Design approach of Limbe wastewater treatment works, Blantyre, Malawi, using the ED-WAVE Tool

V. Chipofya[a*], A. Kraslawski[b], Y.Avramenko[b]

[a]*Centre for Water, Sanitation, Health and Appropriate Technology Development (WASHTED), University of Malawi, The Polytechnic, Private Bag 303, Blantyre 3, Malawi*)
[b]*Department of Chemical Technology, Lappeenranta University of Technology, P.O.Box 20, FI-53851, Lappeenranta, Finland*

[*]Corresponding author. Tel.: +265 888 878055; fax: +265 1 870578
E-mail address: vchipofya@poly.ac.mw (V.Chipofya)

ABSTRACT

The ED-WAVE tool is a PC based package for imparting training on wastewater treatment technologies. The system consists of four modules viz. Reference Library, Process Builder, Case Study Manager, and Treatment Adviser. The principles of case-based design and case-based reasoning as applied in the ED-WAVE Tool are utilised in this paper to evaluate the design approach of Limbe wastewater treatment works (Limbe WWTW) in Malawi. The plant has an average dry weather flow rate of 1,800 m^3/day. The study established that a similar case to both the dry season and wet season conditions of Soche wastewater treatment works is Municipal Case 1 in Sri Lanka, with a flow rate of 1,700 m^3/day. The study further established that that there are certain unit treatment processes that are important in wastewater treatment. These include a primary sedimentation process, achieved through the imhoff tank at the plant in Sri Lanka, chemical precipitation followed by sedimentation as suggested by the dry season and wet season unit treatment processes, and the receiving pond in the actual set up at Limbe. Municipal Case 1 in Sri Lanka utilises trickling filters for aerobic biological treatment while the Limbe plant accomplishes this process through the facultative ponds. The suggested sequencing of dry and wet weather conditions by the Treatment Adviser provides for activated sludge for aerobic biological treatment.
Screening is incorporated at the Limbe plant. This process is not there at Municipal Case1 in Sri Lanka. Screening is necessary in developing countries because of the nature and quantity of solids present in sewage, which include still born babies, maize cobs and pieces of cloth used for anal cleaning, and domestic garbage. Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), and Total Dissolved Solids (TSS) removal efficiency in the dry season was 93%, 40% and 93%, respectively. The study further established that the BOD_5, COD and TSS removal efficiency in the wet season was 92%, 5% and 20%, respectively. BOD_5, COD and TSS removal efficiency at the plant in Sri Lanka was 83%, 76% and 77%, respectively. The close correlation in the treatment processes at Municipal Case 1 in Sri Lanka, the suggested dry and wet season unit treatment processes according to the Treatment Adviser, and the actual set up at Limbe WWTW confirms the practical use of case-based design and case-based reasoning principles in the ED-WAVE tool in the design of wastewater treatment systems.

Keywords: aerobic biological treatment, case-based design, grit removal, humus tank, imhoff tank, unit treatment processes

Introduction

Wastewater needs to be dully treated in order to minimize its negative effects on people, animals, birds, and aquatic biota. Polluted water is unsuitable for drinking, recreation, agriculture, and industry. It diminishes the aesthetic quality of surface water sources (Kuyeli, 2007). In order to reduce the undesirable effects of wastewater, it is necessary to treat it to meet the consent requirements of effluent quality set by the environmental regulatory agency (Banda, 2007).

Wastewater treatment is the engineering process that employs physical, biological, and chemical processes to reduce the concentration of pollutants found in wastewater to a harmless or near-harmless level in the effluent (Banda, 2007). Wastewater treatment plants are large non-linear systems subject to large perturbations in wastewater flow rate, load and composition. Nevertheless these plants have to be operated continuously meeting stricter and stricter regulations
(Gernaey, et al., 2009).

This paper evaluates a design approach of Limbe WWTW using the principles of case-based design and case-based reasoning as incorporated in the ED-WAVE tool. (Althoff, et al., 1995; Avramenko, (2005); and Avramenko and Kraslawski, 2008).

