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Comparison of Wastewater Treatment Technologies in the ED-WAVE Tool to Technologies of Similar Cases in Malawi: Case of Blantyre and Soche WWTW

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Abstract: This paper compares the wastewater treatment technologies at Blantyre and Soche wastewater treatment works (WWTW) in Malawi with technologies of a similar case according to the ED-WAVE tool to determine if existing cases in the tool can be invoked and appropriately modified to arrive at a particular design alternative. 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, Process Builder, Case Study Manager, and Treatment Adviser. The paper also compares the reduction in the levels of BOD_5, COD, and TSS at the three respective treatment works. The study established that there is a similarity in the sequencing of treatment units of Municipal Case 6 in the ED-WAVE tool and the sequencing of treatment units at Blantyre and Soche WWTW, respectively. All the three plants incorporate screening, grit removal, aerobic biological treatment, and sedimentation. Soche and Blantyre WWTW use hand-raked inclined bar screens and constant velocity grit channels, where longitudinal flow velocity is hydraulically controlled. Rotary mechanically-raked bar screens and mechanically stirred grit chambers are used in the ED-WAVE tool. In addition, Municipal Case 6 uses oxidation ditches for aerobic biological treatment while Blantyre and Soche WWTW use trickling filters. BOD_5 removal efficiency at Soche WWTW at 95% and 96% for dry season and wet season, respectively, is comparable to the removal efficiency at Municipal Case 6 (95%). The dry season BOD_5 removal efficiency at Blantyre WWTW at 87% is slightly lower than the removal efficiency at Municipal Case 6. TSS removal efficiency at Soche WWTW is at 80% in the wet season and 35% in the dry season. TSS removal efficiency at Blantyre WWTW is only 3% in the wet season, while there is an increase of 11% in the wet season. TSS removal efficiency at Municipal Case 6 is 96%. Inspite of the difference in the BOD_5 and TSS removal efficiencies at Municipal Case 6 as compared to Blantyre and Soche WWTW, there is a close match in technologies at Blantyre and Soche WWTW, and Municipal Case 6 in Greece as invoked by the Case Study Manager in the ED- WAVE tool. What is evident from this study is the need to appropriately modify the case arrived at through the Case Study Manager in order to come up with a design appropriate to the local situation in terms of operation and maintenance.

Keywords: Aerobic biological treatment, case-based design, grit removal, sedimentation, unit treatment processes, wastewater treatment.

1. INTRODUCTION

The need for wastewater treatment in Malawi is underscored by the existing regulatory framework and policy guidelines. These regulatory instruments are aimed at safeguarding the ecologically fragile and sensitive receiving water courses where the water, further downstream is used by people for washing clothes and bathing, or irrigating crops which may be eaten raw [1]. There is a high degree of policy harmonization and collaboration amongst institutions dealing with water and environmental sanitation in Malawi [2].

In addition, formalized national effluent standards exist in Malawi [3].

This paper compares the wastewater treatment technologies at Blantyre and Soche wastewater treatment works (WWTW) in Malawi with technologies of a similar case according to the ED-WAVE tool to determine if existing cases in the tool can be invoked and appropriately modified to arrive at a particular design alternative.

2. METHODOLOGY

2.1. Study Site

The study was conducted at Blantyre and Soche WWTW located at the south-western end of Blantyre city (Fig. **1**).

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Blantyre works is the largest of the city's treatment plants. It is a conventional works with an average dry weather flow rate of 6,700 m^3/day. About 70% of wastewater loading into the Blantyre plant is industrial effluent coming from the main industrial areas of Ginnery Corner and Makata. The rest is domestic effluent emanating from residential areas and storm water. Soche works serves a physical catchment area of some 24km^2 comprising the south-west residential area of the city, including Queen Elizabeth Central Hospital (QECH). 30% of the influent to the works is from the light industrial areas of Ginnery Corner and Maselema. The average dry weather flow rate for the plant is 5,573 m^3/day. The works is a principal tanker reception centre for latrine and septic tank emptyings. On the average, about six tankers are received per day, totaling approximately 36 m^3/day.

