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Evaluation of case-based design principles in the design of Soche wastewater treatment plant, Blantyre, Malawi

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ABSTRACT

This paper evaluates case-based design principles in the design of Soche wastewater treatment works (WWTW) in the city of Blantyre, Malawi. According to the Case Study Manager in the ED-WAVE tool, a similar case to both dry season and wet season conditions of Soche plant is Municipal Case 6 in Greece. The raw material at Municipal Case 6 in Greece is raw municipal sewage where the typical wastewater parameters are BOD_5, and TSS. The treatment target is BOD_5, and TSS reduction. The study confirmed the practical use of case-based design principles in the design of wastewater treatment systems, where after encountering a new situation; already collected decision scenarios (cases) are invoked and modified in order to arrive at a particular design alternative. What is necessary, 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 taking into account technical, socio-economic and environmental aspects.

Keywords: Aerobic biological treatment; Case-based design; Grit removal; Unit treatment processes; Wastewater treatment

1. Introduction

Rising population, rapid urbanization, growing industrialization and the expanding agro industry, combined with pollution from untreated sewage and industrial effluents have severely stressed both water quality and its availability in Malawi, a country in sub-Saharan Africa. It is predicted that Malawi will face a water stress situation by 2025 [1]. In the City of Blantyre, which is the country's commercial capital, this situation is aggravated by the serious pollution threat from the grossly inadequate sewage treatment capacity that is only 23.5% of the wastewater being generated presently. In addition, limited or non-existent industrial effluent treatment has contributed to the severe water quality degradation. This situation poses a threat to the ecologically fragile and sensitive receiving water courses within the city, where the water, further downstream, is used for domestic purposes; a situation that underscores the need for wastewater treatment in the country.

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

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aesthetic quality of surface water sources [2]. 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 [3].

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 [3]. 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 [4].

This paper evaluates case-based design principles [5–8] in the design of Soche WWTW in the City of Blantyre, Malawi.

2. Methodology

2.1. Study site

The study was conducted at Soche WWTW located at the south-western end of Blantyre city in Malawi (Fig. 1). The city of Blantyre lies within the Shire Highlands, with a topography ranging from 800 m to 1600 m, in the southern part of Malawi. Malawi lies between latitudes 9 and 17° South and between longitudes 33 and 36° East [1]. Climatically, Blantyre like most of the districts in Malawi has two main seasons during the year, the dry and the wet. The wet season lasts from December to May and the remainder of the year is dry, with temperature increasing until the onset of the next rains. Soche works serves a physical catchment area of some 24 km^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/d. 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/d.

2.2. Data collection and analysis

Data was collected through a desk study which was based on the work by Kuyeli [2]. Sampling was done