Methodology

Study area

The study focused on Limbe WWTW whose catchment is situated on the eastern edge of the Blantyre urban area and serves parts of the wards of Chichiri South, Limbe Central and Limbe West (Fig. 1). The catchment contains a large are of principally commercial properties, the main railway workshops of Malawi and numerous industrial premises. The treatment facilities consist of a waste stabilisation pond system which was originally established in the 1970's and comprised an inlet works with manually raked screens, grit channels and a flow measuring flume, followed by a series of four stabilisation ponds. The works was extended by the construction of a further twelve ponds which were commissioned in 1985. The waste stabilisation pond treatment system thus currently comprises the original inlet works followed by four parallel four pond series (Fig.2). (Carl Bro International, 1995).

Data Collection

Data was collected through a desktop study on the operational data maintained for Limbe WWTW, Malawi, and through personal communication with the Pollution Control Officer, Blantyre City Assembly, as well as site visits. Separate data was collected for the dry season and the wet season (i.e. the two seasons prevalent in Malawi). For this one wastewater treatment plant, therefore, this gave a total of two cases for this study. The data was analysed using excel.

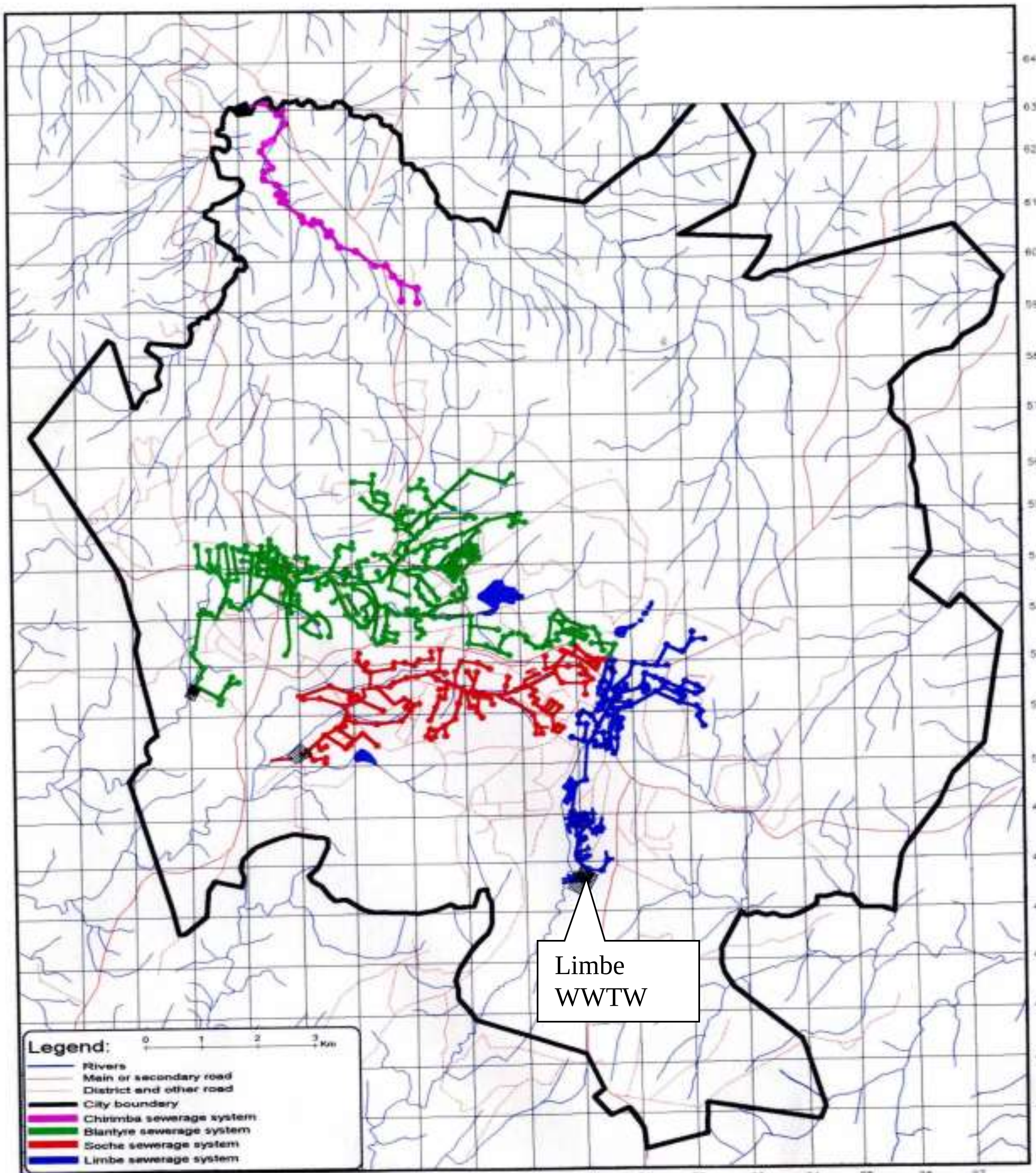


Fig. 1: Location of Limbe WWTW in the City of Blantyre; Source: Carl Bro International, 1995

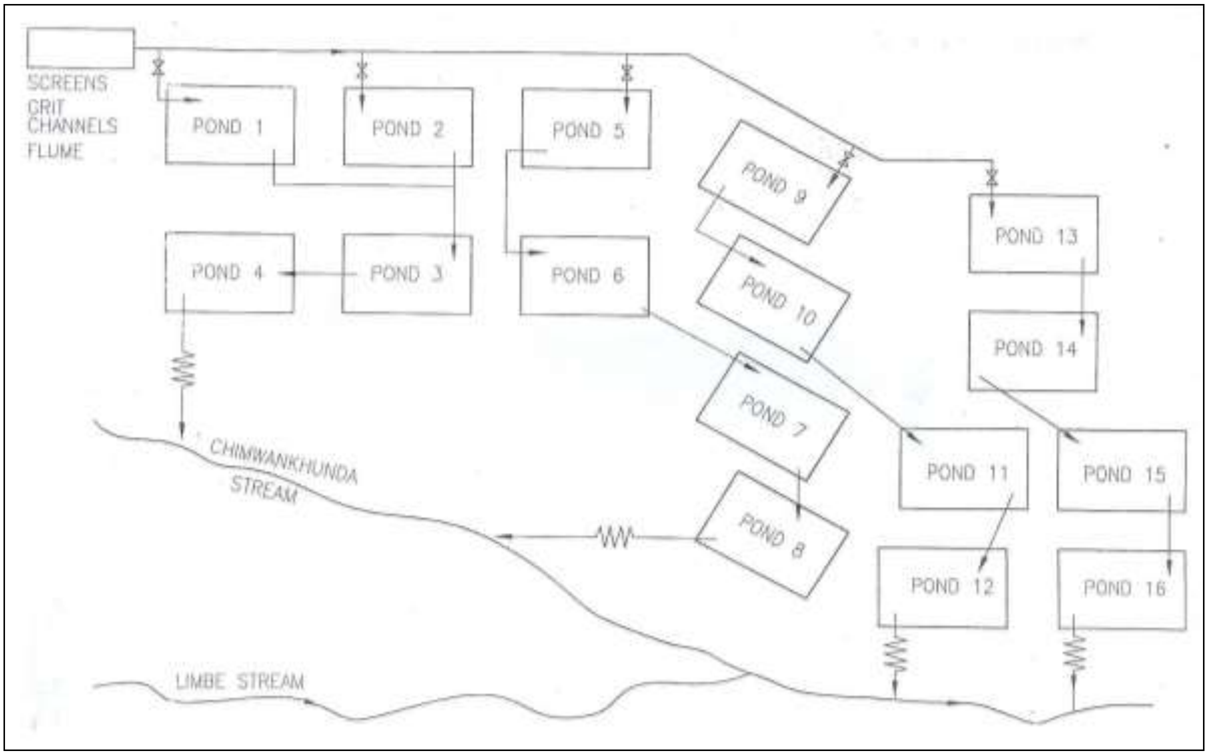


Fig. 2. Waste stabilisation pond system at LWWTW: Source, Carl Bro International, 1995

The ED-WAVE Tool

The ED-WAVE tool was used for the conceptual design of Limbe WWTW in the City of Blantyre. The Tool consists of virtual industrial and municipal environments created using an IT based tool using real-life applications.

The ED-WAVE tool is a shareware PC based package for imparting training on wastewater treatment technologies. The system consists of four modules viz. Reference Library (RL), Process Builder (PB), Case Study Manager (CM), and Treatment Adviser (TA).