The raw material at both Blantyre and Soche WWTW is municipal sewage, where the typical wastewater parameters are Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), and Total Suspended Solids (TSS). The treatment target at both plants is BOD_5, COD, and TSS reduction.

2.2. Data Collection and Analysis

Data was collected through a desk study which was based on the work by Kuyeli, (2007) [4]. Sampling was done between the months of October to November, 2005 for the dry season, and February, 2006 for the wet season using the grap sampling method. Samples were collected using one-liter plastic bottles that had been cleaned by soaking in 10% nitric acid, and rinsed several times with distilled water. Three one-liter samples were collected at each point. BOD_5 was determined by the Winkler method of oxygen measurement in the samples before and after incubating for five days at 20^0C, whereas TSS were determined by filtering the samples through pre-weighed glass fibre filters as described in APHA, (1985) [6]. COD was determined by adding 10ml aliquot of standard potassium dichromate (0.02M) containing mercuric sulphate and 30mls of sulphuric acid containing silver sulphate to about 20 ml of the homogenized sample in the reflux condenser. The mixture heated for 2 hours in the range of 148 and 150^{o}C and then cooled to room temperature. The condenser was washed by distilled water and the final mixture was used to make 100ml solution which was titrated against 0.12M ammonium iron (II) sulphate (FAS) using ferroin indicator.

COD levels were calculated using the following equation:

$$COD=\frac{8000(b-s)n}{Sample(ml)}$$

Where b is the volume of FAS used in the blank sample,

s is the volume of FAS in the original sample, and

n is the normality of FAS [4].

A mean concentration was calculated along with a standard deviation on the results obtained for three samples collected from each point.

