follows:

$$C_e = \frac{C_{in}}{1 + K_T * HRT} \quad \text{..........} \textbf{Eq. (3.11)}$$

Where, C_e is effluent concentration for BOD (mg/l), this was calculated based on average removal efficiency as given in table 3.7, C_{in} is influent concentration for BOD (mg/l), K_T is decay constant (d^{-1}), HRT is hydraulic retention time (days). K_T was calculated using equation **(3.9)** and Area was calculated using equation **(3.10)**.

The total land requirement for a treatment train is calculated by adding the land requirement for each unit in the treatment train.

Removal of TN, TP, FC and SS

In the absence of any design equation for TP,TN, FC and SS removal, the effluent concentration in terms of TN, TP, FC and SS was calculated based on average % removal data available in literature.

Construction, operation and maintenance (O&M) costs

In the absence of elaborate data on construction and O&M costs, present selection tool uses costs/P.E (costs per population equivalent)data to calculate construction and O&M costs for different treatment units.

The total costs for a treatment train is calculated by adding the costs for each unit in the treatment train.

Table 3.7: List of values used for FAL

Treatment Unit	Parameter	Symbol	Value	Unit	Source
FAL	Decay constant at 20^0C	K_{20}	0.7	d^{-1}	von Sperling and Chernicharo (2005)
	Temperature coefficient	θ	1.035	[-]	von Sperling and Chernicharo (2005)
	Average depth	d	3.25	m	von Sperling and Chernicharo (2005)
	Construction Costs		30	US$/P.E	Von Sperling (2007)
	O & M Costs		3	US$/P.E	von Sperling (2007)
	BOD removal		80	%	von Sperling and Chernicharo (2005)
	TN removal		40	%	von Sperling (2007)

Treatment Unit	Parameter	Symbol	Value	Unit	Source
	TP removal		40	%	von Sperling (2007)
	SS removal		75	%	von Sperling and Chernicharo (2005)
	FC removal		78	%	von Sperling (2007)

3.3.6 Sedimentation tank (ST) and primary treatment (PT)

Land Requirement

In the absence of any design equation for ST's and PT's, land requirement was calculated based on average unit land required / P.E mentioned in literature.The values are given in table 3.8.
The total land requirement for a treatment train is calculated by adding the land requirement for each unit in the treatment train.

Removal of BOD, TN, TP, FC and TSS

In the absence of any design equation for BOD, TP,TN, FC and TSS removal, the effluent concentration in terms of BOD, TN, TP, FC and TSS was calculated based on average % removal data available in literature as given in table 3.8.

Construction, operation and maintenance (O&M) costs

In the absence of elaborate data on construction and O&M costs, present selection tool uses costs/P.E data to calculate construction and O&M costs for different treatment units. The values are given in table 3.8.
The costs for a treatment train is calculated by adding the costs for each unit in the treatment train.

Table 3.8: List of values used for PT and ST

Treatment Unit	Parameter	Symbol	Value	Unit
PT	Construction Costs		25	US$/P.E

Treatment Unit	Parameter	Symbol	Value	Unit
	O & M Costs		0.5	US$/P.E
	Land Required		0.05	m^2/P.E
	BOD removal		35	%
	TN removal		15	%
	TP removal		15	%
	TSS removal		75	%
	FC removal		10	%
ST	Construction Costs		25	US$/P.E
	O & M Costs		0.5	US$/P.E
	Land Required		0.05	m^2/P.E
	BOD removal		38	%
	TN removal		15	%
	TP removal		20	%
	TSS removal		90	%
	FC removal		10	%

Source: von Sperling (2007)

3.3.7 Calculation of water loss

Water loss was calculated to provide warnings related to effluent reuse. The equation is given by

$$WaterLoss = (E - P) * A \quad \text{......Eq. (3.12)}$$

Where, E is annual average evaporation (mm/yr), P is annual average precipitation (mm/yr) and A is area in (m^2). Water loss is finally converted as (m^3/year) during calculations.