The RL module gives a comprehensive overview of each technology through visuals of real life units accompanied by animations to explain the sequence of operation. This is supplemented by the theoretical description that, in turn, is illustrated by a worked out example and an excel spreadsheet model. The user can modify or select parameters in the spreadsheet to understand the effect on the unit performance.

The CM consists of a collection of case studies obtained from municipal and industrial wastewater treatment plants from both Asia and Europe. The industrial sectors include pulp and paper mills, alcohol distilleries, tanneries, rubber and latex processing, textile and garment manufacturing and metal-finishing units.

For a user specified wastewater stream, the TA generates a treatment sequence; alternatively the user can use the PB to construct a valid treatment sequence (Balakrishnan, et al. 2005).
The tool is based on the principles of case-based design and case-based reasoning as applied in Process Systems Engineering (Althoff, et al., 1995; Avramenko, 2005; Avramenko and Kraslawski, 2008).

Case-based design and case-based reasoning

Case-based design and case-based reasoning are some of the commonly used mechanisms of approximate reasoning in intelligent systems and decision support systems. These mechanisms offer a powerful and general environment in which is generalized a basis of already accumulated experience being represented in the form of a finite and relatively small collection of cases. Those cases constitute the essence of the existing domain knowledge. When encountering a new situation, already collected decision scenarios (cases) are invoked and eventually modified to arrive at a particular design alternative (Althoff, et al., 1995; Avramenko, 2005; Avramenko and Kraslawski, 2008).

Results

Operational data for Limbe WWTW

Tables 1(a) and 1(b) below show the influent and effluent characteristics of the wastewater at Limbe WWTW during the dry season and wet season, respectively, with corresponding Malawi effluent standards (MBS, 2005). Table 1(c) shows the influent and effluent characteristics of Municipal Case 1 in Sri Lanka.

Table 1(a)
Limbe works influent and effluent physicochemical characteristics for the dry season in mg/l

Parameter	**BOD**	**COD**	**TSS**
Influent	740	1296	220
Effluent	51	777	16
Reduction			
Efficiency (%)	*93*	*40*	*93*
Malawi Standard	20	60	30

Table 1(b)
Limbe works influent and effluent physicochemical characteristics for the wet season in mg/l

Parameter	**BOD**	**COD**	**TSS**
Influent	811	821	268
Effluent	63	779	214
Reduction			
Efficiency (%)	*92*	*5*	*20*
Malawi Standard	20	60	30

Table1(c)
Influent and effluent characteristics of Municipal Case 1 in Sri Lanka in mg/l

Parameter	**BOD**	**COD**	**TSS**
Influent	152	198	110
Effluent	26	47	25
Reduction			

Efficiency (%)	*83*	*76*	*77*
Malawi Standard	20	60	30

The BOD and TSS removal efficiency in the dry season was 93% for both parameters. The COD removal efficiency was 40%. BOD, COD and TSS removal efficiency in the wet season was 92%, 5% and 20%, respectively.

The mean effluent BOD and COD levels for both the wet and dry season are above the Malawi standard. The effluent TSS level in the dry season is below the Malawi standard while the level in the wet season is above the Malawi standard.

Application of case-based design principles in the design of Limbe WWTW

According to the Case Study Manager in the ED-WAVE tool, a similar case to both the dry season and wet season conditions of Limbe wastewater treatment works is Sri Lanka Case 1, with a flow rate of 1,700 m^3/day. The treatment sequence for this plant and the comparative sequencing of the treatment units at the Limbe plant, dry and wet season, and the actual sequencing of treatment units at Limbe treatment works are illustrated in Table 2, below. Figures 2, 3, and 4 further illustrate this sequencing according to the Process Builder in the ED-WAVE tool.

