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TRAINING SYSTEM FOR CONCEPTUAL DESIGN AND EVALUATION FOR WASTEWATER TREATMENT

Thesis for the degree of Doctor of Philosophy to be presented with due permission for public examination and criticism in the Room No 4304 at Lappeenranta University of Technology, Lappeenranta, Finland on the 17th of December, 2010, at noon.

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ACRONYMS AND SYMBOLS

BOD_5	Biochemical Oxygen Demand
Cd	Cadmium
CIMO-NSS	Centre for International Mobility, North-South-South Higher Institution Network in Finland
Cl^-	Chloride
COD	Chemical Oxygen Demand
Cr	Chromium
Cu	Copper
dl	Detectable limit
ED-WAVE tool	An educational software for training in wastewater treatment technologies using virtual application sites
IWRM	Integrated Water Resources Management
MDGs	Millennium Development Goals
MGDS	Malawi Growth and Development Strategy
MDW&S	Mapeto David Whitehead & Sons textile and garments factory
NO_3^-	Nitrate
NSP	National Sanitation Policy
NWP	National Water Policy
Pb	Lead
QECH	Queen Elizabeth Central Hospital
TSS	Total Suspended Solids
UN	United Nations
WWTW	Wastewater Treatment Works

ABSTRACT

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Rising population, rapid urbanisation and growing industrialisation have severely stressed water quality and its availability in Malawi. In addition, financial and institutional problems and the expanding agro industry have aggravated this problem. The situation is worsened by depleting water resources and pollution from untreated sewage and industrial effluent. The increasing scarcity of clean water calls for the need for appropriate management of available water resources. There is also demand for a training system for conceptual design and evaluation for wastewater treatment in order to build the capacity for technical service providers and environmental practitioners in the country. It is predicted that Malawi will face a water stress situation by 2025. In the city of Blantyre, this situation is aggravated by the serious pollution threat from the grossly inadequate sewage treatment capacity. This capacity 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. This water is used for domestic purposes further downstream. This manuscript outlines the legal and policy framework for wastewater treatment in Malawi. The manuscript also evaluates the existing wastewater treatment systems in Blantyre. This evaluation aims at determining if the effluent levels at the municipal plants conform to existing standards and guidelines and other associated policy and regulatory frameworks. The raw material at all the three municipal plants is sewage. The typical wastewater parameters are Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), and Total Suspended Solids (TSS). The treatment target is BOD_5, COD, and TSS reduction. Typical wastewater parameters at the wastewater treatment plant at MDW&S textile and garments factory are BOD_5 and COD. The treatment target is to reduce BOD_5 and COD. The manuscript further evaluates a design approach of the three municipal wastewater treatment plants in the city and the wastewater treatment plant at Mapeto David Whitehead & Sons (MDW&S) textile and garments factory. This evaluation utilises case-based design and case-based reasoning principles in the ED-WAVE tool to determine if there is potential for the tool in Blantyre. The manuscript finally evaluates the technology selection process for appropriate wastewater treatment systems for the city of Blantyre. The criteria for selection of appropriate wastewater treatment systems are discussed. Decision support tools and the decision tree making process for technology selection are also discussed. Based on the treatment targets and design criteria at the eight cases evaluated in this manuscript in reference to similar cases in the ED-WAVE tool, this work confirms the practical use of case-based design and case-based reasoning principles in the ED-WAVE tool in the design and evaluation of wastewater treatment systems in sub-Sahara Africa, using Blantyre, Malawi, as the case study area. 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. This work provides a training system for conceptual design and evaluation for wastewater treatment.

Keywords: case-based design, case-based reasoning, conceptual design and evaluation, decision support tools, ED-WAVE tool, wastewater treatment

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Professor Andrzej Kraslawski provided excellent guidance from the start of the PhD research programme throughout the period of the research. Dr Yury Avramenko introduced me to the ED-WAVE tool for wastewater treatment technologies, and to the concept of the decision tree as a tool for technology selection process in wastewater treatment. Thank you Andrzej and Yury for the high standard you set for this thesis. Without your support and advice, this thesis could not have been produced the way it is. Professor Andrzej Kraslawski and Dr Yury Avramenko deserve special thanks for believing in my potential that I could do the research work successfully. This has been a source of strength and encouragement in carrying out this work.

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In memory of my late father, Alfred Chipofya. I know he would have been truly pleased with this achievement.

This work is dedicated to my wife Irene, all our six children, and grandson, Wongani.

Lappeenranta, August, 2010.
Victor Helix Chipofya

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LIST OF PUBLICATIONS

The thesis includes the following original publications submitted to refereed journals for which confirmation of acceptance was received from the respective Editors. The publications are referred to in the text by their assigned Roman numerals in the appendices (I-IV).

I. Chipofya, V., Kraslawski, A., Avramenko, Y., (in press) *ED-WAVE tool design approach: case of a textile wastewater treatment plant in Blantyre, Malawi.* Physics and Chemistry of the Earth, Elsevier.

II. Chipofya, V., Kraslawski, A., Avramenko, Y., (in press*) ED-WAVE tool design approach: case of Limbe WWTW, Blantyre, Malawi.* Desalination and Water Treatment journal, Desalination Publications.

III. Chipofya, V., Kraslawski, A., Avramenko, Y., (in press) *Comparison of pollutant levels in effluent from wastewater treatment plants in Blantyre, Malawi.* International Journal of Water Resources and Environmental Engineering, Academic Journals.

IV. Chipofya, V., Kraslawski, A., Avramenko, Y., (in press) *Comparison of wastewater treatment technologies in the ED-WAVE tool to technologies of similar cases in Malawi: case of Blantyre and Soche WWTW.* Open Civil Engineering Journal, Bentham Publishing.

Conference Proceedings

Some of the information presented in the thesis has been published in Conference Proceedings. The following publications from Conference Proceedings are not included in the thesis.

Chipofya, V., Kraslawski, A., Avramenko, Y., *Design approach of Blantyre wastewater treatment plant, Malawi, using the ED-WAVE tool*, Water, Sanitation and Hygiene: Sustainable Development and Multisectoral Approaches, 34th WEDC International Conference, 135-138, Addis Ababa, Ethiopia, 18-22 May, 2009.

Chipofya, V., Kraslawski, A., Avramenko, Y., *ED-WAVE tool for wastewater treatment technologies: Is there potential for the tool in Malawi?* IWRM: Environmental Sustainability, Climate Change and Livelihoods, 10th WaterNet/WARFSA/GWP-SA Symposium, Water for People, Volume of Abstracts, 28-30 October, 2009, Entebbe, Uganda.

Chipofya, V., Kraslawski, A., Avramenko, Y., *Comparison of pollutant levels in effluent from WWTW in Blantyre, Malawi, with Malawi standards and WHO guidelines,* 2nd All Africa Environmental Health Congress, Malawi 2010: Environmental Health – The Key to a Better Life for All, pp71, 24-27 May, 2010, Lilongwe, Malawi.

The author’s contribution to the work in the above publications

The author personally undertook site visits and evaluated all cases. The author further personally undertook desk studies and literature review related to the work. The author undertook all manuscript writing.

The author co-authored the publication appended below.

Avramenko, Y., Chipofya, V., Kraslawski, A., *Educational training system for design of efficient water treatment,* ICHeap Conference, Italy, May, 2009.

Introduction

Justification of research

Rising population, rapid urbanisation and growing industrialisation have severely stressed water quality and its availability in Malawi. In addition, financial and institutional problems and the expanding agro industry have aggravated this problem. The situation is worsened by depleting water resources and pollution from untreated sewage and industrial effluent. The increasing scarcity of clean water calls for the need for appropriate management of available water resources. There is also demand for a training system for conceptual design and evaluation for wastewater treatment in order to build the capacity for technical service providers and environmental practitioners in the country. It is predicted that Malawi will face a water stress situation by 2025. In the city of Blantyre, this situation is aggravated by the serious pollution threat from the grossly inadequate sewage treatment capacity. This capacity 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. This water is, further downstream, used for domestic purposes.

Wastewater needs to be dully treated in order to minimise 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. 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.

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. 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.

Training systems on wastewater engineering have over the years evolved from collection, treatment and disposal to new technological developments in the last decade. In addition, awareness of environmental issues among world communities has reached unprecedented levels. This active awareness is driving the wastewater industry to achieve high levels of performance. This has resulted to the focus in wastewater practice to shift to nutrient removal, with particular emphasis on biological nutrient removal. Equipment for this high level of treatment can hardly be afforded in developing countries in terms of capital cost and skills required to operate and maintain the plant.

It is because of this situation that systematic approaches to improving the conceptual design of wastewater treatment as well as decision making methods for proper evaluation of wastewater treatment systems in developing countries are important.

The design of efficient wastewater treatment systems is a complicated task which requires significant knowledge and experience in the design and operation of wastewater treatment plants. The task that usually faces a design engineer is to determine the levels of treatment that must be accomplished. The design engineer also needs to determine the sequence of methods that can be used to remove the components found in the wastewater in order to reduce the environmental impact. The wastewater also needs to meet ecological requirements. The solution to this task requires the detailed assessment of local conditions and needs, application of scientific knowledge and engineering judgment based on past experience. Therefore an information reference system accumulating knowledge in the field of wastewater treatment and water reuse would be of great interest to engineers. The information should also be easily accessible. This would help to raise awareness among many technical service providers and environmental practitioners regarding the range of wastewater treatment methods and equipment available. This would further help to change the focus by wastewater technologists and practitioners from engineering to such essential factors as skills and training. There is, therefore, an urgent need to impart practical education among students. This education should cover legislative, public health, and technological issues towards facilitating full-scale adoption of appropriate wastewater treatment systems. There is also a need to provide information on the conceptual variables that determine the selection criteria for sustainable wastewater treatment systems, particularly in developing countries. Previously published studies on this subject excluded policy and regulatory framework. They also excluded trace and heavy metal contaminants. These studies only included European Member States and South Asia, South-East Asia and China. This study focuses on Malawi, in sub-Sahara Africa. It brings together policy, science and practice in the context of wastewater treatment. The study also includes trace and heavy metal contaminants in the wastewater parameters.

Aims and objectives

The aim of this research was to develop a training system for conceptual design and evaluation for wastewater treatment based on the city of Blantyre, Malawi, in sub-Sahara Africa, as case study area.

The principal objectives towards achieving the aim of this research were as follows:

1. To determine the challenges faced by the country in the context of wastewater treatment and outline the policy and legal framework on water resources management in Malawi,
2. To evaluate the design and operation of selected wastewater treatment plants in Blantyre to determine compliance of effluent characteristics to regulatory standards,
3. To evaluate the ED-WAVE tool design approach of a sample of wastewater treatment plants in Blantyre in order to establish appropriateness of local designs and to determine if the effluent meets the required standards, and
4. To evaluate a technology selection and decision tree making process for appropriate wastewater treatment systems for the city of Blantyre.

Arrangement of thesis

Apart from the introduction, the thesis evaluates four aspects of a training system for conceptual design and evaluation for wastewater treatment in Blantyre, Malawi, namely: 1) Determination of the existence of regulatory instruments and evaluation of compliance to the same. This was done through a desk study. 2) Evaluation of the design and operation of selected wastewater treatment plants in Blantyre to determine compliance of effluent characteristics to regulatory standards. This was done through site measurements and a desk study. 3) Evaluation of the ED-WAVE tool design approach of a sample of wastewater treatment plants in Blantyre in order to establish appropriateness of local designs and to determine if the effluent meets the required standards. This was done through a desk study. 4) Technology selection and decision tree making process for appropriate wastewater treatment systems for the city of Blantyre. This activity was done through a desk study.

This information is presented in Chapters 1, 2, 3 and 4, respectively.

Chapter 1 presents the policy and legal framework on water resources management in Malawi. It outlines the challenges faced by the country in the context of wastewater treatment. The chapter makes reference to existing water pollution control policies in the country and bye-laws which regulate discharge standards in the city of Blantyre.

Chapter 2 analyses eight cases relating to existing wastewater treatment systems in the city of Blantyre. The chapter looks at the three main wastewater treatment plants that service the city, namely: Blantyre wastewater treatment works (WWTW), Soche WWTW, and Limbe WWTW. Both Blantyre and Soche plants are conventional plants. Limbe WWTW consists of a waste stabilisation pond system. The chapter also presents the end-of-pipe wastewater treatment technology at Mapeto David Whitehead and Sons (MDW&S) textile and garments factory. Finally the chapter looks at the sewage treatment and sewerage operating costs for Blantyre City Assembly. It is observed that with a Euro/Malawi Kwacha exchange rate of €1.00 = MK220, the unit treatment cost of wastewater is €0.98 per cubic metre. This is three times more than the unit treatment cost of €0.33 per cubic metre of wastewater at Municipal Case 6 in Greece (2003). It is recommended that Blantyre City Assembly critically scrutinises their operating costs in order to determine where costs would be reduced. In the same vein, the Assembly should re-visit the fees it charges the various industries that it services. In addition, income received from the reception of industrial effluent discharges to cover sewerage and treatment costs should be spent within the pollution control section. This will enable the section to properly maintain, operate and upgrade the treatment works.

Chapter 3 evaluates of the design approach of Blantyre wastewater treatment plants using the ED-WAVE tool. The chapter looks at case-based design and case-based reasoning principles in the ED-WAVE tool in the design of Blantyre WWTW, Soche WWTW, Limbe WWTW, and the wastewater treatment plant at MDW&S textile and garments factory.

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. This experience is 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. 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.

Chapter 3 concludes by observing 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 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. This local situation takes into account technical, socio-economic and environmental aspects. In the case of Limbe WWTW, there is close correlation in the treatment processes of this plant with the treatment processes at Municipal Case 1 in Sri Lanka. There is also a close relation in the suggested dry and wet season unit treatment processes according to the Treatment Adviser with the actual set up at Limbe WWTW. This confirms the practical use of case-based design and case-based reasoning principles in the ED-WAVE tool in the design of municipal wastewater treatment systems. Textile Case 4 in Sri Lanka incorporates an aerobic biological treatment process through the provision of rotating biological contactors. There is a provision of activated sludge treatment for MDW&S in the suggested sequencing of dry and wet season conditions by the Treatment Adviser. The actual sequencing of treatment units at MDW&S deploys oxidation ditches. This confirms the practical use of the ED-WAVE tool in the design of a wastewater treatment system for a textile and garments factory. After encountering a new situation, already collected decision scenarios (cases) are invoked and modified in order to arrive at a particular design alternative.

Finally chapter 4 looks at the technology selection and decision tree making process for appropriate wastewater treatment systems for the city of Blantyre. The chapter observes that appropriate technology suitable for local conditions is one of the key solutions to overcome operational failure of wastewater treatment systems in many developing countries. The suitable option is not only a system that provides the best performance at least cost. The system should also be sustainable in terms of meeting local needs with regard to social-cultural acceptability, technological and institutional feasibility, economical affordability, and environmental acceptability. The chapter further discusses the concept and scope of appropriate wastewater treatment systems, and the selection criteria of appropriate wastewater treatment systems.

The chapter finally goes through the decision tree making process for technology selection and looks at the application of the decision tree in the conceptual design and evaluation for wastewater treatment in Malawi.

The thesis ends with a summary which concludes with the main contributions of this work.