3.4 Selection Criteria and indicators

Several criterias were identified to evaluate different treatment trains. Furthermore, proper indicators were carefully defined to test these criterias. These criterias and indicators have been described in table 3.9. The table 3.9 also shows the output of analysis of testing of these indicators.

Table 3.9: Description of Criterias, indicators and their analysis

Criterias	Indicators	Indicators met	Indicators not met
Technical	Removal BOD	1	-1
	Removal TN		
	Removal TP		
	Removal SS		
	Removal FC		
	Availibility of Gravel locally	1	1 for ponds and FWSCW -1 for SSFCW
	Land Requirement	Normalized point between 1 and -1	NF
	Water Loss	1	1 for SSFCW, -1 for others
Economic	Construction Costs	Normalized point between 1 and -1	
	Operation and Maintenance Costs	Normalized point between 1 and -1	
Social	Odour	1	1for SSFCW, -1 for FWSCW, ponds and FAL
	Noise	1	-1 for FAL, 1 for other systems
	Malaria prevalence	1	-1 for ponds, FAL and FWSCW, 1 for SSFCW

Based on these values accredited to each treatment train after analysis, cummulative weight is calculated and is given by equation:

$$CW = \sum_{n=0}^{\alpha} W * P \quad \text{.......... Eq. (3.13)}$$

Where, CW is the cummulative weight, W is the weightage provided by the user for each indicator and P is the individual point received by each treatment train during analysis.

The normalized point for land requirement and costs were calculated by dividing the value calculated by the model for each treatment train by the maximum value for land requirement or costs from the entire treatment trains. This normalized point (ranging between 0 - 1) was extrapolated into the range between 1 and -1 (from most favourable to least favourable) by considering 0 to equivalent to 1 and 1 to be equivalent to -1.

3.5 How to add or edit the treatment trains

This section provides the steps to be followed to add or edit treatment trains. To understand the steps, first an overview of the model in Excel has been provided. The model in Excel has been divided into five sheets which contains different aspects of the model. Sheet named "**User Defined Input**" has the data provided by the user via the userform. These input is required by the model during calculation. The next sheet is "**Equations**" which consists of equations and values for parameters. The third sheet is "**Calculation**" where actual calculation for each treatment train is done. This sheet consists of several columns designated to each indicator. And each cell of the column consists of equation for calculation of respective indicator for the respective treatment unit of the treatment train. The next sheet is "**Analysis**" which does IF analysis for the criterias and provides points to each treatment train based on the criterias met. This sheet also calculates the Cumulative weight for each treatment train and ranks them on the basis of the cumulative weight. Furthermore, this sheet also has equations for the warnings for each treatment train. The next sheet of interest is the "**Result**" sheet which provides information about the treatment trains with cumulative weight, their rank and warnings associated with each treatment train. The last sheet is "**Links**" which provides links to different pdf documents for reference. The reference documents includes: WHO guidelines for reuse of wastewater in agriculture, WHO guidelines for reuse of wastewater for reuse in aquaculture, Guidelines for CW and WSP, Design manual for CW, Literature review on use of natural systems for wastewater treatment and Manual for SETNAWWAT.

Steps for editing any treatment train:

1. Unhide the sheets and follow the next step.

2. Go to calculation sheet, and start editing the cell you want to change the equation in. For e.g, if you want to change the equation for calculation of Construction cost for a particular type of treatment unit, you can edit the equation in respective cell for that treatment unit. And the same change needs to be repeated for that unit in all treatment trains. It is important to take care about the reference of the cells used in equation.