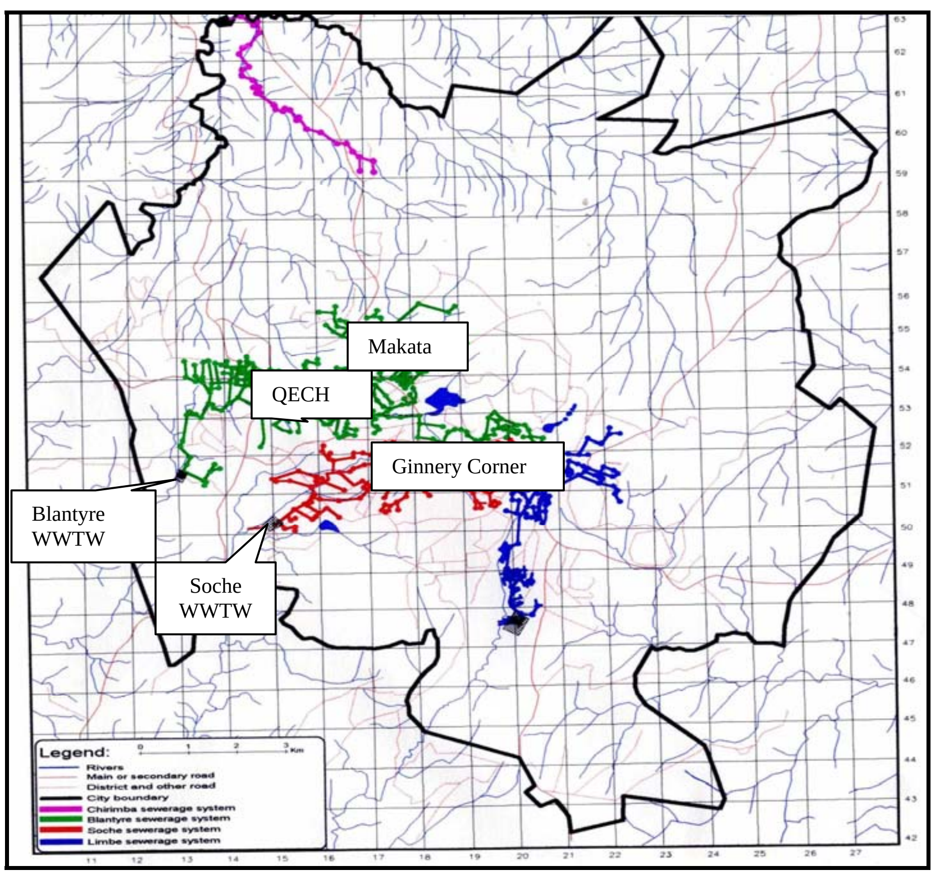

Fig. (1). Location of Blantyre and Soche wastewater treatment works in the City of Blantyre.

2.3. The ED-WAVE Tool

The ED-WAVE tool was used for the conceptual design of Blantyre and Soche wastewater treatment plants 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) (Fig. **2**) [7, 8].

2.3.1. Reference Library

The purpose of the Reference Library is to provide the user with a comprehensive overview of processes and operations used for wastewater treatment. The general description of the wastewater treatment technology is supplemented by the theoretical background with examples and a model.

The particle treatment processes are usually classified as physical operations, chemical and biological processes. Reference Library supports several classifications of the unit operations and processes. They are grouped according to the level of the provided treatment (preliminary, primary, secondary, and advanced treatment), and type of unit operations (physical, chemical, biological).

The module provides the user with a comprehensive overview of 21 technologies used for wastewater treatment. Each item consists of the following sections:

- the theoretical background section; which is based on textbooks and published papers, and provides theoretical information about the principle of each technology as well as an analysis of the elements of each unit operation;

- the design parameters section provides practical information about the range of parameters used in the design of the technologies and sizing the various tanks/reactors, usually in the form of comprehensive tables;
- the example section, which is a worked out example in basic design and sizing of each wastewater treatment unit operation. The examples were taken from operational wastewater treatment plants, from real design studies, from textbooks. The user combines the information from the theoretical part such as mass balances, and the practical information of the design parameters section in order to complete the example;
- the model is a design model implemented in Microsoft excel workbook, that resolves the example from the previous section in computer form, one for each technology;
- the view section, where a user can find a schematic representation of each technology, view 3D image(s) of each process and also view a full animation with exemplary text showing and describing each process. In most cases 3D images were rendered from digital pictures and engineering drawings, from operating wastewater treatment plants. In animations, the user is taken in a virtual step-by-step walk through each process;
- the reference section, where the user can find the textbooks used and material for further reading.

The model is supplemented with a list of terms use in environmental engineering.

2.3.2. Case Study Manager

The Case Study Manager accumulates the specific design experience contained in real life situations, and tries to reuse it when solving new user's problems. The manager performs the retrieval of the most similar cases to the current problem from the case base containing the past situations of wastewater treatment. The case base of the case study manager includes more than 100 case studies obtained from municipal and industrial wastewater treatment plants from Asia and