Chapter 1

Wastewater treatment in Malawi: policy and regulatory framework on water resources management

1.1 Background

Rising population, rapid urbanisation and growing industrialisation have severely stressed water quality and its availability in Malawi. In addition, financial and institutional problems and the expanding agro industry have aggravated this problem. The situation is worsened by depleting water resources and pollution from untreated sewage and industrial effluent (Ujang & Bucley, 2002). The increasing scarcity of clean water in the country sets the need for appropriate management of available water resources. It also sets the need for a training system for students, wastewater technologists and practitioners for conceptual design and evaluation for wastewater treatment.

It is predicted that Malawi will face a water stress situation by 2025 (Malawi Government, 2007). In the city of Blantyre, the country's commercial capital, this situation is aggravated by a serious pollution threat. This pollution threat emanates from the grossly inadequate sewage treatment capacity that is only 23.5% of the wastewater being generated presently. Furthermore, Malawi, like most African countries, is experiencing industrial growth which is making environmental conservation difficult (Kadongola, 1997; Phiri et al., 2005). One of the pronounced causative factors of water quality degradation is the poor treatment of industrial waste produced by industries.

The Malawi economy is predominantly agro-based. However, recent years have seen considerable industrial development in and around the four major cities of Blantyre, Lilongwe, Mzuzu, and Zomba. Blantyre, on the other hand, is the country's major industrial and commercial centre since the establishment of the African Lakes Corporation in 1878 (Carl Bro International, 1995).

According to the United Nations Industrial Development Organization 2004 report (IDR, 2004), the textile sector accounted for 10.4% of industrial organic water pollution in sub-Sahara Africa in 1999. Food and beverages accounted for the bulk of industrial organic water pollution (63.2%), followed by paper and pulp (11.2%), chemicals (7.3%), primary metal (4%), wood (3%), stone, glass (0.1%) and others (0.8%).

The discharge of poor quality effluents by industries into the municipal wastewater treatment plants reduces the performance of these treatment facilities over time. This is due to hydraulic overloading and corrosion of the sewer pipe system (Ikhu-Omoregbe et al., 2005). Industrial wastewaters involve a large spectrum of different organic compounds depending on the specific production scheme (Orhon et al., 2009).With the exception of a few specific industrial categories, physical or chemical methods of treatment can only provide partial removal of the organic content in the wastewater. The majority of industrial effluents require biological treatment for effective removal of organic matter, with or without a pre-treatment step. The proper design and operation of industrial wastewater treatment plants is important in order to minimise the negative effects on the receiving municipal wastewater treatment plants.

In the case of Blantyre, limited or non-existent industrial effluent treatment has contributed to the severe water quality degradation in the city. 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.

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 and meet stricter and stricter regulations (Gernaey et al., 2009).

1.2 National policy and regulatory framework on water resources management

The need for wastewater treatment in Malawi is underscored by the existing policy guidelines, institutional arrangements and regulatory framework. 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 (Carl Bro International, 1995).

A number of water management policies and legislations have been enacted in the country. The policies and legislations have been regulatory in nature. The Water Resources Act (1969) and its subsidiary Water Resources (Pollution Control) Regulations provide the main regulatory framework for water resources management. On the other hand, Water Works Act (1995) is the main authority that established water supply and water borne sanitation delivery services. There is a high degree of policy harmonization and collaboration amongst institutions dealing with water and environmental sanitation in Malawi (Chipofya et al., 2009).

The National Water Policy (NWP) (2005) ensures water of acceptable quality for all needs in Malawi.

The National Sanitation Policy (NSP) (2008) stipulates the need to improve delivery of improved sanitation services. **.**

Further to the above policy framework relating to water pollution control, the Malawi Government launched the Malawi Growth and Development Strategy (MGDS) in 2007. The MGDS is the overarching operational medium term strategy for Malawi designed to attain the nation's Vision 2020 (1995).

One of the nine priority areas in the MGDS is Irrigation and Water Development. Under this priority area is a sub-theme for conservation of the natural resource base and in particular water supply and sanitation.

In addition, formalized national effluent standards exist in Malawi (MBS, 2005). The main policing agent to ensure compliance is the Department of Environmental Affairs in the Ministry of Natural Resources, Energy and Environment.

Malawi, as a member state of the United Nations (UN), is also obliged to meet the UN Millennium Development Goals (MDGs) www.un.org/millenniumgoals/ (accessed 09.02.2010). Goal number seven in the MDGs relates to ensuring environmental sustainability by 2015.

1.3 Blantyre City Assembly Bye-laws

Bye-laws exist in the city of Blantyre in respect of industrial waste reception, including in-plant control measures (Local Government Act, 1982, 1998). These are administered by the Blantyre City Assembly Legal Department on advice of an infringement from the treatment works operational staff.

"Wet process" industrialists require end-of-pipe industrial waste effluent facilities. These are required to be in place prior to commencement of production. This is a consideration that is dealt with when applications are received by the City Assembly planning committee. For this reason, the head of the pollution control section sits on this committee to ensure compliance in the applications under consideration.

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Industrial wastes from "wet processing" have an impact on the sewerage system and the various wastewater treatment works processes. Beyond this, they may also affect WWTW effluent quality and the integrity of sludges and their by-products (Carl Bro International, 1995).

Industrial liquid waste constitutes the bulk of the pollution load, overall, to the treatment works (Kuyeli, 2007).

Under the Bye-Laws and Agreement procedures, industrialists are required to pre-treat their effluent before discharge to sewer.

Income is received from the reception of industrial effluent discharges to cover sewerage and treatment costs. This is substantial and is the second highest source of revenue to the Blantyre City Assembly after the rates on property. In practice, however, this income is not spent within the pollution control section in order to properly maintain, operate and upgrade the treatment works.

Chapter 2

Situation analysis of existing wastewater treatment systems in Blantyre

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2.1 Introduction

The city of Blantyre is Malawi's commercial capital. It has a population of 661,256 (Malawi Government, NSO, 2009). The city 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 degrees South and between longitudes 33 and 36 degrees East (Malawi Government, 2007). 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.The city is serviced by three main municipal wastewater treatment works. These are: Blantyre WWTW, Soche WWTW, and Limbe WWTW. There is a fourth plant to serve the industrial area of Chirimba, but it is not yet in use (Fig. 2.1).

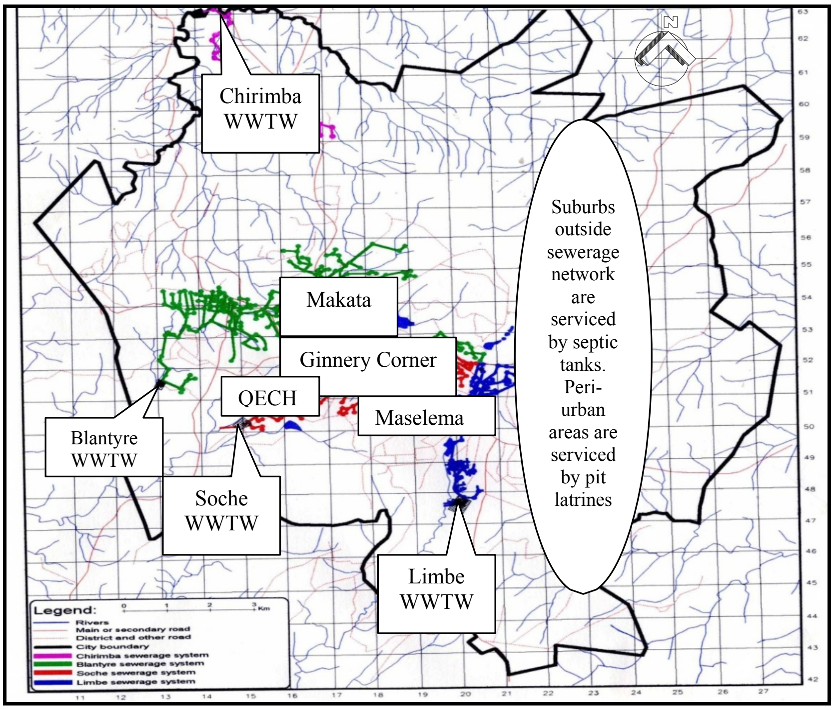


Fig. 2.1 Location of Blantyre, Soche, and Limbe wastewater treatment works in the city of Blantyre

Blantyre plant 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. The effluent from Blantyre works is discharged into the Mudi River. Soche is also a conventional treatment plant with an average dry weather flow rate of 5, 573 m^3/day. The plant receives about 30% of its effluent from the light industrial areas of Ginnery Corner and Maselema, with the rest coming from residential areas and storm water. The effluent from Soche treatment plant is discharged into Mlambalala River. Limbe plant, with an average dry weather flow rate of 1,800 m^3/day, receives almost equal volumes of industrial and domestic effluent. Limbe plant uses a waste stabilisation pond system and discharges into the Limbe River (Malawi Government, 1995; Kuyeli, 2007). A network of sewer lines provided by Blantyre City Assembly conduits the effluents from all designated areas to these treatment plants. In addition to the flows conveyed to the plants by sewer, Limbe and Soche plants also receive septage brought by road tanker. Although the piped sewerage system in Blantyre is notionally “separate”, surface water ingress occurs during wet weather at all operational works (Malawi Government, 1995).

2.2 Blantyre WWTW

The following is the sequencing of treatment technologies at Blantyre WWTW: screening, grit channels, primary sedimentation, trickling filters, humus tanks and aeration ponds.

2.2.1 Screening and grit removal

The original works comprised a single hand-raked inclined bar screen and two constant velocity grit channels (manual grit removal). These units are in continuous use because of breakdown of the newer mechanical grit removal chambers. When the extensions were constructed, they were deliberately retained for emergency use only.

Screen channel	0.66 m wide, 0.4 m max flow depth
Bar gap/thickness	25/15 mm
Through-bar area	0.17 m^2
Grit channels	9 m long, 0.8 m wide, 0.7 m max flow depth
Cross-sectional area	2 x 0.485 = 0.97 m^2, total

The extensions comprised a rotary mechanically-raked bar screen, aerated spiral flow type grit channel with traveling bridge mounted de-gritter and de-scummer. The screening and grit removal facilities have been out of use for many years.

Screen channel	0.9 m wide, 0.3 m flow depth
Bar gap	20 mm
Through-bar area	0.26 m^2
Aerated grit tank	20 m x 4.5 m x 3.5 m
Capacity	315 m^3

Only the original hand raked screen is operational at this plant. The screen is in reasonable physical condition.

The screen bar gaps at 25 mm do permit considerable amounts of debris to pass through. This causes problems with sludge treatment.

Screenings are dumped adjacent to the grit tanks and allowed to dry out and compost, with lime being added. Periodically they are burned.

The grit abstracted comprises fine sand with a small amount of organic matter.

2.2.2 Primary sedimentation

The original works comprised four circular, inverted cone, upward flow tanks. The overflow weirs are plain concrete without weir plate. Scum boards are provided. Manual desludging by hydrostatic head is provided.

Dimensions	7.55 m diameter, 1.6 m sidewall depth, 60^0 cone slope
Surface area	4 x 44.8 = 179 m^2 total
Volume	4 x 97.5 = 390 m^3 total

The later plant extensions added a rectangular horizontal flow tank, with a bridge mounted desludging scraper traveling longitudinally. As the scraper traveled, it scraped sludge into twin inverted pyramid sludge hoppers at the inlet end of the tank. Desludging occurred under hydrostatic head.

Dimensions	49.2 x 6.03 x 2.0 m (average depth)
Surface area	297 m^2
Volume	593 m^3

Total surface area for all tanks: 476 m^2

Although flows are normally passed through both the newer rectangular tank and older circular units, the sludge scraping machinery in the rectangular tank has been out of use for some years due to mechanical breakdown. The tank is periodically taken out of service and the sludge emptied manually.

Desludging of the circular tanks is carried out on daily basis and appears to be carried out satisfactorily.

2.2.3 Trickling filters

Two sets of two no. circular filters are provided at both the original plant and the extension.

Dimensions (original filters)	19.1 m diameter, 3.5 m depth
Surface area	2 x 280 (net) = 560 m^2 total
Volume	2 x 980 = 1960 m^3 total

Dimensions (extension)	22 m diameter, 4.75 m media depth
Surface area	2 x 380 (net) = 760 m^2 total
Volume	2 x 980 = 1960 m^3 total

Total media volume 3,920 m^3

The filter medium at top surface level is 90-100 mm nominal size, of gabbro stone.

Recirculation is provided at the plant. This would enhance the performance of the filters as it would limit the accumulation of biomass on the filter medium. The pumps have, however, not been operational for a number of years. This has resulted into poor distribution of flow onto the filters.

The media itself is in good condition, with very little evidence of breakdown.

2.2.4 Humus tanks

Six no. inverted cone upward flow humus tanks are provided. The overflow weirs are of plain concrete without weir plate. Scum boards are provided. Manual desludging under hydrostatic head is provided.

Dimensions	10.9 m diameter, 1.6 m sidewall depth, 60^0 cone slope
Surface area	6 x 93.5 = 560 m^2 total
Volume	6 x 443 = 2,658 m^3 total

These operate as originally designed. Under storm flow conditions, however, overloading and poor solids removal would be expected.

2.2.5 Aerated lagoons and settlement lagoon

Two concrete-lined aerated lagoons and a settlement lagoon placed at the downstream end of the humus tanks give a limited amount of faecal coliform removal prior to the effluent being discharged into the Mudi River downstream (Carl Bro International, 1995).

	Lagoon 1	Lagoon 2	Total
Dimensions	90 x 45 x 2 m	110 x 22 x 1.5 m	
Volumes	8,100 m^3	3,630 m^3	11,730 m^3

The final settlement lagoon has a capacity of 3,113 m^3.

2.2.6 Operational data for Blantyre WWTW

The raw material at Blantyre WWTW is municipal sewage. Typical wastewater parameters are biochemical oxygen demand (BOD$_5$), chemical oxygen demand (COD), and total suspended solids (TSS). The treatment target is BOD$_5$, COD, and TSS reduction. Chlorides, nitrates, trace and heavy metal contaminants were included in all eight cases in this study in order to facilitate inclusion of data from Malawi, sub-Sahara Africa, in the ED-WAVE tool.

2.2.6.1 Data collection and analysis

Data was collected through a desk study which was based on the work by Kuyeli (2007). Sampling was done between the months of October to November, 2005 for the dry season, and February, 2006 for the wet season. The grab sampling method was used. 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.

Chlorides were determined using an argentiometric method where 100 ml or a suitable portion was diluted to 100 ml and the samples were neutralized (pH 7 - 10) by either sulphuric acid or sodium hydroxide as described in APHA (1985). BOD_5 was determined by the Winkler method of oxygen measurement in the samples before and after incubating for five days at 20^0C (APHA, 1985). TSS was determined by filtering the samples through pre-weighed glass fibre filters as described in APHA (1985). Nitrates were determined using the salicylate calorimetric method as described by Yang et al. (1998), using a JENYAY 6405 UV/Vis spectrophotometer.
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 was heated for 2 hours in the range of 148 and 150°C and then cooled to room temperature. The condenser was washed by distilled water and the final mixture was used to make 100ml solution. This was titrated against 0.12M ammonium iron (II) sulphate (FAS) using ferroin indicator.

COD levels were calculated using the following equation:

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

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 (Kuyeli, 2007).

Copper, Nickel, Cadmium, Chromium and Lead were determined using a Buck Scientific model no. 200A atomic absorption spectrophotometer following the methods described in APHA (1985).