Steps for adding new treatment train:

1. Unhide the sheets and follow the next step.
2. First go to "Calculation" sheet, add the units of the new treatment train in the similar way as done already for other treatment trains. Also add the the treatment train number.
3. Next start entering equation for each treatment train unit for calculation of effluent quality for BOD, TN, TP, SS and FC; land requitrement; Construction and O&M costs and other indicators. The details about the equation is given in section 3.3. For convenience, if the treatment unit already exists in the model, the equation can be copied and reference to cells in the equation should be accordingly adjusted.
4. Next is going to "Analysis" sheet and adding functions for screening criterias for each new treatment train added. The equations can be copied from previous treatment train keeping in mind to adjust the cell reference accordingly. One can also refer to the table 3.8 in section 3.4 to get an overview of the points given to a treatment train when a criteria is met or not met. Also insert the equation for calculation of cumulative weight, which is calculated only when the criteria of land requirement is met. Else the treatment train is marked NF. For better understanding, refer to the eqaution for other treatment train already in the model.
5. Also add warning equations for new treatment trains, which again can be copied from previous train taking care of adjusting the reference cells.
6. Next go to "Result" sheet and enter the number, description, CW, Land requirement, and Construction costs, rank and warnings for new treatment trains. Here for CW, rank and warnings reference to respective cell in sheet "Analysis" is given and for Land requirement and Construction cost, reference to respective cell in "Calculation" sheet is given.

3.6 Demonstration of SETNAWWAT with data set

This section demonstrates the applicability of SETNAWWAT in guiding the decision process. This has been done by running the model with a data set for a hypothetical city which is under planning phase. The data used in this tool is described in table 3.10 below.

Table 3.10: List of parameter values used in this tool for the demonstration.

Parameters	Value	Unit
Hydro-meteorological data		
Average air temperature of the hottest month	30	^{0}C
Average air temperature of the coldest month	21	^{0}C
Annual average precipitation	1260	mm/yr
Annual average evapotranspiration	750	mm/yr
Topo graphical data		
Soil type	clay	
Demographic data		
Population	2000000	inhabitants
Population growth rate	2	%
Base year	2010	
Design period	20	years
Wastewater characteristics		
Flow rate	300000	m^3/d
cBOD	450	mg/l
TSS	175	mg/l
TN	56	mg/l
TP	43	mg/l
Faecal coliforms	1.6E+06	#/100ml
Type of wastewater	Raw wastewater	
Reuse option	Irrigation	
Effluent Standards		
cBOD	100	mg/l
TSS	75	mg/l

Parameters	Value	Unit
TN	40	mg/l
TP	35	mg/l
FC	1000	mg/l
Technocal and Economic aspects		
Land available	642150000	m^2
Materials available locally		
Sand	No	
Gravel	No	
Liners	No	
Availibility of electricity	Yes	
Socio-cultural aspects		
Is the planned site in the vicinity of the inhabitants	Yes	
Is malaria prevalent in the area	Yes	
Weight for the criteria		
Ability to meet cBOD standard	0.3	
Ability to meet nutrients(TN &TP) standard	0.1	
Ability to meet FC standard	0.9	
Land requirement	1	
Construction Costs	1	
Operation&Maintenance costs	0.5	
Availibility of materials	0.5	
Odor	0.5	
Noise	0.3	
Malaria	0.5	

The outcome of the model based on the above data is shown below in figure 3.2.