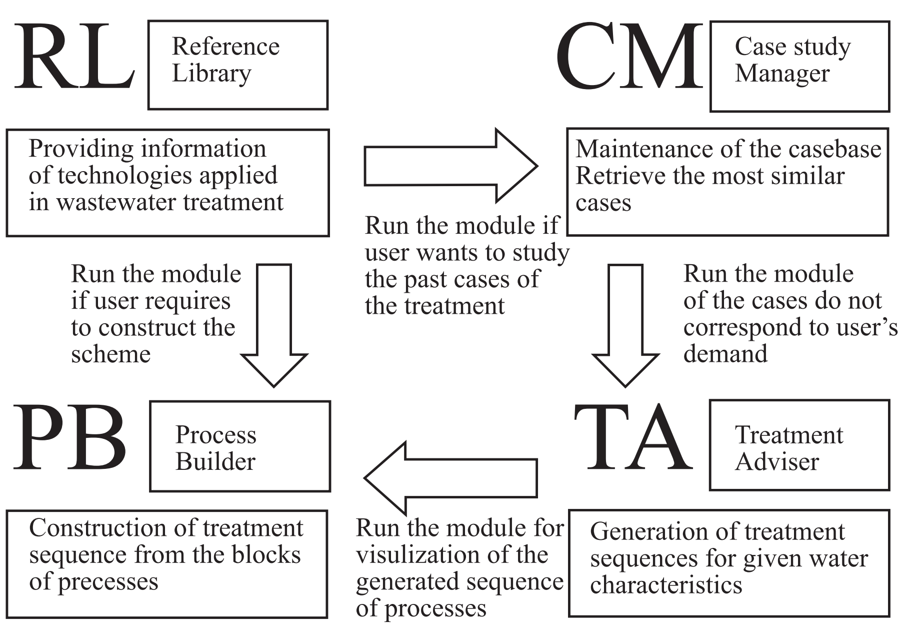

Fig. (2). Schematic diagram of the ED-WAVE software structure; Source: [8].

Europe. The industrial sectors include pulp and paper mills, alcohol distilleries, tanneries, rubber and latex processing, textile and garment manufacturing, and metal finishing units.

The representation of the case includes lists of influent and effluent wastewater characteristics, divided into four groups (physical parameters, organic and inorganic parameters, and microbiological characteristics), short description of the plant generating the wastewater, average flow rate, the sequence of treatment technologies and additional comments. Also, where available from the particular industry, the cost of treatment per unit volume is included.

The module can be used to help in solving user problems, either by the user composing a new case study or a problem or by entering influent wastewater characteristics, demanded flow and sector of industry. In solving a current problem, a similar past problem and its solution are retrieved using a set of rules for measuring similarity between actual problem and those stored in the case base.

In order to define a similarity between cases containing both numeric and textual- symbolic information, the general similarity concept is used [5]. The treatment sequences of similar cases are provided as promising solutions.

2.3.3. Treatment Adviser

Treatment Adviser generates a simple sequence of treatment technologies for a given water characteristics. It analyses the influent water characteristics and supplemented information of other factors (economical, technical or ecological) to select a suitable treatment technology; alternatively the user can use the Process Builder to construct a valid treatment sequence [7]. This is based on the algorithm of selection of the proper wastewater treatment method based on previously constructed rules represented as a decision tree. Negnevitsky (2002) [9] defines a decision tree (or tree diagram) as a map of the reasoning process. The tree is a graph or model of decisions and their possible consequences, including chance event outcomes, resource costs, and utility. It is a decision support tool that uses a tree-like graph or model of decisions and their possible consequences (http://www.mindtools.com/dectree.html) [10]. It provides a highly effective structure within which to explore options, and investigate the possible outcomes of changing those options. The results of outcomes are retrieved from expert opinion and experience.

2.3.4. Process Builder

The Process Builder is the last module in the ED-WAVE tool. It serves to create a treatment system flow diagram from the unified blocks. Each of the blocks represents a type of treatment process or specific part of the process. Blocks can be linked according to internal restrictions, rules and locations of connection points. The module is based on a valid sequence matrix and is based on technical feasibility only and not other parameters such as land availability, cost, or energy consumption.

The aim of the module is that the user, after becoming familiar with the concept of the methods and with the practices used in the industry, creates one's own wastewater treatment sequence. The module is also used to visualize the result proposed by the Treatment Adviser or to illustrate the actual sequencing of treatment units at a particular plant as illustrated if Figs. (**3** and **4**).

The tool is based on the principles of case-based design and case-based reasoning as applied in Process Systems Engineering [5, 11].