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

Table 2.1 and Figure 2.2 below show the influent and effluent characteristics of the wastewater at Blantyre WWTW during the dry season and wet season, respectively. Corresponding

Malawi effluent standards (MBS, 2005), and World Health Organisation (WHO) guidelines (1996) are also shown. Table 2.1 also shows the influent and effluent BOD_5, COD and TSS levels for Municipal Case 6 in Greece (2003). This is a case similar to Blantyre WWTW (Avramenko & Kraslawski, 2008).

Table 2.1
Blantyre works influent and effluent physicochemical characteristics and levels of trace and heavy metal contaminants for the dry season and wet season in mg/l. Comparative data is shown for BOD_5, COD and TSS levels for Municipal Case 6 in Greece (2003).

Parameter	Cl^-	BOD_5	COD	TSS	NO_3^-	Cu	Ni	Cd	Cr	Pb
Dry season										
Influent	34.8±0.9	440.6±5.6	1642.3± 12.5	210±4.05	44.8±18.67	0.040±0.011	<dl	<dl	<dl	<dl
Effluent	33.4±1.1	38.0±3.1	691.01± 5.6	232.1±1.42	152.9±35.66	<dl	<dl	<dl	<dl	<dl
Reduction Efficiency (%)	*4.02*	*86.82*	*58*	*-10.5*	*-241*	*100*	-	-	-	-
Wet season										
Influent	36.9±1.3	510±14.14	691.11 ± 5.03	29.01±0.0	84.47±2.15	<dl	<dl	<dl	<dl	<dl
Effluent	36.2±0.89	450±42.43	503.01 ± 0.91	25.91±2.03	32.37±0.0	<dl	<dl	<dl	<dl	<dl
Reduction Efficiency (%)	*1.9*	*11.76*	*27.22*	*3.1*	*61.68*	-	-	-	-	-
Municipal Case 6 in Greece										
Influent		227	-	355						
Effluent		11	40	16						
Reduction Efficiency (%)		*95*	-	*96*						
Malawi Standard	400	20	60	30	45	1.0	0.15	0.005	0.1	0.05
W.H.O. Guidelines	250	20	60	30	50	2.0	0.02	0.003	0.05	0.01

Key: <dl = less than minimum detectable limit; Cl^- - Chloride; BOD_5 – Biochemical Oxygen Demand; COD – Chemical Oxygen Demand; TSS – Total Suspended Solids; NO_3^- - Nitrate;
Cu – Copper; Ni = Nickel; Cd = Cadmium; Cr = Chromium; Pb = Lead

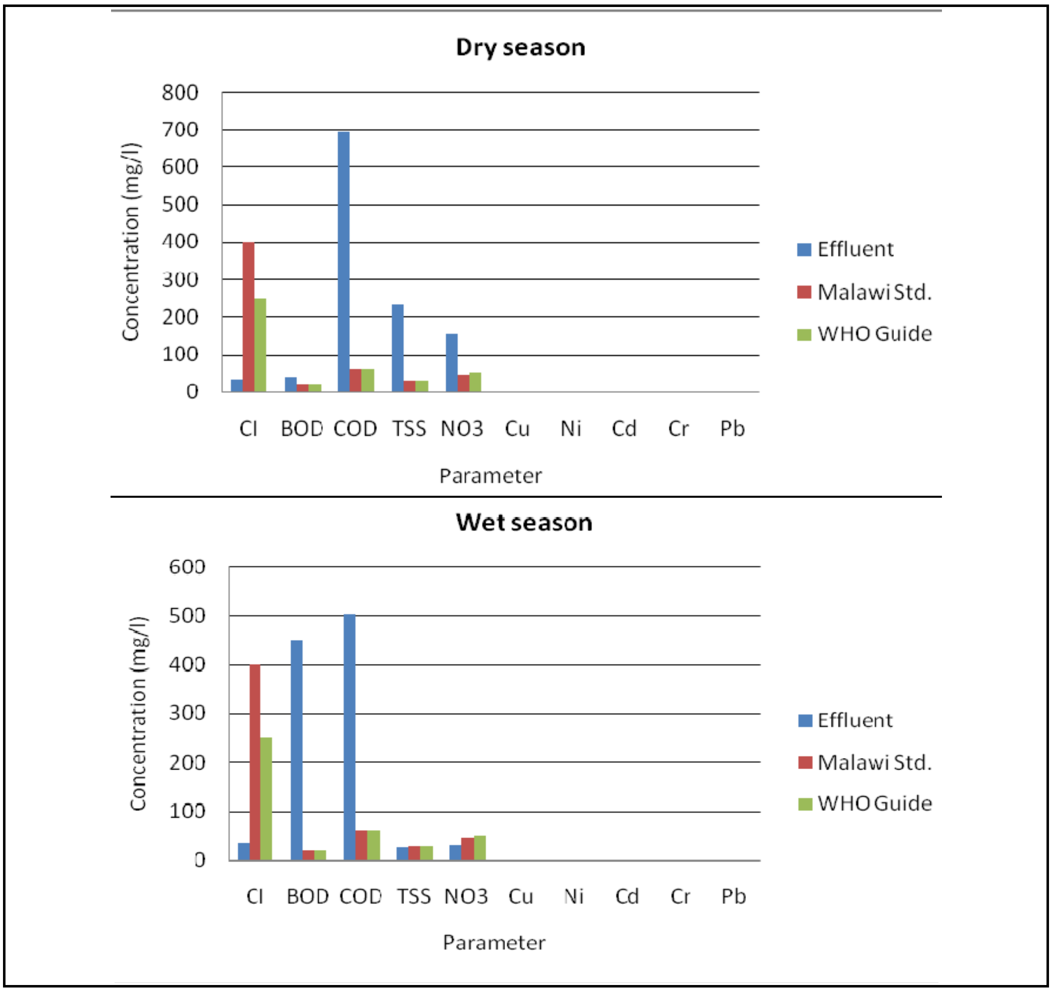


Fig. 2.2 Blantyre WWTW dry season and wet season effluent characteristics

The key parameters in quality control of municipal wastewater treatment processes are BOD_5 and TSS (Barnes, 1981; Metcalf & Eddy, 2004). The BOD_5 level relates to organic matter in the effluent being discharged into public water courses where it would exert an oxygen demand. The TSS relate to suspended particles in the effluent. These would limit light penetration in the water, and hence inhibit photosynthesis. In addition, suspended solids may cause thickening of fish gills which may lead to eventual asphyxiation of the fish. On the river bed, the sediments may interfere with spawning sites and decrease the amount of food available to fish (Barnes, 1991; Bhatia, 2003).

The BOD_5 and TSS removal efficiency in the dry season was 87% and -10.5%, respectively. The BOD_5 and TSS removal efficiency in the wet season was 11.76% and 3.1%, respectively (Figure 2.3). The reason for the rise in the effluent TSS and nitrate levels in the dry season calls for further investigation.

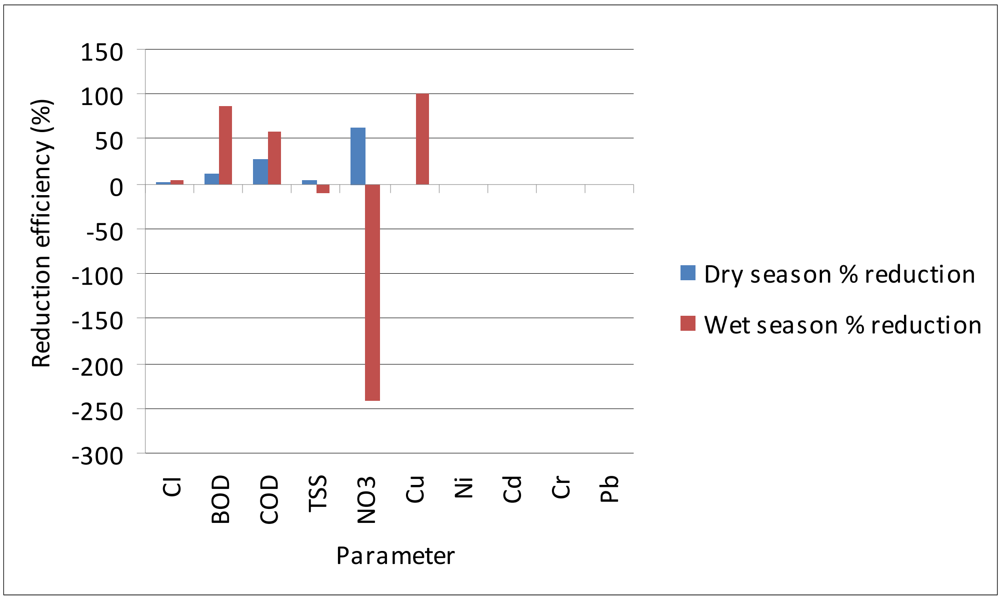


Fig. 2.3 Dry and wet season percentage reduction efficiency of physicochemical characteristics at Blantyre WWTW

Levels of chloride and trace and heavy metals in the effluent, during both dry and wet season, conform to set standards.

However, apart from the effluent TSS levels in the wet season which are less than the set standards, the wet season BOD_5 and the dry season BOD and TSS levels are all higher than the standards. Such high levels pose a pollution threat to receiving waters in Mudi River. The increased levels of nitrate in the dry season effluent, as compared to the influent, calls for further investigation.

Repair of broken down equipment at Blantyre WWTW would most likely improve performance of the treatment plant.

2.3 Soche WWTW

The following is the sequencing of treatment technologies at Soche WWTW: screening, grit channels, primary sedimentation, trickling filters, humus tanks and sand filters (disused).

2.3.1 Screening

A single hand-raked inclined bar screen is provided (Figure 2.4).

Fig. 2.4 Bar screens are followed by parallel constant velocity grit chambers at Soche WWTW. A similar set up is available at Blantyre WWTW

Screen channel	1.3 m wide, 0.65 m max flow depth
Bar gap/thickness	25/10 mm
Through-bar area	0.61 m^2

At a maximum through-bar velocity of 1.0 m/s under maximum (storm) flow conditions, the screen would have a theoretical capacity of 2,160 m^3/hr. This is well in excess of the storm overflow setting.

The screen bar gap at 25 mm is too great and permits excessive amounts of debris to pass through. This causes problems with the filter distributors and with sludge treatment and quality of the final effluent. This is aggravated by the action of raking which tends to push items through the bars.

Screenings are tipped in a nearby area and allowed to dry out and compost. Lime is added to provide some stabilisation. In due course the screenings are buried.

2.3.2 Grit removal

Two no. constant velocity type grit channels (manual grit removal) are provided.

Grit channels	18 m long, 1.8 m wide, 1.0 m max flow depth
Cross-section area	2 x 1.8 = 3.6 m^2 total

The grit channels are generously sized, each having a theoretical maximum capacity of about 1940 m^3/hr. However, they are simple rectangular cross-sections, which are not able to maintain a constant velocity at all flow rates. If benching to trapezoidal or parabolic section were provided, the capacity would be reduced by around one third, albeit with a corresponding improvement in performance.

The grit, as removed, contains some organic matter, but not to an excessive degree. Two to three wheelbarrow loads per day are taken to the same depository site as the screenings and used as a cover material.

2.3.3 Primary sedimentation

The plant has two sets of 2 no. sedimentation tanks. One set has circular inverted cone upward flow tanks. The overflow weirs have V-notch weir plates with scum boards. Manual desludging by hydrostatic head is provided. These tanks are also provided with hand operated rotating surface scum skimming arms.

Dimensions	7.15 m diameter, 1.6 m sidewall depth, 60^0 cone slope
Surface area	2 x 40 = 80 m^2 total
Volume	2 x 147 = 294 m^3 total

The second set of sedimentation tanks also has circular inverted cone tanks. These have plain concrete weirs without weir plates, but with scum baffles and hand operated rotating tubes for scum removal. Desludging is done manually under hydrostatic head.

Dimensions	9.11 m diameter, 1.6 m sidewall depth, 60^0 cone slope
Surface area	2 x 65 = 130 m^2 total
Volume	2 x 276 = 552 m^3 total

Total surface area	210 m^2

At the present estimated dry weather flow, assuming all tanks were in use, and flows split in the correct proportion, the hydraulic surface loading rate would be 29.6 m^3/m^2.d at peak hour dry weather flow. These may be regarded as conventional design loadings, giving, typically, TSS and BOD_5 removal of 67% and 33%, respectively (Carl Bro International, 1995). Analyses of primary settled sewage were not carried out for any of the eight cases in this study. This was outside the scope of this work.

All four tanks are desludged daily. The tanks are emptied and cleaned out annually, using mobile pump units.

2.3.4 Trickling filters

There are two circular filters built under different phases (Figure 2.5).

Fig. 2.5 Trickling filters at Soche WWTW, similar to Blantyre WWTW

Dimensions (original)	30.8 m diameter, 3.75 m media depth
Surface area	745 m^2
Volume	2,794 m^3
Dimensions (extension)	30.5 m diameter, 3.5 m media depth
Surface area	731 m^2
Volume	2,557 m^3 total
Total media volume	5,351 m^3

Each filter is fed from a dosing siphon.

The filter medium at top surface level is 60-80 mm nominal size. It is of gabbro stone. The newer filter has an intermediate ventilation layer with tiles, at approximately half depth.
Three recirculation pumps are provided. These are, however, not always in operational state. Assuming they were always operational and delivering at their original rated output, a recirculation ratio of 1.33:1 would be possible at the present estimated dry weather flow. Theoretically, this would achieve an average BOD_5 in settled effluent of 31 mg/l (Carl Bro International, 1995).

The filter media appears in good condition.

2.3.5 Humus tanks

The plant has four inverted upward flow humus tanks (Figure 2.6). Two are from the original plant, and the other two from the extension. The overflow weirs for the original tanks have v-notch weirs, with no scum baffles. The second pair of humus tanks has plain concrete overflow weirs, with scum baffles and hand operated rotating tubes for scum removal. Desludging is done manually under hydrostatic head for both sets of humus tanks.

Fig. 2.6 Humus tanks at Soche WWTW, similar to Blantyre WWTW

Original tanks

Dimensions	7.3 m diameter, 1.6 m sidewall depth, 60^0 cone slope
Surface area	2 x 42 = 84 m^2 total
Volume	2 x 155 = 310 m^3 total

Extension

Dimensions	9.15 m diameter, 1.6 m sidewall depth, 60^0 cone slope
Surface area	2 x 66 = 132 m^2 total
Volume	2 x 279 = 558 m^3 total

2.3.6 Sand filters

Three sand filters were provided for effluent polishing. The filters are no longer in use. The filters had a graded sand to gravel filter depth of about 0.4 m, and a total bed area of 940 m^2. The units were essentially slow sand filters, but with a backwashing and surface scraping facility.

2.3.7 Operational data for Soche WWTW

The raw material at Soche WWTW is municipal swage. Typical wastewater parameters are BOD_5, COD, and TSS. The treatment target is BOD_5, COD, and TSS reduction.

2.3.7.1 Data collection and analysis

Data was collected and analysed following the procedure outlined in section 2.2.6.1.