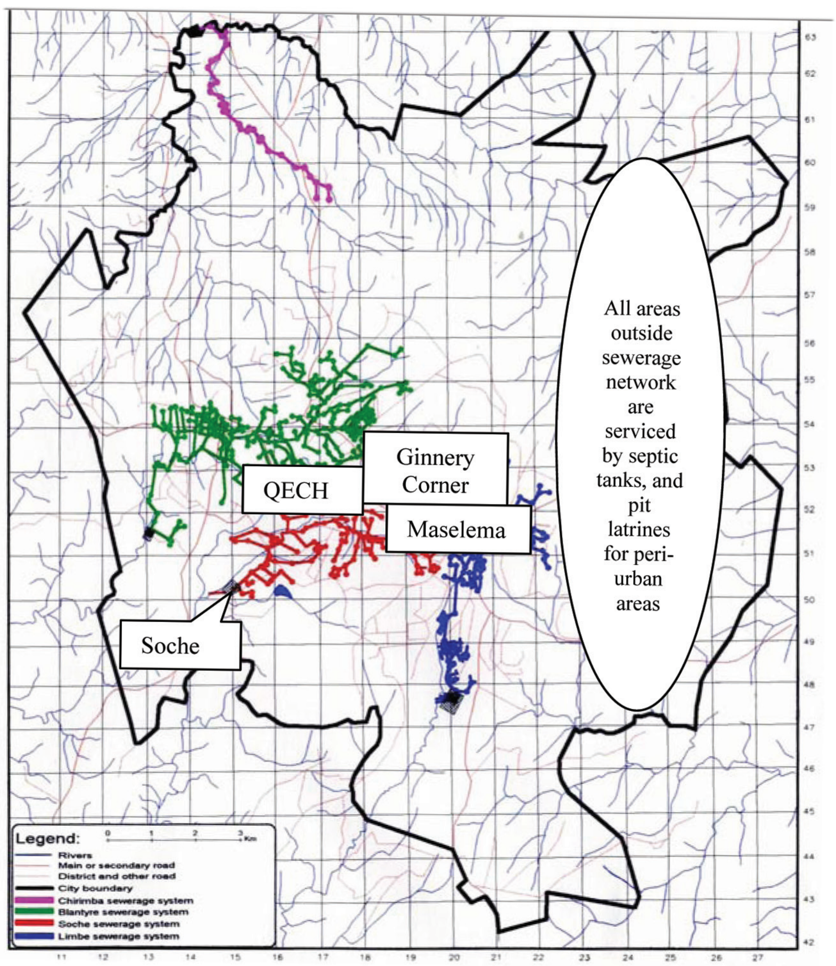

Fig. 1. Location of Soche WWTW at the bottom end of the Soche sewerage system.

between the months of October–November 2005 for the dry season, and February 2006 for the wet season using the grab 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°C, whereas TSS were determined by filtering the samples through pre-weighed glass fibre filters as described in [9]. A mean concentration was calculated along with a standard deviation on the results obtained for three samples collected from each point.

2.3. Case-based design and case-based reasoning

Case-based design (CBD) and case-based reasoning (CBR) 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. Case storage is an important aspect in designing efficient CBD systems in that it should reflect the conceptual view of what is represented in the case and take into account the indices that characterise the case. The case-base should be organised into a manageable structure that supports the efficient search and retrieval methods. This is accomplished in the ED-WAVE tool [5,7] (Fig. 2).

2.4 The ED-WAVE tool

The ED-WAVE tool was used for the conceptual design of Soche wastewater treatment works in the City of Blantyre.

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 (Fig. 2).

2.4.1. 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

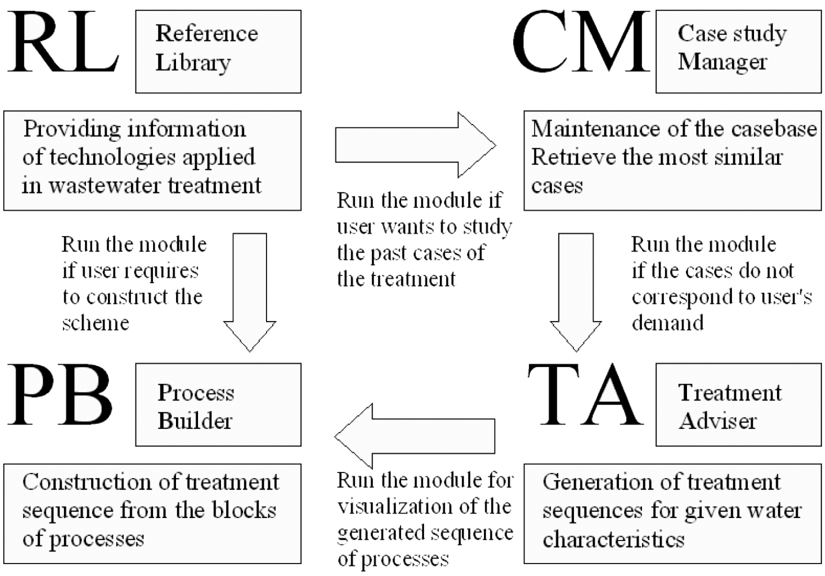

Fig. 2. Structure of the ED-WAVE tool.

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.

2.4.2. 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 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 [6,7]. The treatment sequences of similar cases are provided as promising solutions.

2.4.3. 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 [10]. 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 [11] 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 [12]. 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. The process of selection of a treatment method from a decision tree is illustrated in Fig. 3 where part of a decision tree for selection of an aerobic treatment type is presented. Each treatment level is considered, and after successfully passing all decision trees, the final treatment sequence is considered.