Table 2. Comparative sequencing of treatment units

Plant/ Step No.	**Municipal Case 1, Sri Lanka**	**Suggested sequencing of dry season conditions by Treatment Adviser**	**Suggested sequencing of wet season conditions by Treatment Adviser**	**Actual sequencing of Limbe plant**
1	Grit chamber	Grit removal	Grit removal	Screening
2	Imhoff tank	Neutralisation	Neutralisation	Grit Chambers
3	Dosing chamber	Chemical precipitation	Chemical precipitation	Receiving pond
4	Trickling filters	Activated sludge	Activated sludge	Facultative pond
5	Humus tank	Activated carbon	Activated carbon	Maturation ponds
6		Ion exchange	Ion exchange	

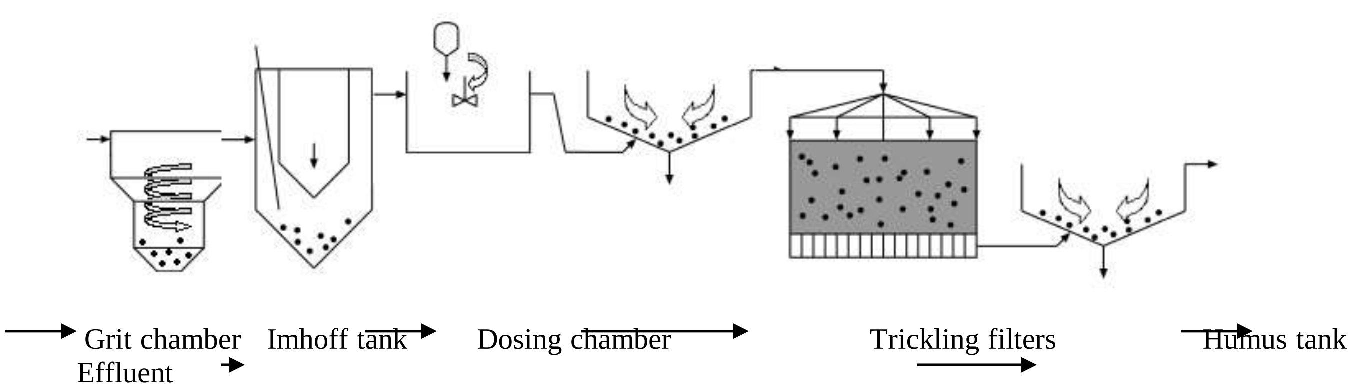
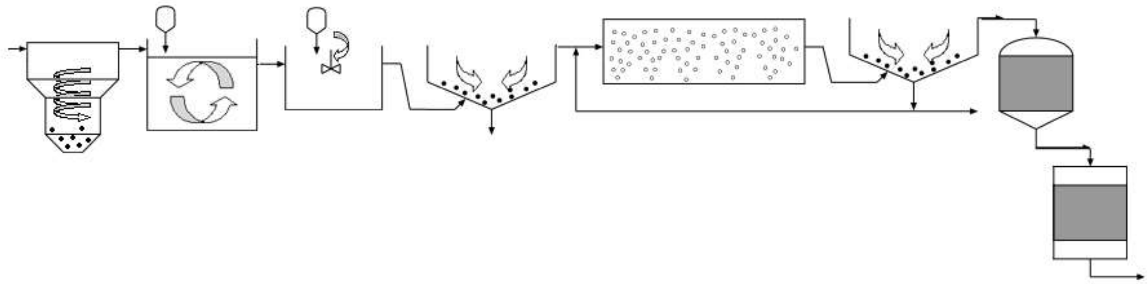


Fig. 3. Sequencing of treatment units at Municipal Case 1, Sri Lanka, according to the Process Builder

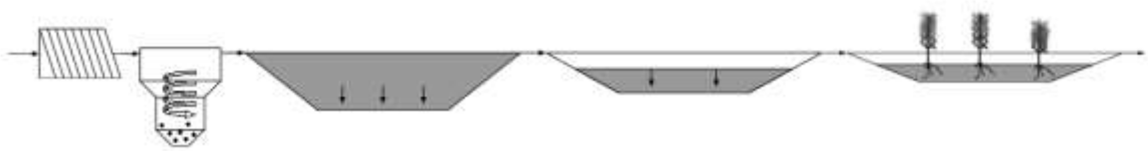


Grit removal Neutralisation Chemical precipitation Activated sludge Activated Ion exchange

carbon

adsorption

Fig.4. Suggested sequencing of treatment units for dry and wet season conditions at Limbe WWTW



Screening Grit chambers Receiving ponds Facultative ponds Maturation ponds Effluent