Table 2.2 and Figure 2.7 below show the influent and effluent characteristics of the wastewater at Soche WWTW during the dry season and wet season, respectively. Corresponding figures are shown for Malawi effluent standards (MBS, 2005) and World Health Organisation (WHO) guidelines (1996). Table 2.2 also shows the influent and effluent $BOD_{5,}$ COD and TSS levels for Municipal Case 6 in Greece (2003). This is a case similar to Soche WWTW (Avramenko & Kraslawski, 2008).

Table 2.2
Soche works influent and effluent physicochemical characteristics and levels of trace and heavy metal contaminants for the dry season and wet season in mg/l. Comparative data is shown for BOD_5, COD and TSS levels for Municipal Case 6 in Greece (2003).

Parameter	**Cl^-**	**BOD_5**	**COD**	**TSS**	**NO_3^-**	**Cu**	**Ni**	**Cd**	**Cr**	**Pb**
Dry season										
Influent	44±1.0	490±9.8	883.30± 12.5	157±2.32	12.45±2.30	<dl	<dl	<dl	<dl	<dl
Effluent	46.2±2.3	24.82±0.6	353± 4.31	101.65±5.64	9.42±0.77	<dl	<dl	0.002 ±0.001	<dl	<dl
Reduction Efficiency (%)	*-5.0*	*95*	*60.04*	*35*	*24.3*	-	-	-	-	-
Wet season										
Influent	40.51±0.01	760±0.0	907.00± 10.05	40±0.0	33.09±0.0	<dl	<dl	<dl	<dl	<dl
Effluent	39.10±0.00	33.90±2.69	734.90±16.55	8.02±0.02	218.9±10.45	<dl	<dl	<dl	<dl	<dl
Reduction Efficiency (%)	*3.5*	*96*	*20*	*80*	*-562*	-	-	-	-	-
Municipal Case 6 in Greece										
Influent		227	-	355						
Effluent		11	40	16						
Reduction Efficiency (%)		*95*	-	*96*						
Malawi Standard	400	20	60	30	45	1.0	0.15	0.005	0.1	0.05
W.H.O. Guidelines	250	20	60	30	50	2.0	0.02	0.003	0.05	0.01

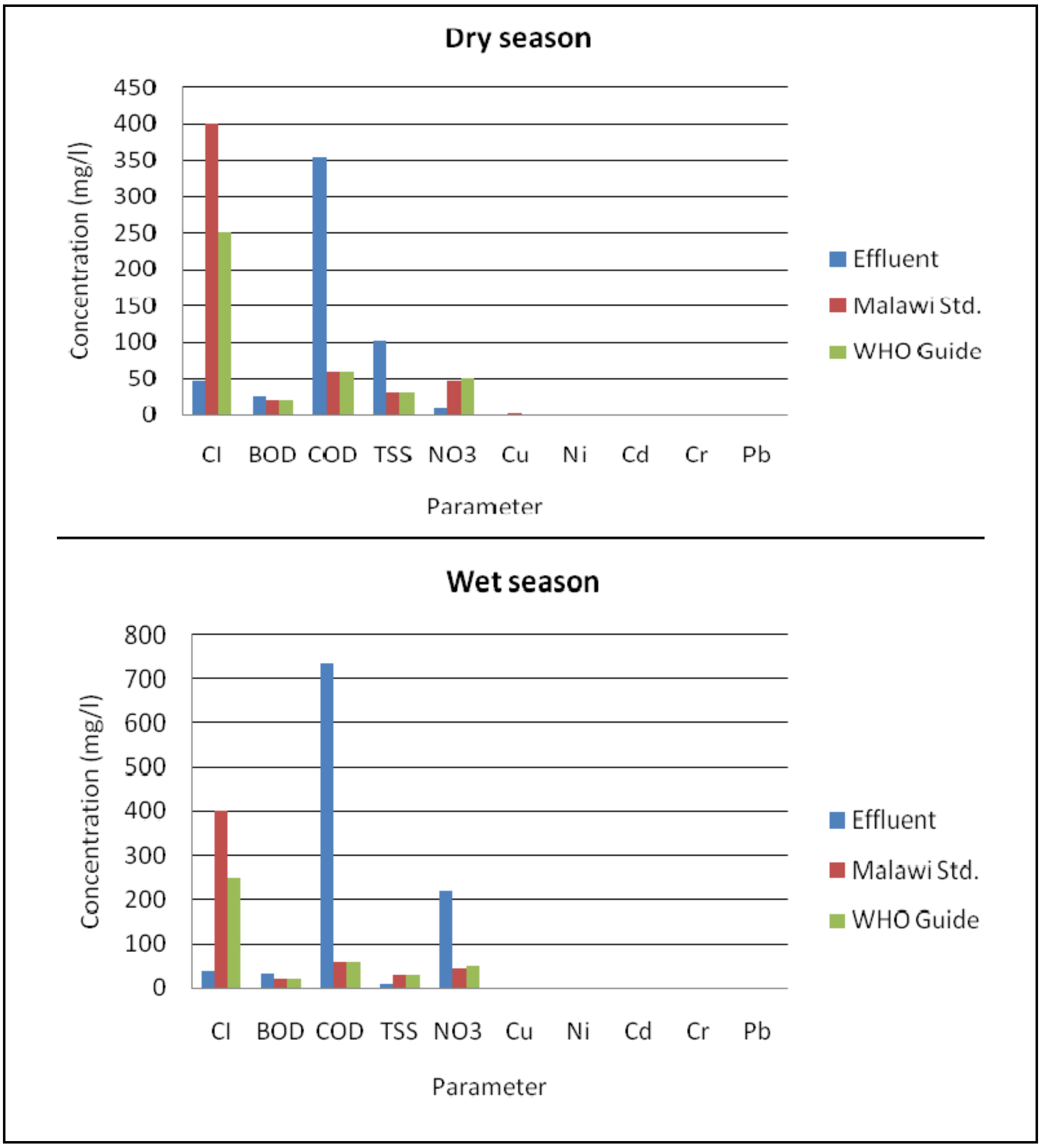


Fig. 2.7 Soche WWTW dry season and wet season effluent characteristics

The BOD_5 and TSS removal efficiency in the dry season was 95% and 35%, respectively. The BOD_5, and TSS removal efficiency in the wet season was 96%, and 80%, respectively (Figure 2.8).

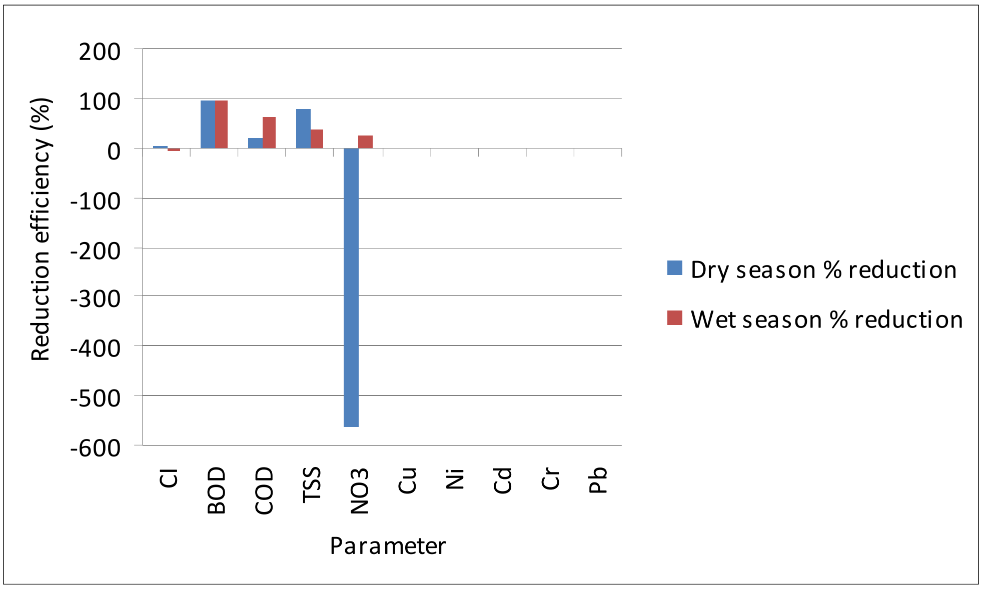


Fig. 2.8 Dry and wet season percentage reduction efficiency of physicochemical characteristics at Soche WWTW

The effluent BOD_5 and TSS levels in the dry season are both above the set standards. However, the effluent TSS level in the wet season is lower than in the dry season, and conforms to the set standards. The effluent BOD_5 level in the wet season is still higher than the standard. These high BOD_5 levels and the high TSS level in the dry season pose a pollution threat to the receiving waters in the Mlambalala River. .

The reason for the rise in the effluent nitrate levels in the dry season calls for further investigation.

Levels of chloride and heavy metals in the effluent, during both dry and wet season, conform to set standards.

Repair of broken down plant and equipment at Soche WWTW as well as proper sizing of screen bar gap would most likely improve performance of the treatment plant.

2.4 Limbe WWTW

The treatment facilities at Limbe WWTW consist of a waste stabilisation pond system.

2.4.1 Preliminary treatment

Preliminary treatment is effected by manually raked screens, constant velocity flow grit channels, and a flow measuring flume.

Screens	19 No. 10 mm x 28 mm bars with a bar gap of 25 mm
Maximum through bar area	0.073 m^2
Constant velocity channels	3 No. 10.8 m x 845 mm wide
Cross sectional area	0.606 m^2

2.4.2 Pond system

The preliminary treatment is followed by four parallel four pond series comprising of receiving ponds, facultative ponds, primary maturation ponds and secondary maturation ponds (Figure 2.9).

The original four ponds form the first series, with twelve lagoons constructed later providing the other three series. The approximate pond dimensions and details are given in Table 2.3.

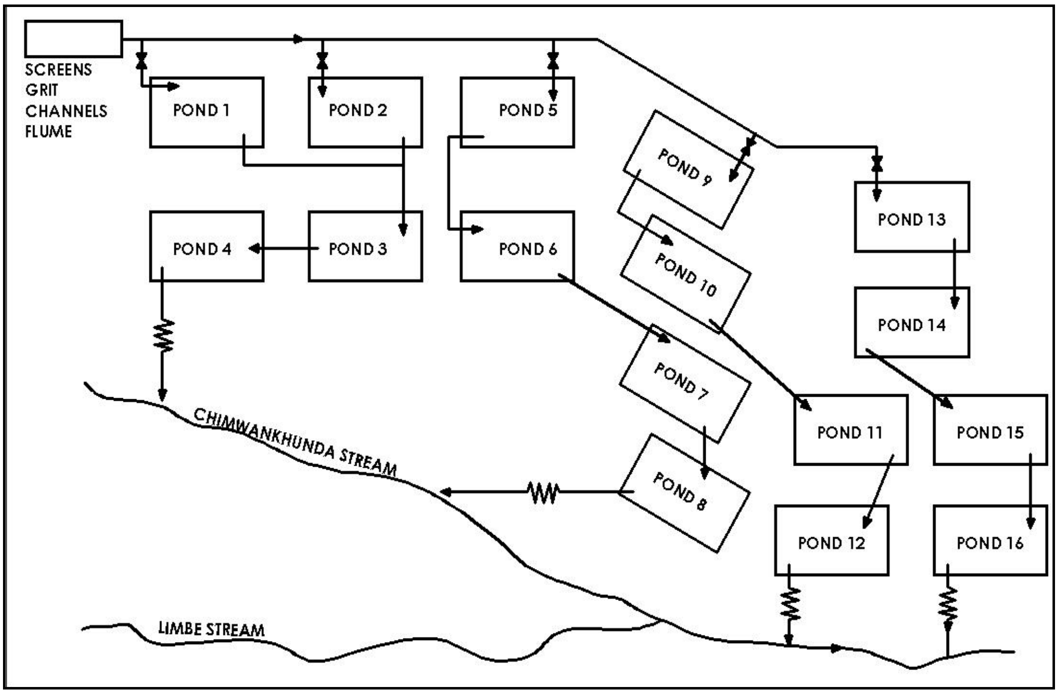


Fig. 2.9 Waste stabilisation pond system at LWWTW; Source: Carl Bro International, 1995

Table 2.3
Approximate operating dimensions

System	Pond	Length (m)	Breadth (m)	Depth (m)	Area (m^2)	Volume (m^3)
1	1	85	45	1.00	3,825	3,825
	2	95	45	1.00	4,275	4,275
	3	105	35	1.00	3,675	3,675
	4	70	40	1.00	2,800	2,800
2	5	100	48	2.00	4,800	9,600
	6	100	48	2.00	4,800	9,600
	7	100	44	1.60	4,400	7,040
	8	90	40	1.60	3,600	5,760
3	9	100	50	2.00	5,000	10,000
	10	100	50	2.00	5,000	10,000
	11	80	45	1.60	3,600	5,760
	12	95	40	1.60	3,800	6,080
4	13	100	50	2.00	5,000	10,000
	14	100	50	2.00	5,000	10,000
	15	80	45	1.60	3,600	5,760
	16	98	35	1.60	3,430	5,488

2.4.3 Operational data for Limbe WWTW

The raw material at Limbe WWTW is municipal sewage. Typical wastewater parameters are BOD_5, COD, and TSS. The treatment target is BOD_5, COD, and TSS reduction.

2.4.3.1 Data collection and analysis

Data was collected and analysed following the procedure outlined in section 2.2.6.1.

Table 2.4 and Figure 2.10 below show the influent and effluent characteristics of the wastewater at Limbe WWTW during the dry season and wet season, respectively. Corresponding figures are shown for Malawi effluent standards (MBS, 2005) and World Health Organisation (WHO) guidelines (1996). Table 3.4 also shows the influent and effluent BOD_5, COD and TSS levels for Municipal Case 1 in Sri Lanka. This is a case similar to Limbe WWTW (Avramenko & Kraslawski, 2008).

Table 2.4
Limbe works influent and effluent physicochemical characteristics and levels of trace and heavy metal contaminants for the dry season and wet season in mg/l. Comparative data is shown for BOD_5, COD and TSS for Municipal Case 1 in Sri Lanka.