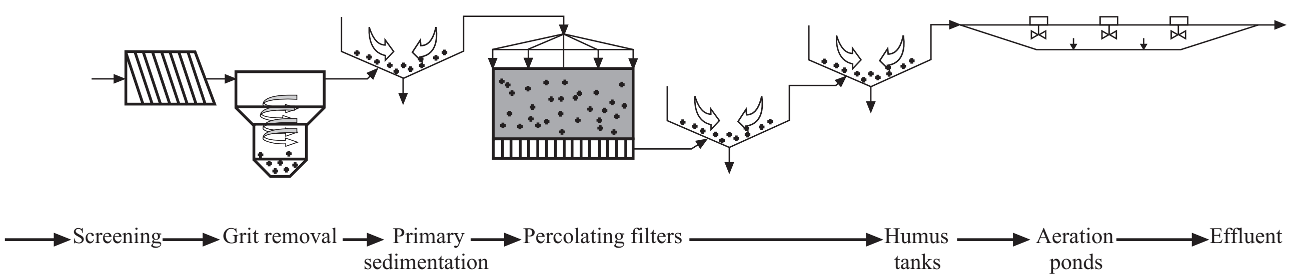

Fig. (3). Actual sequencing of treatment units at Blantyre WWTW.

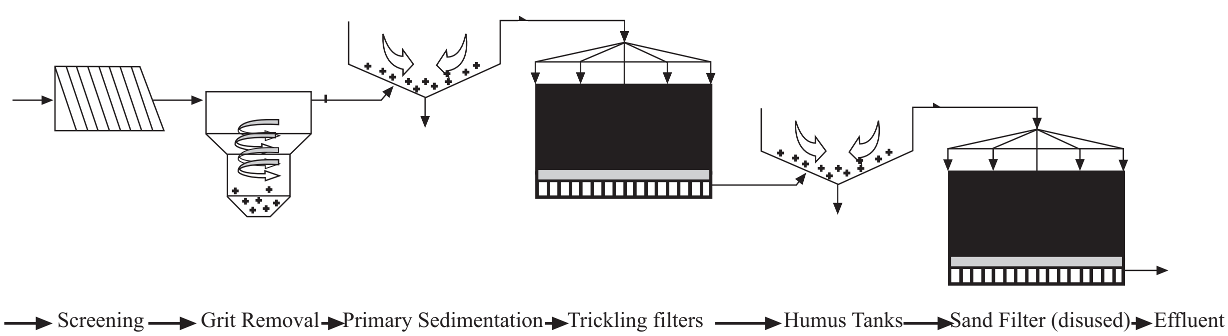

Fig. (4). Sequencing of treatment units at Soche WWTW according to Process Builder

3. RESULTS AND DISCUSSION

3.1. Comparative Sequencing of Treatment Units

According to the Case Study Manager in the ED-WAVE tool, a similar case to both the dry season and wet season conditions of Blantyre WWTW is Municipal Case 6 in Greece (2003), with a flow rate of 6,600 m^3/day. The treatment sequence for this plant and the comparative sequencing of the treatment units at the Blantyre plant, dry and wet season, and the actual sequencing of treatment units at Blantyre works are illustrated in Table **1**. Similarly, the Case Study Manager gives the same Municipal Case 6 in Greece as a case similar to both the dry season and wet season conditions of Soche WWTW. The comparative sequencing of the treatment units at the Soche plant, dry and wet season and the actual sequencing of treatment units at Soche WWTW are illustrated in Table **2**.

3.2. Operational Data for Blantyre WWTW

Tables **3**(**a**) and **3**(**b**) below show the influent and effluent characteristics of the wastewater at Blantyre WWTW during the dry season and wet season, respectively, with corresponding Malawi effluent standards [3]. Table **3**(**c**) shows the influent and effluent characteristics of Municipal Case 6 in Greece.

The BOD, COD and TSS removal efficiency in the dry season was 87%, 58% and -11%, respectively. BOD, COD and TSS removal efficiency in the wet season was 12%, 27% and 3%, respectively. On the other hand, BOD and TSS removal efficiency at Municipal Case 6 in Greece was 95% and 96%, respectively. The reason for the rise in the effluent TSS levels in the dry season calls for further investigation.