2.4.4. 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

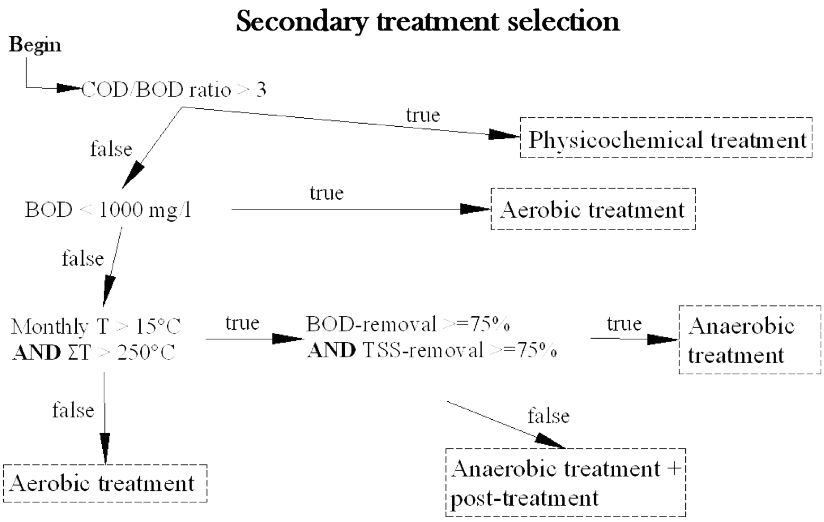

Fig. 3. Decision tree for selection of an aerobic treatment type.

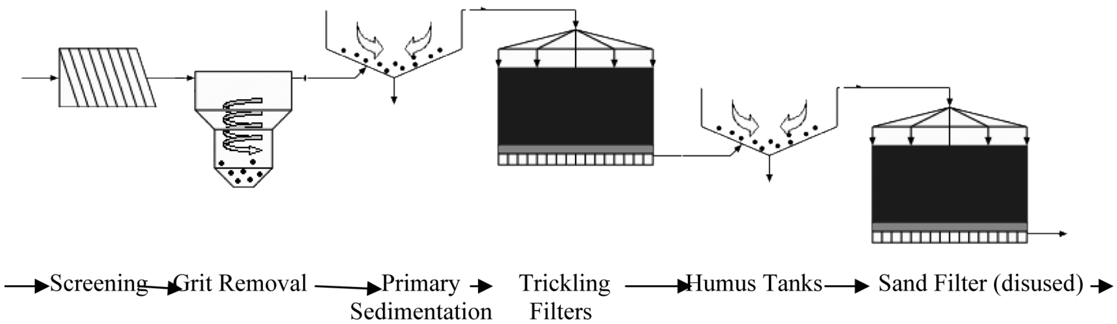

Fig. 4. Sequencing of treatment units at Soche WWTW according to Process Builder.

at a particular plant as illustrated in Fig. 4 (sequencing of wastewater treatment units at Soche WWTW).

3. Results

3.1. Operational data for Soche WWTW

Table 1 shows data for influent and effluent BOD_5 and TSS levels for Soche WWTW in the City of Blantyre, Malawi.

3.2. Application of case-based design principles in the design of Soche 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 Soche WWTW is Municipal Case 6 in Greece (2003), with a flow rate of 6,600 m^3/d. The treatment sequence for this plant and 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. Figs. 5,

Table 1
Influent and effluent BOD5 and TSS levels for Soche WWTW in mg/l

Parameter	BOD_5	TSS
Dry season		
Influent	490±9.8	157±2.32
Effluent	24.82±0.6	101.65±5.64
Reduction efficiency (%)	95	35
Wet season		
Influent	760±0.0	40±0.0
Effluent	33.90±2.69	8.02±0.02
Reduction efficiency (%)	96	80
Malawi standard	20	30
WHO standard	20	30

BOD_5 = biochemical oxygen demand,
COD = chemical oxygen demand

Table 2
Comparative sequencing of treatment units

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 of Soche plant
1	Screening	Grit chamber	Neutralisation	Screening
2	Grit chamber	Neutralisation	Chemical precipitation	Grit chamber
3	Oxidation ditch	Chemical precipitation	Activated sludge	Primary sed.
4	Sedimentation	Activated sludge process	Activated carbon adsorp.	Trickling filters
5	Chlorination	Activated carbon adsorp.	Ion exchange	Humus tanks
6	—	Ion exchange	–	Sand filters (disused)

6, 7 and 8 further illustrate this sequencing according to the Process Builder in the ED-WAVE tool.