Parameter	**Cl^-**	**BOD_5**	**COD**	**TSS**	**NO_3^-**	**Cu**	**Ni**	**Cd**	**Cr**	**Pb**
Dry season										
Influent	53.3±4.3	740±10.1	1296 ± 102.1	220±0.0	5.27±0.03	0.104±0.01	<dl	<dl	<dl	<dl
Effluent	78.0 ±5.1	50.5 ±1.0	777.05 ± 17.67	16.04 ±0.19	17.58 ±0.11	0.096 ±0.0	<dl	0.014 ±0.004	<dl	<dl
Reduction Efficiency (%)	*-43*	*93*	*40*	*93*	*-234*	*7.6*	-	-	-	-
Wet season										
Influent	48.29±1.01	810.5±41.72	821.32 ± 10.06	268.45±3.56	61.68±0.0	<dl	<dl	<dl	<dl	<dl
Effluent	34.10±0.0	63.07 ±4.24	78.56 ±19.20	214.0 ±2.96	30.58 ±10.35	<dl	<dl	<dl	<dl	<dl
Reduction Efficiency (%)	*29*	*92*	*5*	*20*	*50*	-	-	-	-	-
Municipal Case 1 in Sri Lanka										
Influent		152	198	110						
Effluent		26	47	25						
Reduction Efficiency (%)		*83*	*76*	*77*						
Malawi Standard	400	20	60	30	45	1.0	0.15	0.005	0.1	0.05
W.H.O. Guidelines	250	20	60	30	50	2.0	0.02	0.003	0.05	0.01

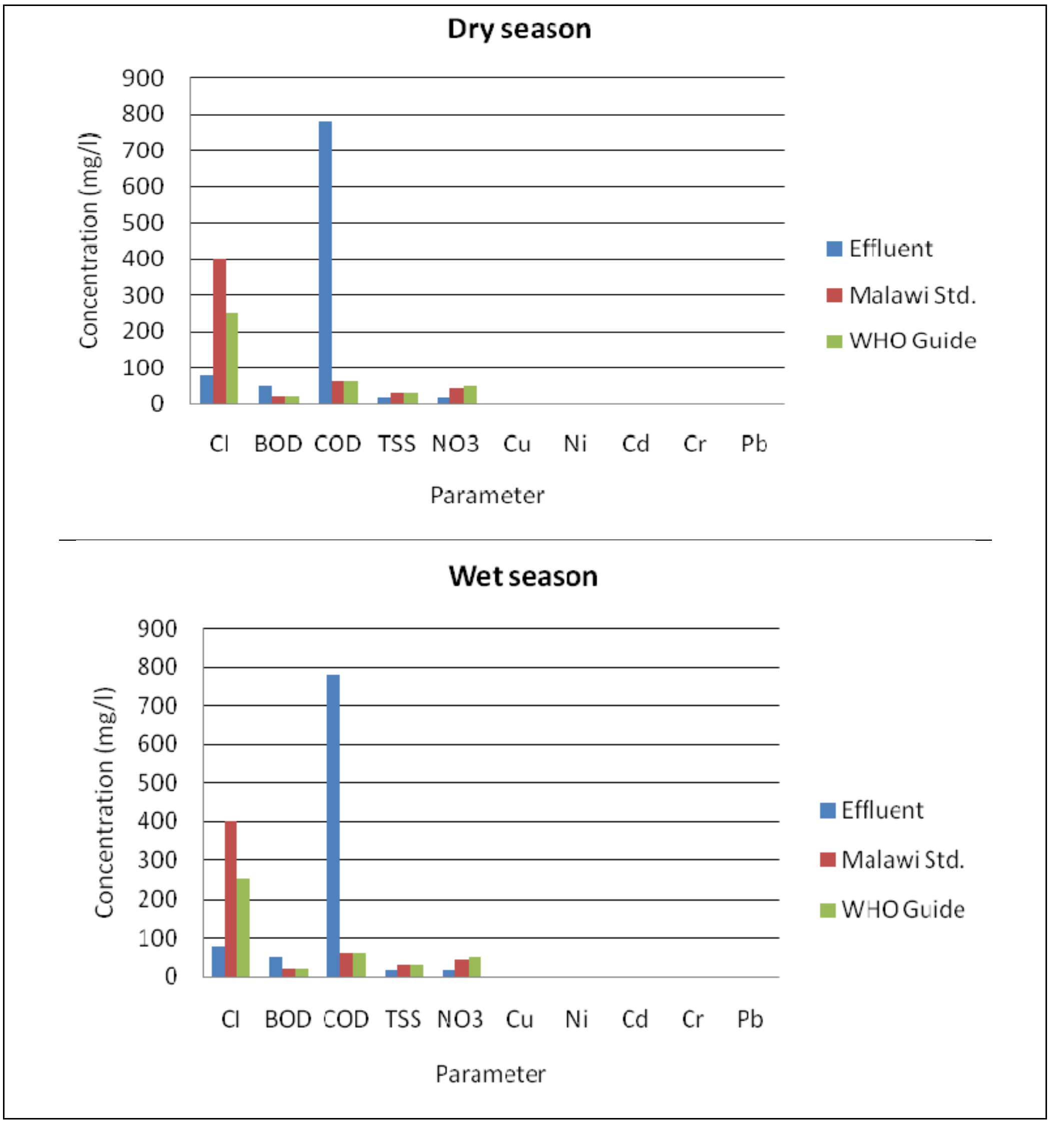


Fig. 2.10 Limbe WWTW dry and wet season effluent characteristics

The BOD_5 and TSS removal efficiency in the dry season was 93% for both parameters. The BOD_5 and TSS removal efficiency in the wet season was 92% and 20%, respectively (Figure 2.11).

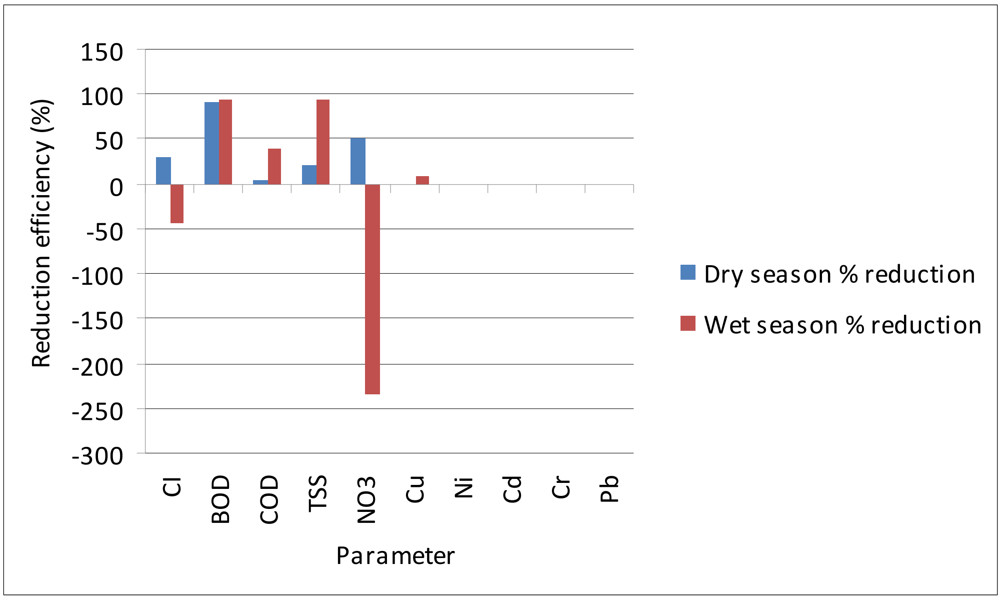


Fig. 2.11 Dry and wet season percentage reduction efficiency of physicochemical characteristics at Limbe WWTW

The mean effluent BOD_5 levels for both the wet and dry season are above the set standards. The effluent TSS level in the wet season is also above the standards. Nitrate levels in both seasons are above the Malawi standard but within the WHO guidelines. The BOD_5 levels and the TSS levels in the wet season are likely to pose a pollution threat to the receiving waters in the Limbe River.

Except for the recovery of Cadmium (0.014 mg/l) in the dry season effluent, levels of chloride and all other heavy metals, during both dry and wet season, conform to set standards. The high level of cadmium calls for further investigation.

Blantyre City Assembly may consider incorporating constructed wetlands at the bottom end of the secondary maturation ponds in order to improve on quality of the effluent. Land belonging to the Assembly is available at the site.

2.5 Wastewater treatment plant at Mapeto David Whitehead and Sons (MDW&S) textile and garments factory

MDW&S textile and garments factory is the largest textile and garments factory in the city of Blantyre. The factory has a wastewater treatment plant with a flow rate of 30 m^3/day. The typical wastewater parameters are BOD_5 and COD. The treatment target is to reduce BOD_5 and COD.

2.5.1 End-of-pipe wastewater treatment technology

The end-of-pipe wastewater treatment technology at MDW&S textile and garments factory uses a screening process, an oxidation ditch, followed by a sedimentation tank (Figure 2.12).

Fig. 2.12 Treatment units at MDW&S with oxidation ditch (L) and sedimentation tank (R) situated downstream of oxidation ditch

The effluent from the plant is discharged by sewer to Blantyre WWTW. The plant at MDW&S textile and garments factory effectively operates as a pre-treatment facility.

2.5.2 Operational data for wastewater treatment plant at MDW&S textile and garments factory

Data was collected and analysed following the procedure outlined in section 2.2.6.1.

Table 2.5 shows the influent and effluent physicochemical characteristics and levels of trace and heavy metal contaminants at the wastewater treatment plant at MDW&S textile and garments factory. Comparative data is shown for BOD_5 and COD levels for Textile Case 4 in Sri Lanka. This is a case similar to the wastewater treatment plant at MDW&S (Avramenko &Kraslawski, 2008).

Table 2.5

Influent and effluent physicochemical characteristics and levels of trace and heavy metal contaminants at MDW&S wastewater treatment plant expressed in mg/l. Comparative data is shown for BOD_5 and COD for Textile Case 4 in Sri Lanka.

Parameter	**Cl^-**	**BOD_5**	**COD**	**TSS**	**NO_3^-**	**Cu**	**Ni**	**Cd**	**Cr**	**Pb**
Dry season										
Influent	11.4± 0.1	1090.0 ± 8.0	5011.5 ± 12.0	208 ± 3.22	17.10 ± 5.20	.369 ± 0.09	0.222 ± 0.0	< dl	< dl	< dl
Effluent	13.5± 0.3	920.76 ± 4.0	4320.73 ± 40.2	80.60 ± 0.17	17.75±2.45	0.224 ± 0.0	< dl	< dl	< dl	< dl
***Reduction Efficiency* (%)**	***-18***	***16***	***14***	***61***	***-3***	***39***	***100***	**-**	**-**	**-**
Wet Season										
Influent	26.90 ± 0.0	860.0 ± 56.57	4666.05 ± 13.06	52.00 ± 0.00	20.52 ± 4.90	0.341 ± 0.0	< dl	< dl	< dl	< dl
Effluent	24.91 ± 0.06	730.05 ± 42.39	2765.02 ± 33.13	40.04 ± 4.40	6.72 ± 0.10	0.546 ± 0.048	< dl	< dl	< dl	< dl
***Reduction efficiency* (%)**	***7***	***15***	***41***	***23***	***67***	***-60***	**-**	**-**	**-**	**-**
Textile Case 4 in Sri Lanka										
Influent		640	2400							
Effluent		90	340							
Reduction Efficiency (%)		***87***	***85***							

BOD_5, COD, and TSS removal efficiency in the dry season was 16%, 14%, and 61%, respectively, and 15%, 41%, and 23%, respectively, in the wet season. Chloride and nitrate levels are relatively insignificant in both the dry season and the wet season.

Levels of trace and heavy metal contaminants in the effluent are below the minimum detectable limit.

2.6 Sewage and sewerage operating costs for Blantyre City Assembly, 2008/2009

Table 2.6 summarises the sewage and sewerage operating costs for Blantyre City Assembly for the period July 2008 to June 2009, in respect of the three municipal wastewater treatment plants.

Table 2.6
Details of sewage treatment and sewerage operating costs for Blantyre City Assembly, 2008/2009

Item of Expenditure	**Cost (MK)**
Wages	5,231,253.00
Alterations, repairs and maintenance	14,113,250.00
Chemical supplies	3,561,100.75
General office expenses	586,850.00
Cleaning materials	231,111.00
Protective clothing	1,842,311.11
General supplies	14,063.99
Printing and Stationery	430,716.48
Tools and equipment	5,680,360.00
Total expenditure	**31,691,016.40**
Total Income	**11,5000.00.00**
Net Rate Charge	**(20,191,016.33)**

With a total volume flow rate of 14,073 m^3/day for the three municipal wastewater treatment plants, and a total operating cost of MK31,691,016.40, the unit treatment cost equals 1 ÷ 14,073 x 31,691,016.40 = MK2,251.96.

With a Euro/Malawi Kwacha exchange rate of €1.00 = MK220 (www.XE.com, accessed 29.7.2009), the unit treatment cost converts to €0.98 per cubic metre of wastewater. This is three times more than the unit treatment cost of €0.33 per cubic metre of wastewater at Municipal Case 6 in Greece (2003). It is recommended that Blantyre City Assembly critically scrutinises their operating costs in order to determine any reductions in cost. In the same vein, the Assembly should re-visit the fees it charges the various industries that it services. In addition, income received from the reception of industrial effluent discharges to cover sewerage and treatment costs should be spent within the pollution control section in order to properly maintain, operate and upgrade the three municipal treatment plants.

Chapter 3

ED-WAVE tool design approach: case of four major wastewater treatment systems in Blantyre

3.1 Introduction

The design of efficient wastewater treatment systems is a complicated task which requires significant engineering experience as well as deep theoretical knowledge by the designers. Usually the task facing engineers is two fold: (1) to determine the levels of treatment that must be achieved and (2) to determine a sequence of methods that can be used to remove or to modify the components found in the wastewater in order to reduce the environmental impact and to meet ecological requirements. Therefore, an information reference system accumulating knowledge in the field of wastewater treatment and water reuse in an easily accessible way would be of great interest to the engineers. This is accomplished in the ED-WAVE tool, an educational tool for training on technologies for efficient water reuse using virtual application sites.

3.2 ED-WAVE tool

The ED-WAVE tool was used for the conceptual design of Blantyre WWTW, Soche WWTW, Limbe WWTW and the wastewater treatment plant at MDW&S textile and garments factory, respectively, in the city of Blantyre. The principles of case-based design and case-based reasoning as described in sections 3.3 and 3.4 below are applied in the ED-WAVE tool. 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) (Figure 3.1) (Althoff et al., 1995; Balakrishnan et al., 2005; Avramenko, 2005; Avramenko and Kraslawski, 2008; Chipofya et al., 2010).

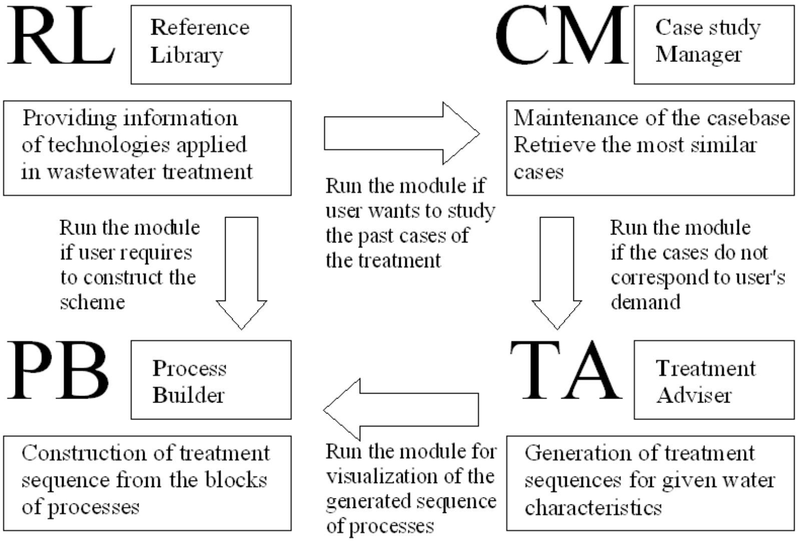


Fig. 3.1 Schematic diagram of the ED-WAVE software structure; Source: Paraskeva et al., 2007

3.3 Case-based design

Case-based design (CBD) is one 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. Case storage 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 (Figure 3.1) (Avramenko & Kraslawski, 2008).

3.4 Case-based reasoning

Case-based problem solving is based on the premise that a design problem solver makes use of experiences (cases) in solving new problems instead of solving every new problem from scratch (Kolonder, 1993). Coyne et al. (1990) classify the case based approach into three activities: *creation, modification*, and *adaptation*. Creation is concerned with incorporating requirements to create a new prototype. Modification is concerned with developing a working design from a particular category of cases. Adaptation is concerned with extending the boundaries of the class of the cases.