3.3. Operational data for Soche WWTW

Tables **4**(**a**) and **4**(**b**) below show the influent and effluent characteristics of the wastewater at Soche WWTW during the dry season and wet season, respectively, with corresponding Malawi effluent standards.

The BOD, COD and TSS removal efficiency in the dry season was 95%, 60% and 35%, respectively. In the wet season, BOD, COD and TSS removal efficiency was 96%, 19% and 80%, respectively.

BOD_5 removal efficiency at Soche WWTW is comparable to the removal efficiency at Municipal Case 6. BOD_5 removal efficiency at Blantyre WWTW is only comparable to the removal efficiency at Municipal Case 6 during the dry season. TSS removal efficiency at Soche WWTW is only comparable to the removal efficiency at Municipal Case 6, during the wet season, although to a lesser extent. TSS removal efficiency at Blantyre WWTW is most inferior when compared to Municipal Case 6, or Soche WWTW.

All the three plants under review use physical, biological, and chemical processes as outlined by Banda (2007) [12] to reduce the concentration of pollutants in the wastewater. These include screening which is necessary, particularly in developing countries, because of the nature and quantity of

Table 1. Comparative Sequencing of Treatment Units for Municipal Case 6 and Blantyre WWTW

Plant/ Step No.	Municipal Case 6, Greece	Suggested Sequencing of Dry Season Conditions by Treatment Adviser	Suggested Sequencing of wet Season Conditions by Treatment Adviser	Actual Sequencing for Blantyre Plant
1	Screening	Grit chamber	Grit chamber	Screening
2	Grit chamber	Neutralisation	Neutralisation	Grit channels
3	Oxidation ditch	Chemical precipitation/ sedimentation	Chemical precipitation sedimentation	Primary sedimentation
4	Sedimentation	Activated sludge process	Activated sludge process	Trickling filters
5	Chlorination	Facultative lagoon	Activated carbon adsorption	Humus tanks
6	-	Activated carbon adsorption	Ion exchange	Aeration ponds

Table 2. Comparative Sequencing of Treatment Units for Municipal Case 6 and Soche WWTW

Plant/ Step No.	Municipal Case 6, Greece	Suggested Sequencing of Dry Season Conditions by Treatment Adviser	Suggested Sequencing of Wet Season Conditions by Treatment Adviser	Actual Sequencing for Soche Plant
1	Screening	Grit chamber	Neutralisation	Screening
2	Grit chamber	Neutralisation	Chemical precipitation	Grit channels
3	Oxidation ditch	Chemical precipitation	Activated sludge	Primary sedimentation
4	Sedimentation	Activated sludge process	Activated carbon	Trickling filters adsorption
5	Chlorination	Activated carbon adsorption	Ion exchange	Humus tanks
6	-	Ion exchange	-	Sand filters (disused)

Table 3. (a) Blantyre Works Influent and Effluent Physicochemical Characteristics for the Dry Season in mg/l

Parameter	BOD	COD	TSS
Influent	440.66±5.6	1642.3±12.5	210.0±4.05
Effluent	38.0±3.1	691.0±5.6	232.1±1.42
Reduction			
Efficiency (%)	87	58	-11
Malawi Standard	20	60	30
WHO Guidelines	20	60	30

Table 3. (b) Blantyre Works Influent and Effluent Physicochemical Characteristics for the wet Season in mg/l

Parameter	BOD	COD	TSS
Influent	510±14.14	691±5.03	29.01±0.0
Effluent	450±42.43	503±0.91	25.91±2.03
Reduction			
Efficiency (%)	12	27	3
Malawi Standard	20	60	30
WHO Guidelines	20	60	30

Table 3. (c) Influent and Effluent Characteristics of Municipal Case 6 in Greece in mg/l