4. Discussion

Through this study, case based design principles gave Municipal Case 6 in Greece as a wastewater treatment plant similar to Soche WWTW. The plant in Greece has five unit treatment processes. The dry season set up for Soche works has six unit treatment processes while the wet season set up has five unit treatment processes. The actual sequencing for Soche works has six unit treatment processes. A similarity between Municipal Case 6 in Greece and the actual set up at Soche works is the provision for screening. 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 [2,13–15]. BOD_5 and TSS effluent levels at Soche were 24.82 g/l and 101.65 mg/l, respectively, in the dry season, and 33.90 mg/l, and 8.02 mg/l, respectively, in the wet season. This represented a BOD_5 and TSS removal efficiency of 95% and 35%, respectively in the dry season and 96% and 80%, respectively, in the wet season. BOD_5 and TSS effluent levels at the plant in Greece were 11 mg/l and 16 mg/l, respectively. This represented a BOD_5 and TSS removal efficiency of 95% and 96%, respectively. The study further established that BOD_5 and TSS levels in the effluent are higher at Soche than the set standards. This calls for an investigation into the mode of operation of Soche WWTW. A critical analysis of the unit treatment processes at the plant in Greece, the suggested dry season unit treatment processes and the actual set up at the Soche plant suggests that there are certain unit treatment

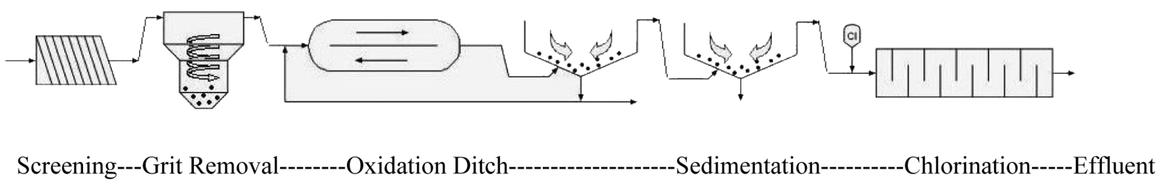

Fig. 5. Sequencing of treatment units at Municipal Case 6, Greece.

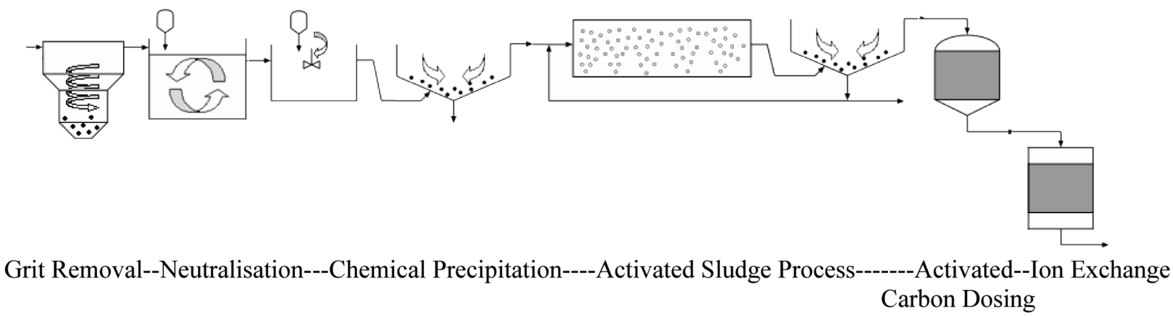

Fig. 6. Suggested sequencing of treatment units for dry season conditions at Soche WWTW.