Case-based reasoning (CBR) solves new problems by adapting previously successful solutions to similar problems.

A CBR approach can handle incomplete data: it is robust with respect to unknown values because it does not generalize the data. Instead, the approach supports decision making relying on particular experience (Avramenko & Kraslawski, 2008).

3.5 ED-WAVE tool design approach: case of Blantyre WWTW

According to the Case Study Manager in the ED-WAVE tool, a similar case to both the dry season and wet season conditions at Blantyre WWTW has similarities to Municipal Case 6 in Greece (2003). It has 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 3.1. Figures 3.1, 3.2 and 3.4 further illustrate the sequencing according to the Process Builder in the ED-WAVE tool. The influent and effluent characteristics of Municipal Case 6 in Greece are tabulated in Table 2.1.

Table 3.1
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	Percolating filters
5	Chlorination	Facultative lagoon	Activated carbon adsorption	Humus tanks
6	-	Activated carbon adsorption	Ion exchange	Aeration ponds

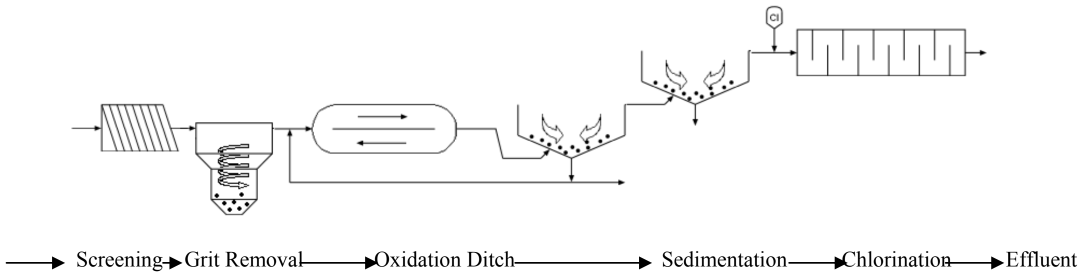


Fig. 3.1 Sequencing of treatment units at Municipal Case 6, Greece, according to the Process Builder

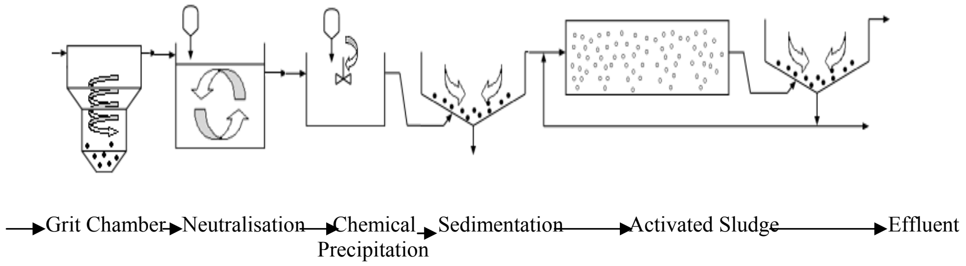


Fig. 3.2 Suggested sequencing of dry season conditions by Treatment Adviser

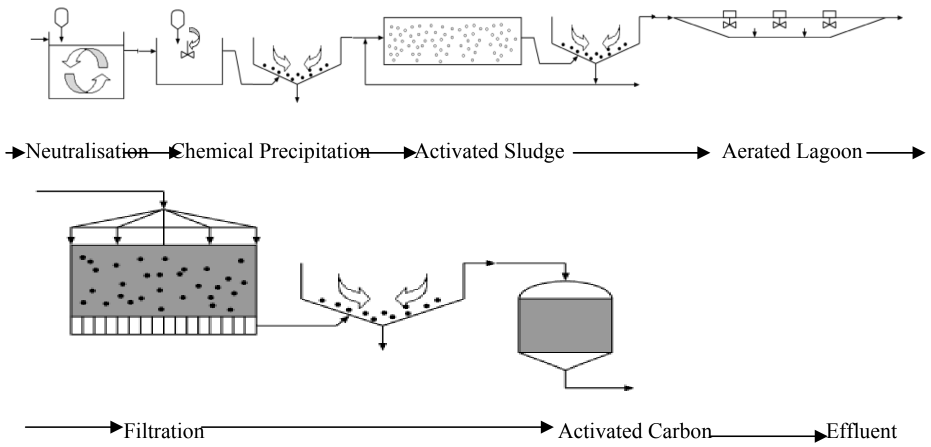


Fig. 3.3 Suggested sequencing of wet season conditions by Treatment Adviser

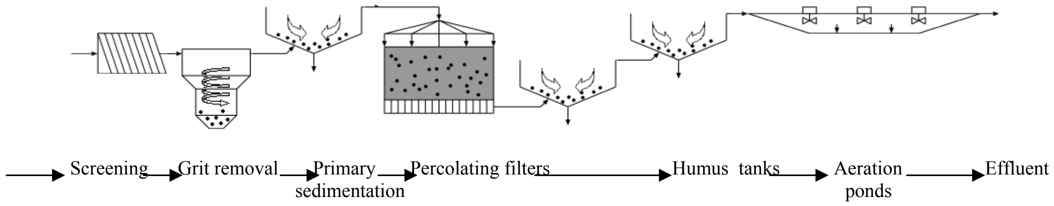


Fig. 3.4 Actual sequencing of treatment units at Blantyre WWTW

3.6 ED-WAVE tool design approach: case of Soche WWTW

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 at 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 3.2. The influent and effluent characteristics of Municipal Case 6 in Greece are tabulated in Table 2.2.

Table 3.2
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 adsorption	Trickling filters
5	Chlorination	Activated carbon adsorption	Ion exchange	Humus tanks
6	-	Ion exchange	-	Sand filters (disused)

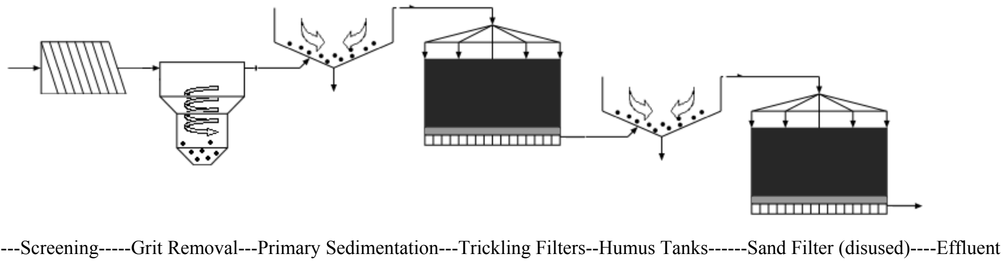


Fig. 3.5 Actual sequencing of treatment units at Soche WWTW according to Process Builder

3.7 ED-WAVE tool design approach: case 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 at Limbe wastewater treatment works has similarities to Municipal Case 1 in Sri Lanka. It has 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 3.3. Figures 3.6, 3.7, and 3.8 further illustrate this sequencing according to the Process Builder in the ED-WAVE tool. The influent and effluent characteristics of Municipal Case 1 in Sri Lanka are tabulated in Table 2.4.

Table 3.3
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	

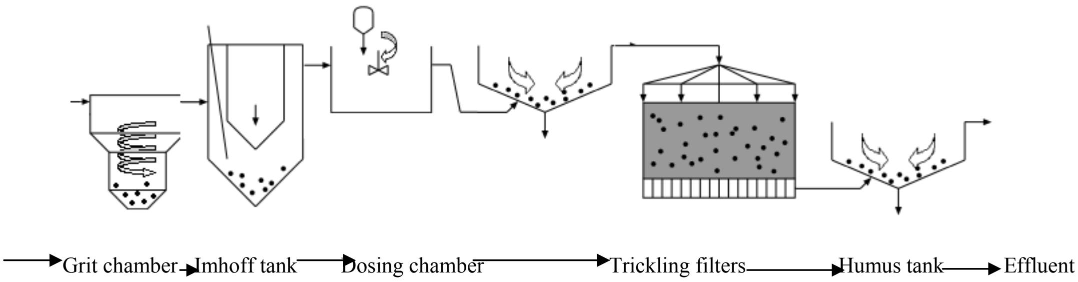


Fig. 3.6 Sequencing of treatment units at Municipal Case 1, Sri Lanka, according to the Process Builder

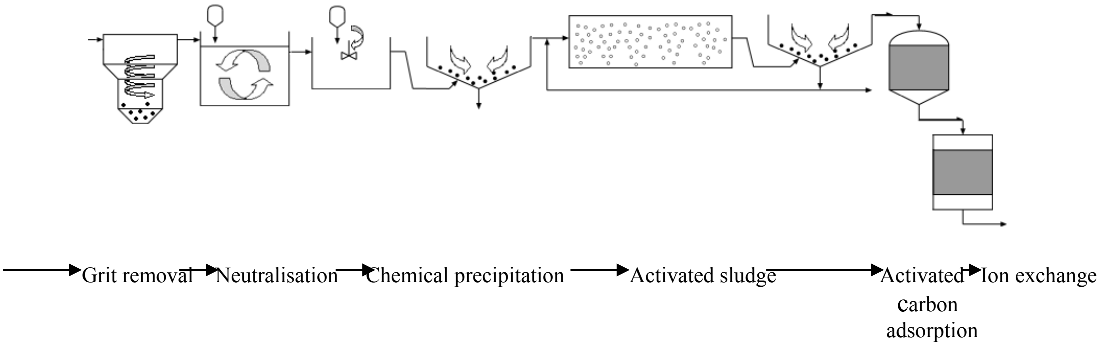


Fig. 3.7 Suggested sequencing of treatment units for dry and wet season conditions at Limbe WWTW

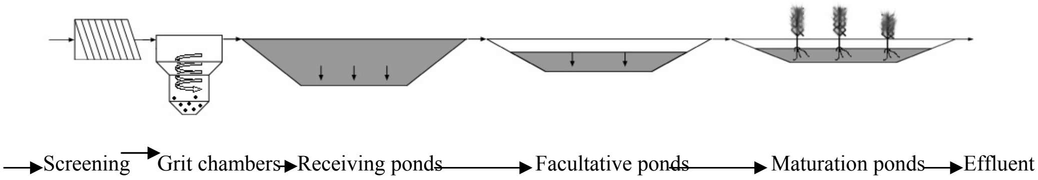


Fig. 3.8 Actual sequencing of treatment units at Limbe WWTW

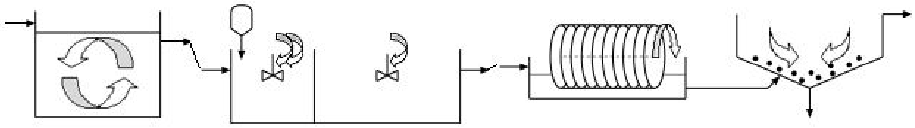
3.8 ED-WAVE tool design approach: case of MDW&S wastewater treatment plant

According to the Case Study Manager in the ED-WAVE tool, a similar case to both the dry season and wet season conditions at MDW&S wastewater treatment plant has similarities to Textile Case 4 in Sri Lanka (2003). This is a textile and garments factory with a flow rate of 100m^3/day. The typical wastewater parameters are BOD_5 and COD. The treatment target is to reduce BOD_5 and COD. The influent and effluent characteristics of Textile Case 4 in Sri Lanka are tabulated in Table 2.5.

The treatment sequence for the plant at Textile Case 4 in Sri Lanka and the suggested sequencing of dry and wet season conditions by Treatment Advisor, and the actual sequencing of treatment units at MDW&S are shown in Table 3.4.

Table 3.4
Comparative sequencing of Treatment Units

Plant/ Step No	Textile Case 4, Sri Lanka	Suggested sequencing of dry and wet season conditions by Treatment Adviser	Actual sequencing at MDW&S
1	Equalisation	Grit removal	Screening
2	Coagulation/ flocculation	Neutralisation	Oxidation ditches
3	Rotating biological contactors	Chemical precipitation	Sedimentation tank
4		Activated sludge	
5		Facultative lagoon	
6		Activated carbon adsorption	



----Neutralisation ⟶ Coagulation/Flocculation ⟶ Rotating Biological Contactor ⟶ Effluent

Fig. 3.9 Sequencing of treatment units at Textile Case 4, Sri Lanka

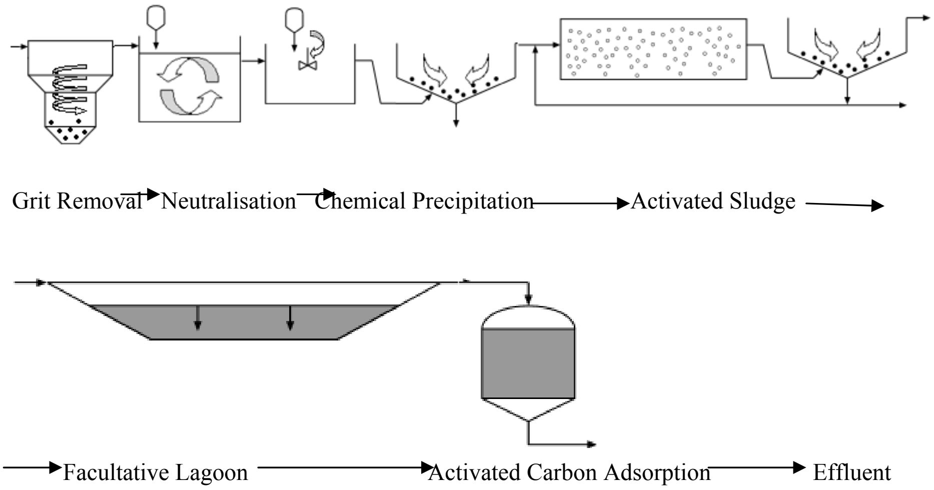


Fig. 3.10 Suggested sequencing of dry and wet season conditions by Treatment Adviser

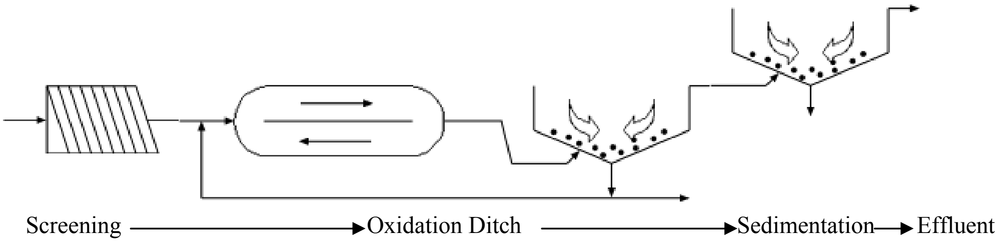


Fig. 3.11 Actual sequencing of treatment units at MDW&S

3.9 Discussion

In the case of Blantyre WWTW, Soche WWTW and Municipal Case 6 in Greece, it is observed that all the three plants use physical, biological, and chemical processes as outlined by Banda (2007). These processes reduce the concentration of pollutants in the wastewater. The processes include screening. Screening is necessary, particularly in developing countries, because of the nature and quantity of solids present in the sewage. These include still born babies, maize cobs and pieces of cloth used for anal cleaning, and domestic garbage (Mara, 1976; Cairncross and Feachem, 1993; Kuyeli, 2007; Kuyeli, 2009; Chipofya et al., 2009, Chipofya et al., 2010). The original plant at Blantyre WWTW comprised a single hand-raked inclined bar screen. It also had 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 not suitable for Malawi because they cannot be repaired readily 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. The grit may cause abrasion of comminutors and impellers of sludge pumps. It may also set hard in sludge hoppers, transmission pipes and in the bottom of digesters calling for more frequent maintenance than normal (Barnes, 1981). Some organic matter is removed along with the grit (Metcalf & Eddy, 2004).