Parameter	BOD	COD	TSS
Influent	227	-	355
Effluent	11	40	16
Reduction			
Efficiency (%)	*95*	-	*96*
Malawi Standard	20	60	30
WHO Guidelines	20	60	30

solids present in the sewage, which include still born babies, maize cobs and pieces of cloth used for anal cleaning, and domestic garbage [13, 14]. The original plant at Blantyre WWTW comprised a single hand-raked inclined bar screen and two constant velocity grit channels where longitudinal flow velocity is hydraulically controlled. Grit is manually removed from one chamber whilst the other is still in use. These units have been in continuous use for more than a decade because of the breakdown of the newer mechanically stirred grit chambers. When the extensions were constructed, they were deliberately retained for emergency use only. The extensions comprised a rotary mechanically-raked bar screen, aerated spiral flow type grit channel with traveling bridge mounted degritter and de-scummer. The mechanized grit channels are clearly not ideal for Malawi because they cannot be readily repaired when they break down. Soche WWTW uses a single hand-raked inclined bar screen and two constant velocity grit channels, where the grit is manually removed. Municipal Case 6 also incorporates a grit chamber.

The grit removal process is necessary for the removal of inorganic grit which may cause abrasion of comminutors and impellers of sludge pumps, or which may set hard in sludge hoppers, transmission pipes and in the bottom of digesters calling for more frequent maintenance than normal [14].

The screening process is not included in the Treatment Adviser's suggested sequencing of either the dry or wet season conditions, at both Blantyre WWTW and Soche WWTW. The grit removal process is also not included in the

Table 4. (a) Soche Sewage Works Influent and Effluent Physicochemical Characteristics for the Dry Season in mg/l

Parameter	BOD	COD	TSS
Influent	490± 9.8	883± 12.5	157±2.32
Effluent	25± 0.6	353± 4.31	102±5.6
Reduction			
Efficiency (%)	95	60	35
Malawi Standard	20	60	30
WHO Guidelines	20	60	30

Table 4. (b) Soche Sewage Works Influent and Effluent Physicochemical Characteristics for the Wet Season in mg/l

Parameter	BOD	COD	TSS
Influent	760 ± 0.0	907 ± 10.05	40± 0.0
Effluent	34± 2.69	735 ± 16.55	8 ± 0.02
Reduction			
Efficiency (%)	*96*	*19*	*80*
Malawi Standard	20	60	30
WHO Guidelines	20	60	30

Treatment Adviser's suggested sequencing of wet season conditions at Soche WWTW.

Municipal Case 6, Blantyre WWTW, and Soche WWTW all have a sedimentation process. This is necessary for the removal of readily settleable matter from the wastewater. Through this process, a BOD_5 reduction of 25-40%, and a TSS reduction of 50-70% is achieved [14, 15].

Finally, all the three plants under review have an aerobic biological treatment stage. This is necessary to ensure 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 [19]. However, Municipal Case 6 uses oxidation ditches while both Blantyre and Soche WWTW use trickling filters. Trickling filters are a preferred technology for Malawi because they do not involve electrical/mechanical equipment. Blantyre City Assembly has not been able to repair some broken down equipment at Blantyre WWTW for over a decade. In addition trickling filters require little maintenance. Some of the filters at Blantyre WWTW have partially blocked vents. These merely require routine cleaning works by the labourers posted at the site. In addition, trickling filters would most likely cost less to install than oxidation ditches because cement and aggregate for construction of the filters are both locally available in Malawi.

4. CONCLUSION

In conclusion, it is observed that there is a close match in technologies at Blantyre and Soche WWTW, and Municipal Case 6 in Greece as invoked by the Case Study Manager in the ED-

WAVE tool. What is important, however, is to appropriately modify the case arrived at through the Case Study Manager in order to come up with a design appropriate to the local situation in terms of operation and maintenance.

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