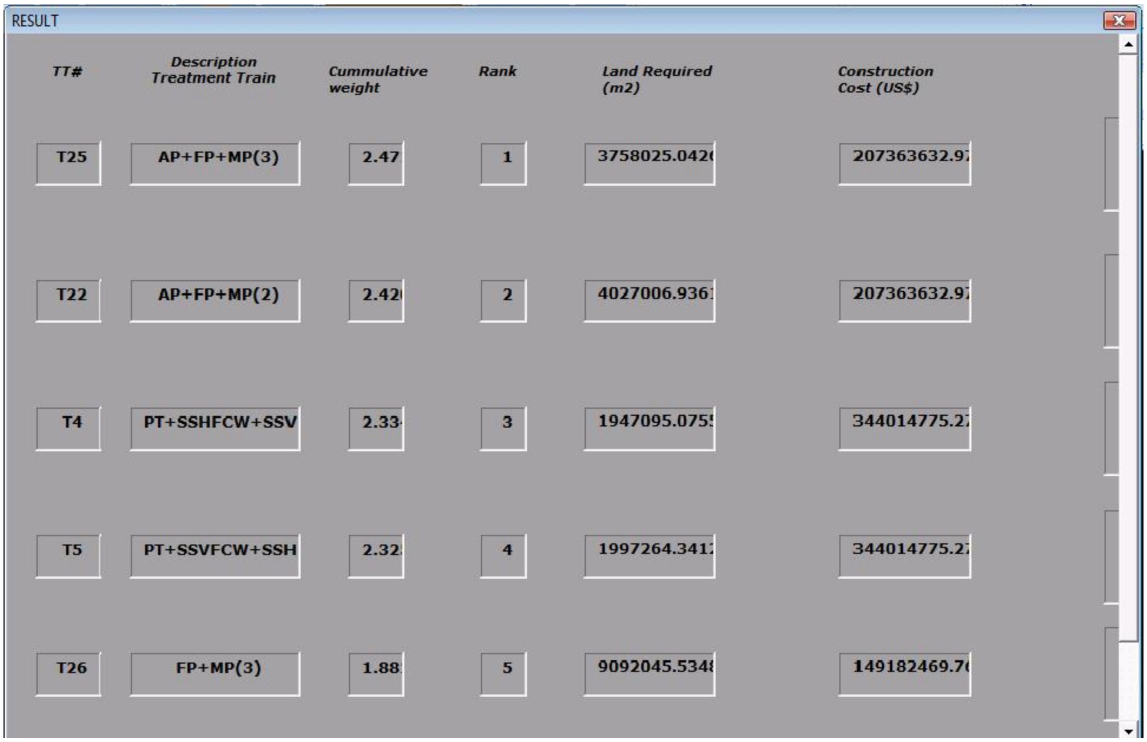

Figure 3.2: Result as obtained from demo run of SETNAWWAT

The detailed result with the values of each feild is describes below in table 3.11.

Table 3.11: Detailed result from SETNAWWAT

Train number	Train description	CW	Rank	Land required (m^2)	Construction costs (US$)	Warnings
T25	AP+FP+MP(3)	2.47	1	3758025.04	207363632.9	Preventive measure for malaria
T22	AP+FP+MP(2)	2.42	2	4027006.93	207363632.9	Preventive measure for malaria
T4	PT+SSHFCW+ SSVFCW	2.33	3	1947095.07	344014775.2	
T5	PT+SSVFCW+ SSHFCW	2.32	4	1997264.34	344014775.2	
T26	FP+MP(3)	1.88	5	9092045.53	149182469.7	Preventive measure for malaria

From above result as calculated by SETNAWWAT model, it is evident that the treatment train # T25 is the most favoured option even though the land required is higher than treatment train numbers T4 & T5. An comparartive overview of above table 3.11 shows that the construction costs for treatment train T4 &T5 are much higher than T25. And since the weight provided for both indicators: land requirement and construction costs is same (i.e.1), T25 gets the highest cummulative score and hence the preferred option.

The output from such models can give an idea to city planners about the feasibility of treatment train option to consider during the planning of construction of wastewater treatment facility.

3.7 Summary of SETNAWWAT

SETNAWWAT is a selection tool which serves as a platform for evaluation of possible natural systems for wastewater treatment to assist in feasibility study during planning process. The evaluation involves multicriteria analysis. The selection tool is good for faesibility study but needs validation with actual case studies. Also, the costs data and average removal efficiency data used in calculation is taken from different regions so might not be true reflection of the actual costs and effluent quality of the local situation under feasibility study. Hence this model is only good for comparative study of different treatment trains.

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