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 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 (Barnes, 1981; Metcalf & Eddy, 2004).

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. The organic matter would otherwise exert an oxygen demand in these receiving waters (Barnes, 1981). 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 electrical/mechanical 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 by the labourers posted at the site. Barnes (1981), however, argues that capital costs for a trickling filter unit are usually higher than those for an activated sludge plant (10 to 50 per cent).

Through this study, case-based design principles in the ED-WAVE tool gave Municipal Case 1 in Sri Lanka as a wastewater treatment plant that has similarities 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 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 (Figure 2.9). The similarities between Municipal Case 1 in Sri Lanka and the actual set up at Limbe include provision of grit chambers for the removal of inorganic grit. The similarities also include provision of 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. 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.

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. Further work is also required to determine 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. This further work may determine whether it is necessary to incorporate constructed wetlands at the bottom end of the maturation ponds in order to improve on quality of effluent.

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. This is achieved through the imhoff tank at the plant in Sri Lanka and chemical precipitation followed by sedimentation as suggested by the dry season and wet season unit treatment processes. The actual set up at Limbe deploys a receiving pond.

Another unit treatment process common to all four set ups in Table 3.4 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. The actual set up at Limbe utilises facultative ponds. Facultative ponds, the technology utilised at Limbe WWTW, are cheap to construct. Waste stabilisation ponds are large shallow basins enclosed by earthen embankments in which wastewater is biologically treated by natural processes involving pond algae and bacteria (Mara, 1976 and 1996).

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, 2004).

With regard to MDW&S wastewater treatment plant, the Treatment Adviser in the ED-WAVE tool gave Textile Case 4 in Sri Lanka as the similar plant. The plant in Sri Lanka has three treatment technologies. The dry and wet season set up for MDW&S works has six unit treatment processes. The actual sequencing for MDW&S works has three unit treatment processes. A similarity between Textile Case 4 in Sri Lanka and the actual set up at MDW&S works is the provision of an aerobic biological treatment process. The Textile Case 4 in Sri Lanka uses rotating biological contactors, while plant at MDW&S uses an oxidation ditch.

The study established that there is a higher rate of removal of BOD_5 and COD at Textile Case 4 in Sri Lanka than at MDW&S. Orhon et al. (2009), however observes that the most commonly implemented aerobic biological treatment unit for a textile and garments wastewater treatment plant is activated sludge. Effective aerobic biological treatment lowers the total COD in the effluent below effluent discharge limitations by removing all biodegradable components. Trickling filters are rarely used aerobic biological treatment alternatives (Orhon et al., 2009).

A sedimentation process is only included in the actual sequencing at MDW&S. This is necessary for the removal of readily settleable matter from the wastewater before the effluent is discharged to the municipal wastewater treatment plant (Barnes, 1981; Metcalf & Eddy, 2004).

3.10 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. The close correlation in the treatment processes at Municipal Case 1 in Sri Lanka, the suggested dry and wet season unit treatment processes, and the actual set up at Limbe WWTW also 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. Finally, incorporation of the aerobic biological treatment process at Textile Case 4 in Sri Lanka and in the suggested sequencing of dry and wet season conditions and the actual sequencing of treatment units at MDW&S confirms the practical use of the ED-WAVE tool in the design of wastewater treatment systems. 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. This design should take into account technical, socio-economic and environmental aspects (Singhrunnosorn and Stenstorm, 2009).

Chapter 4

Technology selection and decision tree making process for appropriate wastewater treatment systems for the city of Blantyre

4.1 Introduction

Appropriate technology suitable for local conditions is one of the key solutions to overcome operational failures of wastewater treatment systems in many developing countries. The suitable option is not only a system providing the best performance at least cost. It is a system that is also sustainable in terms of meeting local social-cultural acceptability, technological and institutional feasibility, economical affordability and environmental acceptability (Mara, 1996; Sarmento, 2001; Ujang & Buckley, 2002).

Van Lier and Lettinga (1999) observe that decision makers in many developing countries choose to apply the conventional wastewater treatment technologies widely utilized in developed nations. They ignore the local contextual conditions and constraints, particularly the affordability, skills and political will of the relevant authorities. Such advanced technologies are not only unaffordable. They are also too complicated to operate and maintain. As a result, a number of treatment plants, or parts thereof, constructed in developing countries have been abandoned due to the failure to provide necessary operation and maintenance. This is the case with the extensions to the screening and grit removal plant at Blantyre WWTW. This plant comprised a rotary mechanically-raked bar screen, aerated spiral flow type grit channel with traveling bridge mounted de-gritter and de-scummer (section 2.2.1). The screening and grit removal facilities have been out of use for many years.

4.2 Concept and scope of appropriate wastewater treatment systems

Factors determining appropriate wastewater treatment technologies differ from place to place according to the unique local urban contexts. Contextual differences exist even in different parts of the same city. Apart from the technical factors, there are certain factors that define the reliability and suitability aspects of technologies These include financial, institutional and environmental reliability and suitability (Ujang & Buckley, 2002). The suitable option is, therefore, not only a system providing the best performance at least cost. It should also be suitable in terms of local needs that relate to social-cultural acceptability, technological and institutional feasibility, economical affordability and environmental acceptability (Mara, 1996; Sarmento, 2001; Ujang & Buckley, 2002).

Traditionally, the process of evaluation and selection is one of the most challenging phases of treatment plant design. The process should achieve the most appropriate treatment system, capable of meeting standards and requirements. These factors are then reformulated into criteria, which are associated with engineering rules in designing, constructing and operating the system i.e. influent wastewater characteristics (flow and quality), efficiency, land requirement, and process reliability (Metcalf & Eddy 2004).

4.3 Selection criteria of appropriate wastewater treatment systems

The following seven elements summarise the technical, socio-economic and environmental aspects of the appropriate systems (Figure 4.1).

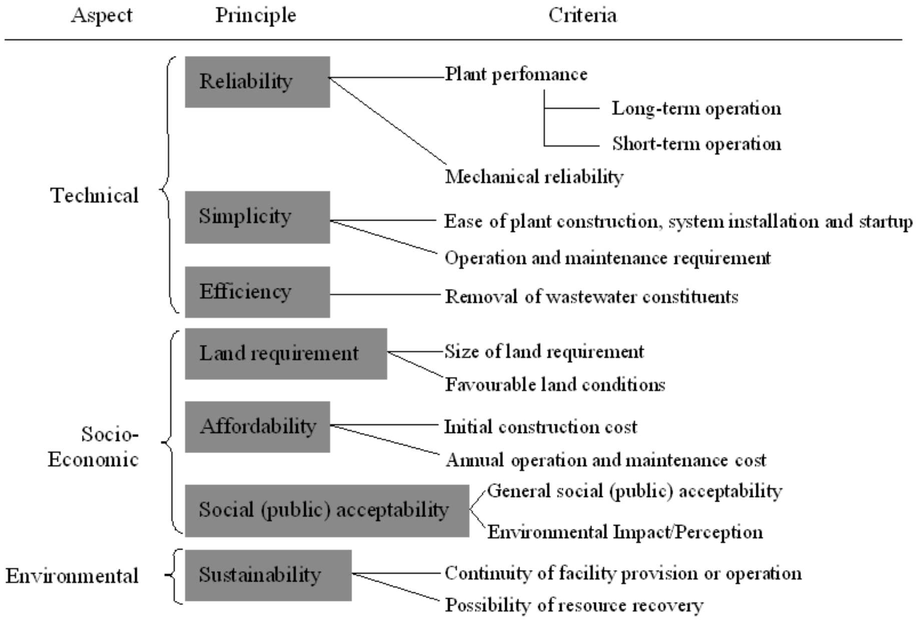


Fig. 4.1 Summary of the conceptual variables determining the selection of appropriate wastewater treatment systems for developing countries; Source: Singhrunnusorn and Stenstrom, (2009)

4.4 Technical aspects

4.4.1 Reliability

Reliability of the system is defined as the possibility of achieving adequate performance for a specific period of time under specific conditions (Von Sperling and Oliveira, 2007). Reliability of the treatment system can be assessed by means of: (1) the variability of treatment effectiveness under normal and emergency operation, (2) the probability of mechanical failures, and (3) the impacts of failures upon effluent quality (Eisenberg et al., 2001). Measuring the variation of product quality reflects the robustness and the way the process responds to changes in wastewater characteristics (Eisenberg et al., 2001; Metcalf & Eddy 2004).

4.4.2 Simplicity

Simplicity of wastewater treatment is one of the most crucial attributes in the selection process of the treatment systems in developing countries. In countries where skilled labour is cheap and available, the reduced construction costs can be achieved with self-help labour (Choguill, 1996). However, lack of skilled workers presents a major constraint when decision makers choose sophisticated treatment systems in remote areas. Operational and maintenance simplicity should be a prime concern, since simplicity could determine the long term operating success of the system.

4.4.3 Efficiency

Wastewater must be treated to the extent that the final water quality complies with regulatory requirements. Most conventional wastewater treatment processes have been designed primarily to remove the suspended solids and dissolved organic constituents (Parr et al., 1999). BOD_5 and TSS are the key process quality control parameters in wastewater treatment (Barnes, 1981; Metcalf & Eddy, 2004).

4.5 Socio-economic aspects

4.5.1 Land requirement

The availability of land is another constraint determining the choice of wastewater treatment systems. In most cases, space sufficiency means not only the space to accommodate the size of the present facilities, but also the possibility for future expansion. Since most wastewater treatment systems are located outdoors, they may cause negative environmental impacts, particularly odour, on the surrounding residences. Therefore system site and plot size should be sufficient to provide a buffer to minimise the visual and physical impacts. Under this criterion, land properties or geo-morphology e.g. topography, soil conditions, and level of groundwater table, are also important factors determining the technical feasibility of construction and maintenance of a particular system.

4.5.2 Affordability

The financial aspect considers not only the initial cost for construction and installation, but also the ability of the local community to pay for the continuing operation and maintenance costs. System design with “affordability” in mind must include the selection of a technology that users are able to pay for. Treatment cost must reflect the level of household income and expenses (Sarmento, 2001). In the context of developing countries, ability to pay is an important issue. This, in turn, determines the type of wastewater treatment to be deployed.

4.5.3 Social (public) acceptability

Social norms and traditions are also important in the designing of a treatment system which aims to meet local needs and be sustainable. Some knowledge and attitudes to environmental issues can also influence perceptions of people, their awareness and susceptibility to any development project (Karbemattern et al., 1982). Social acceptance will depend on people's experiences, social background, and secular knowledge (Pickford, 1995). In addition, people may also have concern about environmental nuisances (Tsagarakis et al., 2001). Systems located close to community and sensitive ecosystems should have minimal odour and visual impacts.

4.6 Environmental Aspects

4.6.1 Sustainability

Sustainability relates to the continuity of operation and the environmental sustainability. For the continuity of the project, it needs to be financially and operationally self-sufficient. The treatment system should be affordable and meet the needs of the local community. It should be such that the local community can maintain the system. The aspect about environmental sustainability relates to the survival of the environment itself. The selected technology applicable for the system must have the least adverse environmental effects. It should be able to recover renewable resources from the treatment systems, such as being able to reuse treated wastewater for irrigation, recharge groundwater, produce biogas, and recycle organic matter. In developing countries, treated wastewater and products from the treatment processes are considered as resources. The water with nutrient content, in particular, is very useful for agriculture activities provided that the effluent is treated properly (Pickford 1995; Parr et al., 1999). Recycled material such as biosolids can be utilised as a fertilizer or soil conditioner for most agricultural soils.

4.7 Decision support methods

Decision support techniques are rational processes/synthetic procedures for applying critical thinking to information, data, and experience in order to make a balanced decision when the choice between alternatives is unclear. They provide organised ways of applying critical thinking skills developed around accumulating answers to questions about the problem. Steps include clarifying purpose, evaluating alternatives, assessing risks and benefits, and making a decision.

Depending on the type of information used and way of achieving result (decision-making), the design supporting methods can be distinguished on three major approaches: algorithmic, knowledge-based inductive reasoning, and case-based reasoning (Negnevitsky, 2002; Avramenko and Kraslawski, 2008).

4.7.1 Algorithmic approach

The algorithmic design approach views the design process as the execution of an effective domain-specific procedure that yields a satisfying design solution in a finite number of steps. The main premise of this approach is that the initial requirements are well defined and there are precisely defined criteria for determining whether or not an algorithm meets the requirements.

Algorithmic approach is the reasoning strategy which is guaranteed to find the solution to whatever the problem is, if there is such a solution (Negnevitsky, 2002; Avramenko and Kraslawski, 2008).

4.7.2 Knowledge-based inductive reasoning approach

This approach to decision support is based on capturing knowledge of a certain domain and using it to solve problems. The design is considered as a problem-solving process of searching through a state-space, from initial problem state to the goal state (Althoff, et al., 1995; Avramenko and Kraslawski, 2008).

4.7.3 Case-based reasoning approach

Case-based problem solving is based on the premise that a design problem solver makes use of experiences (cases) in solving new problems instead of solving every new problem from scratch (Kolonder, 1993). Coyne et al. (1990) classify the case-based approach into three activities: creation, modification, and adaptation. Creation is concerned with incorporating requirements to create a new prototype. Modification is concerned with developing a working design from a particular category of cases. Adaptation is concerned with extending the boundaries of the class of the cases.

Case-based reasoning (CBR) solves new problems by adapting previously successful solutions to similar problems.

A CBR approach can handle incomplete data: it is robust with respect to unknown values because it does not generalize the data. Instead, the approach supports decision making relying on particular experience (Avramenko & Kraslawski, 2008).

4.8 Treatment Adviser and Decision Tree making process

The Treatment Adviser in the ED-WAVE tool 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 (Balakrishnan, et al., 2005). This is based on the algorithm of selection of the proper wastewater treatment method based on previously constructed rules represented as a decision tree.

A decision tree (or tree diagram) is a map of the reasoning process (Negnevitsky, 2002). The tree is a graph or model of decisions and their possible consequences. It includes 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 www.mindtools.com/dectree.html (16.7.2009). A decision tree 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. Decision Trees are useful tools for helping a designer to choose between several courses of action."

"They provide a highly effective structure within which the designer can explore options, and investigate the possible outcomes of choosing those options. Decision Trees also help to form a balanced picture of the risks and rewards associated with each possible course of action (www.mindtools.com/dectree.html accessed 16.07.2009). The process of selection of a treatment method from a decision tree is illustrated in Figsures 4.2, 4.3, and 4.4 where part of a decision tree for selection of primary, secondary and advanced treatment types, respectively, are presented. In each type of treatment, each treatment level is considered, and after successfully passing all decision trees, the final treatment sequence is considered.