Fig.5. Actual sequencing of treatment units for Limbe WWTW

Discussion and Conclusion

Through this study, case-based design principles in the ED-WAVE tool gave Municipal Case 1 in Sri Lanka as a wastewater treatment plant similar to Limbe WWTW. The plant in Sri Lanka has five unit treatment processes, namely: grit chamber, imhoff tank, dosing chamber, trickling filters and a humus tank. The dry season and wet season set up for Limbe both have a grit chamber, neutalisation process, chemical precipitation, activated sludge, activated carbon adsorption, and an ion exchange process. The actual sequencing at Limbe plant essentially has three processes: screening, grit chambers, and a four-stabilisation pond system comprising of receiving ponds, facultative ponds, primary maturation ponds and secondary maturation ponds (Fig. 2). The similarities between Municipal Case 1 in Sri Lanka and the actual set up at Limbe include the provision of grit chambers for the removal of inorganic grit, a primary sedimentation process for anaerobic treatment: an imhoff tank in the case of Municipal Case 1 in Sri Lanka, and receiving ponds in the case of Limbe plant. Municipal Case 1 in Sri Lanka utilises trickling filters for aerobic biological treatment while the Limbe plant accomplishes this process through the facultative ponds. A screening process is incorporated in the actual set up at Limbe. This process is not there at Municipal Case1 in Sri Lanka.

Screening is necessary in developing countries because of the nature and quantity of solids present in the sewage, which include still born babies, maize cobs and pieces of cloth used for anal cleaning, and domestic garbage (Mara, 1976; Cairncross and Feachem, 1993; and Kuyeli, 2007, Chipofya, et al., 2009).

The primary and secondary maturation pond system provides for good polishing up of the wastewater before it is discharged into the receiving river course. Further work is required to determine the impact of the effluent upon the aquatic flora and fauna, the pathogen content of the effluent and risk to public health of users who abstract water from the receiving watercourse for domestic and irrigation purposes.

The study established that the BOD_{5}, COD and TSS removal efficiency in the dry season was 93%, 40% and 93%, respectively. The study further established that the BOD_{5}, COD and TSS removal efficiency in the wet season was 92%, 5% and 20%, respectively. BOD_{5}, COD and TSS removal efficiency at the plant in Sri Lanka was 83%, 76% and 77%, respectively. A close look at the unit treatment processes at the plant in Sri Lanka, the suggested dry season and wet season unit treatment processes, and the actual set up at Limbe plant suggests that there are certain unit treatment processes that are important in wastewater treatment. These include a primary sedimentation process, achieved through the imhoff tank at the plant in Sri Lanka, chemical precipitation followed by sedimentation as suggested by the dry season and wet season unit treatment processes, and the receiving pond in the actual set up at Limbe.

In municipal wastewater treatment, sedimentation is the main process in primary treatment, where it is responsible for removing 50 to 70 percent of the suspended solids (containing 25-40 percent of BOD_5) from the wastewater (Barnes, 1981; Metcalf &Eddy, 2003).

Another unit treatment process common to all four set ups in Table 2 is an aerobic biological treatment process. Municipal Case 1 in Sri Lanka utilises trickling filters, the dry and wet season set up according to the Treatment Adviser utilises the activated sludge process, and the actual set up at Limbe utilises facultative ponds. Aerobic biological treatment ensures that a substantial quantity of organic matter in liquid state is oxidized prior to the effluent being discharged into public water courses where it would otherwise exert an oxygen demand (Barnes, 1981). Facultative ponds, the technology utilised at Limbe WWTW, are cheap to construct. Mara (1976, 2004) describes waste stabilisation ponds as large shallow basins enclosed by earthen embankments in which wastewater is biologically treated by natural processes involving pond algae and bacteria.

The inclusion of activated carbon dosing and ion exchange in the suggested dry and wet season probably relates to the need for a tertiary treatment stage for these works. This tertiary treatment would be necessary for polishing up the effluent (Barnes, 1981; Metcalf & Eddy, 2003). This tertiary treatment is accomplished by the primary and secondary maturation ponds at Limbe WWTW.

The close correlation in the treatment processes at Municipal Case 1 in Sri Lanka, the suggested dry and wet season unit treatment processes according to the Treatment Adviser, and the actual set up at Limbe WWTW confirms the practical use of case-based design and case-based reasoning principles in the ED-WAVE tool in the design of wastewater treatment systems. After encountering a new situation, already collected decision scenarios are invoked and modified inorder to arrive at a particular design alternative.

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