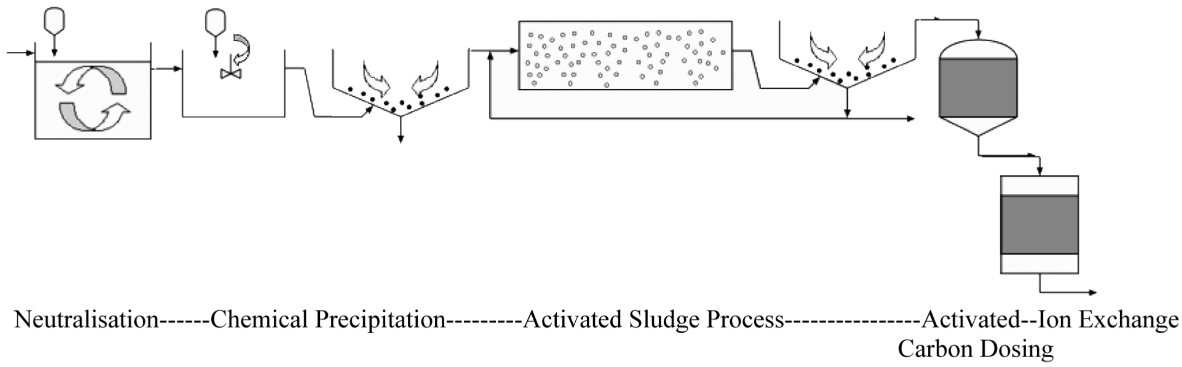

Fig. 7. Suggested sequencing of treatment units for wet season conditions at Soche WWTW.

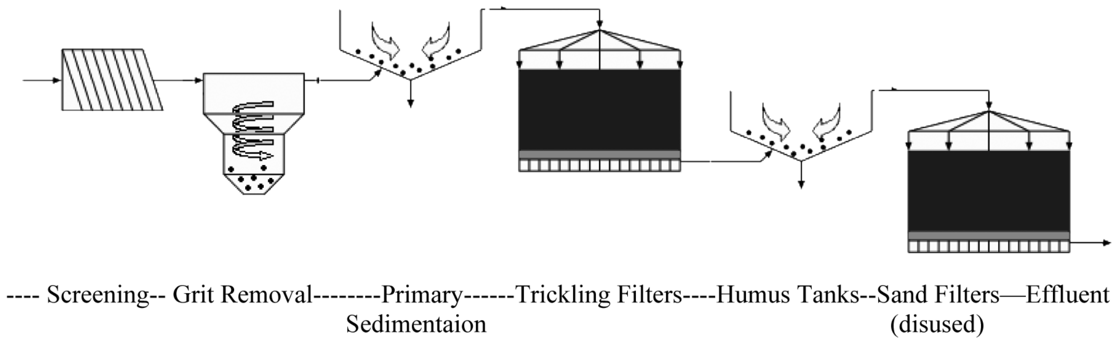

Fig. 8. Actual sequencing of treatment units for Soche plant.

processes that are important in wastewater treatment. These include the grit removal process, for 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. However, the Soche plant uses constant velocity grit chambers, in which longitudinal flow velocity is controlled hydraulically. These are simple to operate and maintain because they do not require electrical/mechanical equipment. Two chambers are constructed in parallel. Grit is manually removed from one chamber whilst the other is still in use [16]. The ED-WAVE tool relates to mechanised grit chambers. These are not ideal for Malawi because of their relatively high initial cost, and the skills required for their operation and maintenance. There is also the 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 [16,17]. Finally the inclusion of an aerobic biological treatment process 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 [16]. Soche WWTW uses trickling filters for this process while Municipal Case 6 in Greece uses oxidation ditches. Trickling filters are a preferred technology for Malawi because their initial cost is relatively lower, and they do not require skilled labour for their operation and maintenance.

Inclusion of the chlorination stage at Municipal Case 6, the ion exchange stage for the suggested dry and wet season set up at Soche, and the filtration process in the actual sequencing for Soche plant probably relates to the need for a tertiary treatment stage for these works. This tertiary stage is necessary for polishing up the effluent [16,17].

5. Conclusion

The close resemblance of Municipal Case 6 in Greece to the suggested dry season unit treatment processes and the actual plant set up at Soche WWTW confirms the practical use of case-based design principles in the design of wastewater treatment systems. After encountering a new situation, already collected design scenarios (cases) are invoked and modified in order to arrive at a particular design alternative. What is necessary, 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 taking into account technical, socio-economic and environmental aspects [18].

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