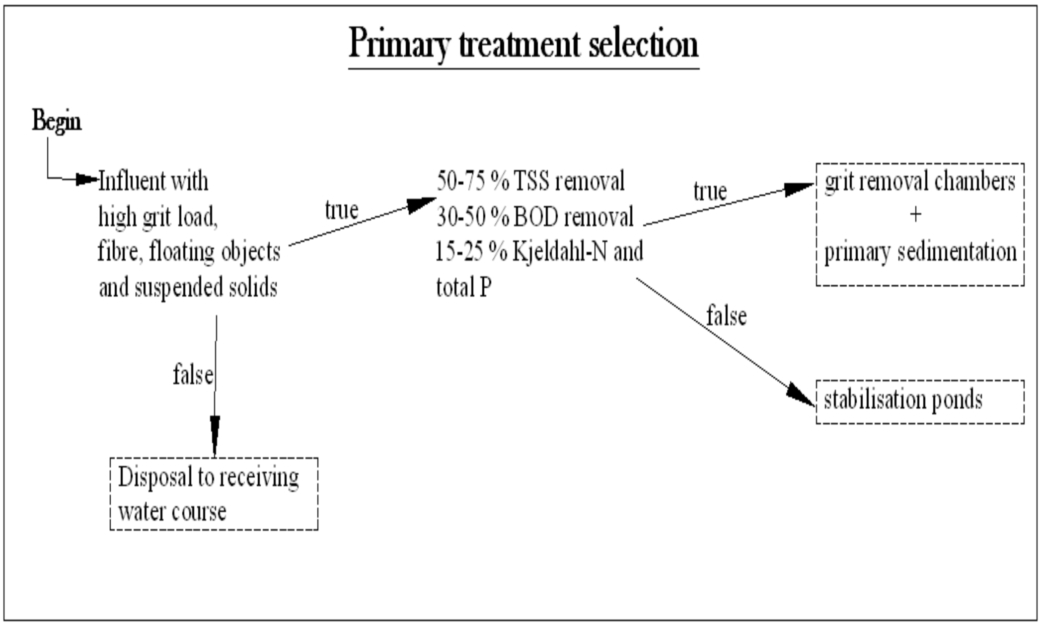


Fig. 4.2 Decision tree for primary treatment selection based on algorithmic and knowledge-based inductive reasoning approaches

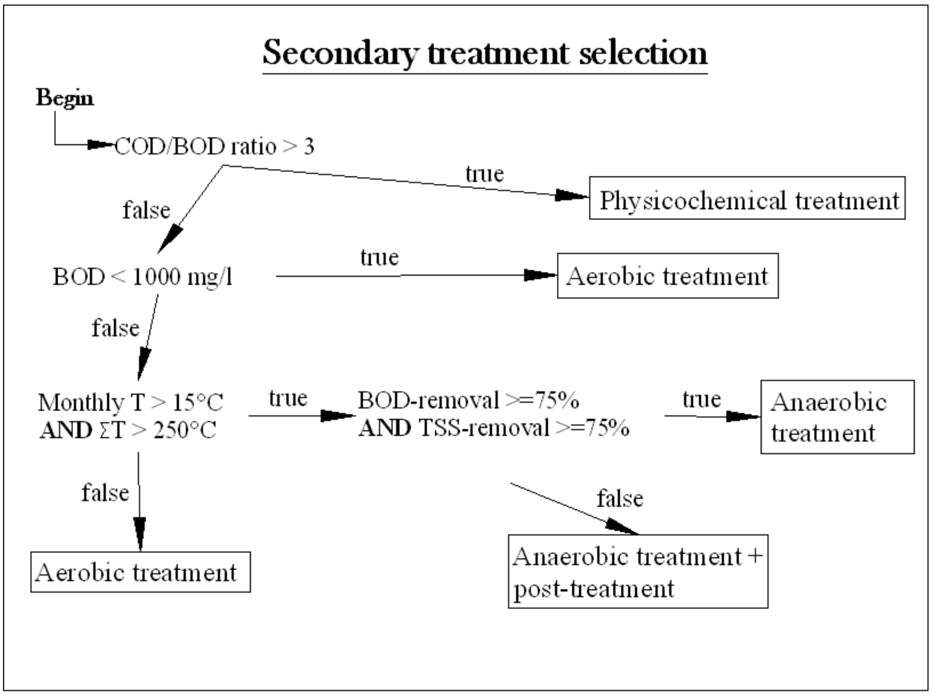


Fig. 4.3 Decision tree for secondary treatment selection based on algorithmic and knowledge-based inductive reasoning approaches

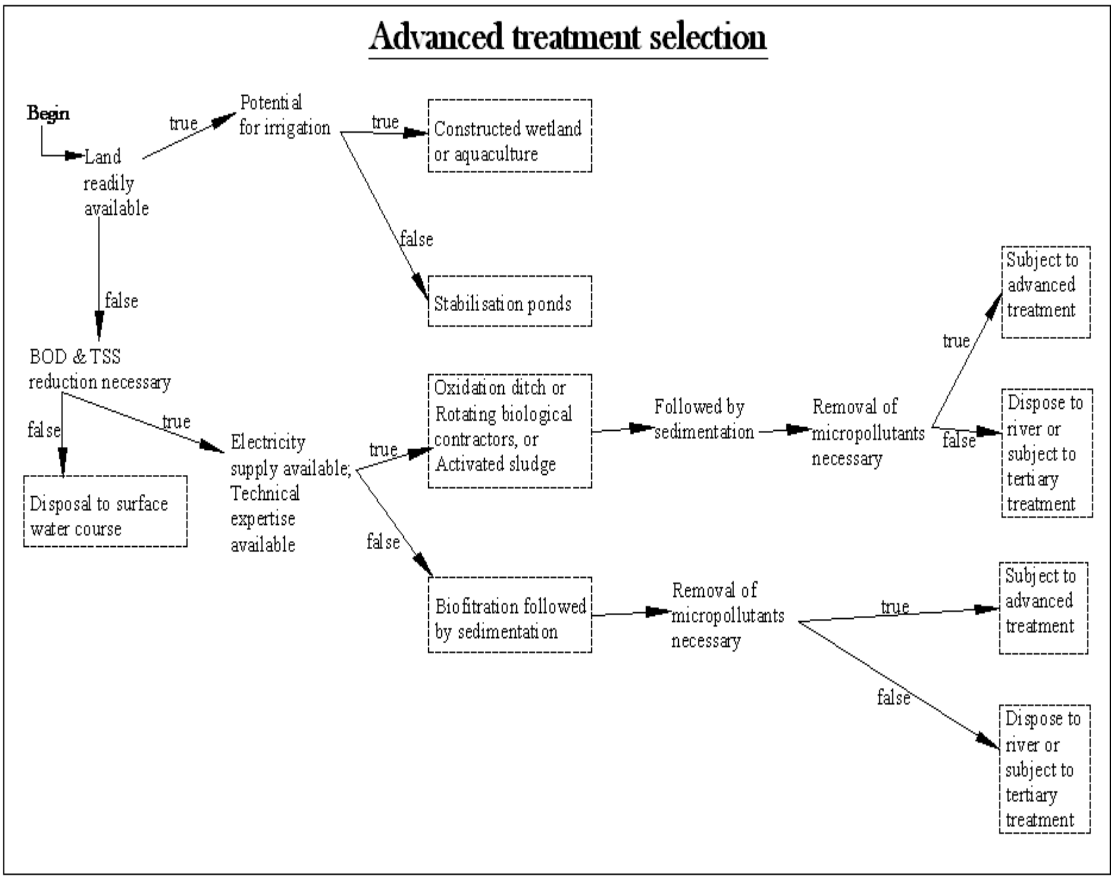


Fig. 4.4 Decision tree for advanced treatment selection based on knowledge-based inductive reasoning approaches

4.9 Application of the decision tree for conceptual design and evaluation for wastewater treatment in Blantyre, Malawi

The engineer in Malawi would think about decision tree making in the context of wastewater treatment. The aim would be to come up with a sequence of wastewater treatment processes that will treat a particular wastewater. The treatment process should produce an effluent that conforms to the required standards in terms of BOD_5, COD, and TSS. This is a legal requirement. The engineer is therefore obliged to ensure that the effluent has minimal impact on the environment and that it meets ecological requirements (Malawi Government, 2005 and 2008).

The potential benefit of the scheme is the conformity of the effluent to national standards (MBS, 2005).

The basic decision will be based on the resources available at hand. It will also be based on the technical expertise available for an effective operation and maintenance programme (http://en.wilkipedia.org/wilki/Decision_tree, 16.07.2009).

According to Singhrunnusorn and Stenstrom (2009), there are seven elements that are critical for the technical selection of a wastewater treatment system in developing countries. These are reliability, simplicity, efficiency, land requirement, affordability, social acceptability and sustainability. These elements integrate social, economic, and environmental concerns necessary to be addressed in evaluating appropriate system alternatives. These are some of the values that have to be questioned in the decision tree making process.

According to results of a survey conducted in Thailand by Singhrunnusorn and Stenstrom (2009), reliability, affordability and efficiency are amongst the most important elements, followed by sustainability and social acceptability. Land requirement and simplicity are low in priority with relatively inferior weighting.

A decision tree would be constructed after an analysis of the above factors (Figures 4.4 and 4.5).

Blantyre WWTW, Limbe WWTW, Soche WWTW, and the wastewater treatment plant at Mapeto David Whitehead and Sons textile and garments factory would, in theory, have resulted from the decision tree as illustrated in Figure 4.5.

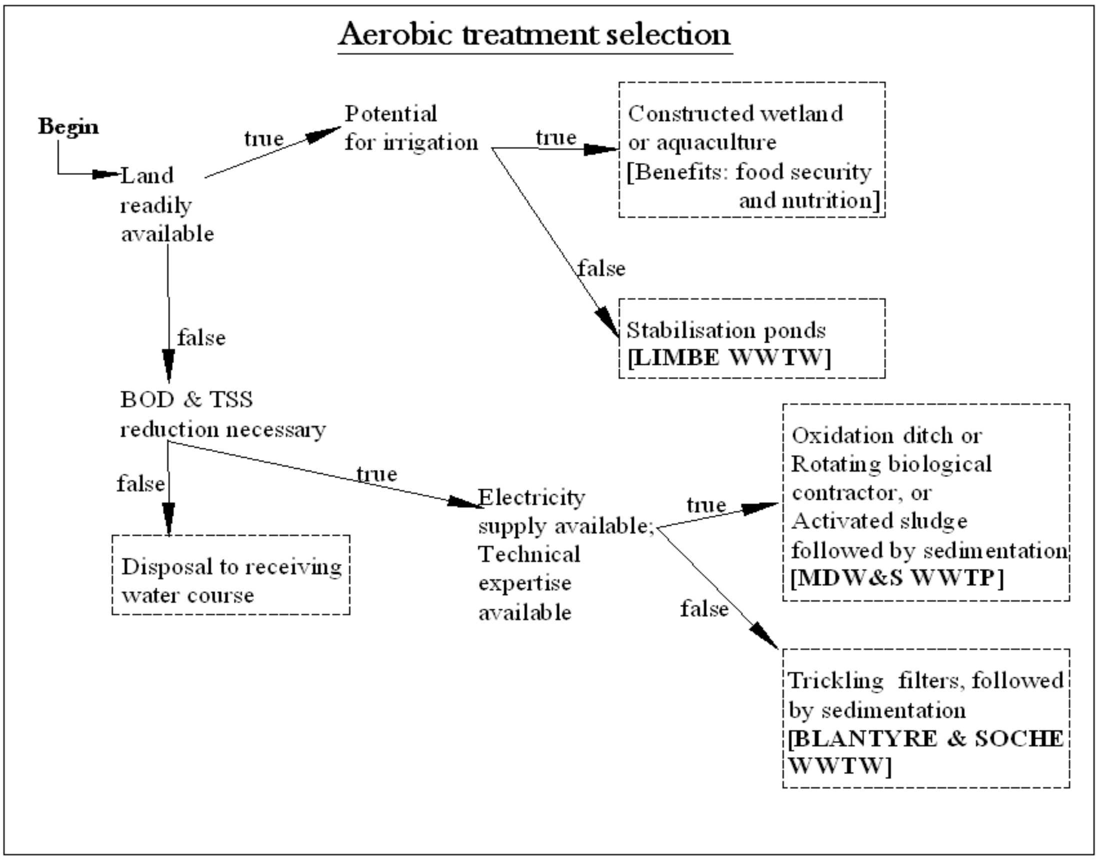


Fig. 4.5 Decision tree for selection of types of aerobic biological treatment based on knowledge-based inductive reasoning approaches

From the above decision tree, it is observed that key elements for the selection of a wastewater treatment system in the city of Blantyre, Malawi, are land availability, availability of reliable electricity supply, and availability of technical expertise for an effective operation and maintenance programme.

Free software for drawing decision trees can be downloaded from http://www.smartdraw.com (16.07.2009). Decision trees may also be drawn using the AutoCAD software.

4.10 Conclusion

Chapter 5 observes that appropriate technology suitable for local conditions is one of the key solutions to overcome operational failure of wastewater treatment systems in many developing countries. The suitable option is not only a system that provides the best performance at least cost. The system should also be sustainable in terms of meeting local needs with regard to social-cultural acceptability, technological and institutional feasibility, economical affordability, and environmental acceptability. The chapter further discusses the concept and scope of appropriate wastewater treatment systems, and the selection criteria of appropriate wastewater treatment systems.

The chapter finally goes through decision support methods and the decision tree making process for technology selection and looks at the application of the decision tree in the conceptual design and evaluation for wastewater treatment in Malawi.

Summary

The results of this work can be divided into four parts:

1. *Need to regulate wastewater treatment in Malawi.*
   The need for wastewater treatment in Malawi is underscored by the existing policy guidelines, institutional arrangements and regulatory framework. 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.
2. *Operation of wastewater treatment systems in the city of Blantyre.*
   The city of Blantyre is serviced by three main municipal wastewater treatment works, namely: Blantyre WWTW, Soche WWTW and Limbe WWTW. Blantyre and Soche WWTW are both conventional wastewater treatment plants. The treatment plant at Limbe WWTW consist of a waste stabilisation pond system. The end-of-pipe wastewater treatment technology at MDW&S textile and garments factory uses a screening process, an oxidation ditch, followed by a sedimentation tank.
3. *ED-WAVE tool design approach of four major wastewater treatment systems in Blantyre.*
   Evaluation of the eight cases in this study confirms the practical use of the ED-WAVE tool in the design of wastewater treatment systems. 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. This local situation should take into account technical, socio-economic and environmental aspects
4. *Technology selection and decision tree making process for appropriate wastewater treatment systems for the city of Blantyre.*
   The following seven elements summarise the technical, socio-economic, and environmental aspects required in the technology selection process of appropriate wastewater treatment systems: **Technical –** Reliability, Simplicity and Efficiency; **Socio-economic –** Land requirement, Affordability and Social (public) acceptability; **Environmental –** Sustainability.

   Based on resources and technical expertise available for an effective operations and maintenance programme, a decision tree for selection of types of aerobic biological treatment for wastewater treatment systems in the city of Blantyre was developed.

Previously published studies on this subject excluded policy and regulatory framework. They also excluded trace and heavy metal contaminants. These studies only included European Member States and South Asia, South-East Asia and China. This study focuses on Malawi, in sub-Sahara Africa. It brings together policy, science and practice in the context of wastewater treatment. The study also includes trace and heavy metal contaminants in the wastewater.

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Appendices