Four Wastewater Treatment Methods Evaluated from a Sustainability Perspective in the Limbe Urban Municipality Cameroon (Central Africa)

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Abstract

Aggravated by rapid population growth, urbanization, and industrialization and most recently by climate change events, the availability of water especially in the third world is reaching critical proportions. This is aggravated by the non treatment of wastewater (sewage) and discharged of untreated wastewater into water bodies.

The study focused on identifying and reviewing four wastewater treatment methods from a sustainability perspective; waste stabilization pond, constructed wetland, up-flow anaerobic sludge blanket reactor and sedimentation/thickening tank systems suitable for the Limbe Urban Municipality (LUM) of Cameroon in Central West Africa with an estimated population of 120,000 inhabitants and experiencing 4.7 per cent annual growth rate.

The attractiveness of these four methods stems from their apparent energy efficiency, simplicity, robustness, low cost effectiveness in situations where as in the LUM, there are huge tracts of available land, warm temperatures, and their capacity to promote effluent re-use opportunities for various sectors.

Issues of sustainability of the water supply and wastewater treatment systems, untreated sewage, and their contribution to escalating environmental and public health impacts in LUM (Cameroon) were critically evaluated and discussed with the aid of Kärrman (2000) framework approach that employs different sets of sustainability criteria (Environmental, Health and Hygiene, and Functional), sub-criteria and indicators.

Results obtained reveal that water and wastewater treatment systems in LUM do not operate or conforms to sustainability perspectives. Inhabitants do not still have access to clean drinking water (an approximate 45 per cent) especially in the dry periods of the year, low sanitation coverage (with the tradition of sewage treatment in septic tanks and pit latrines), rising yearly public health impacts associated with water-borne (cholera, dysentery, malaria, typhoid fever and diarrhea) infections and 6 deaths reported in LUM.

These leading problems are directly or indirectly linked to consumption of contaminated water or foods in different communities such as Mile II, Isokolo, Bonadikombo (Mile four) etc, and New Town areas and flood prone zones in the Limbe urban municipality.

Key words: Environmental, Water, Wastewater, Sustainability, Limbe municipality, Cameroon, Management and Sanitation.
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**Abbreviations**

GOC – Government of Cameroon  
LUM – Limbe Urban Municipality  
UNICEF - United Nations Children’s Fund  
UNEP – United Nations Environment Programme  
WCED - The World Commission on Environment and Development  
CDC - Cameroon Development Corporation

BOD – Biological oxygen demand  
WHO – World Health Organization  
JMP – Joint Monitoring Programme
1. Introduction

Mara (2004) defined wastewater as the water produced by households, industries, commercial centers (after use), and/or from storm-water run-offs (with variable materials mixed), that is ultimately discharged into surface water bodies or infiltrate back into the ground. Worldwide its management is problematic; notwithstanding its increasing recognition as a valuable and reliable resource to meet demand for water demands and other purposes (UNEP 2010).

Despite the development of numerous sustainable wastewater management strategies, UNEP (2010) estimated that about 80 per cent of untreated wastewater is discharged into water bodies (i.e. streams, lakes, oceans etc) in developing countries. This is accelerating water pollution, which is globally threatening environmental and public health impacts, food security, as well as water scarcity.

UN-Water (2006) emphasized that, access to safe drinking water and sanitation are both basic human right obligations. They are significant to achieving gender equality, sustainable development and poverty alleviation. In 2004, about 1.1 billion people (18 per cent) and some 2.6 billion (40 per cent) of the world’s population lacked access to safe drinking water and improved sanitation services. This indicates the lack or break in connection between public sewer, septic system and/or access to a well-placed and well-designed private storage facilities such as laterines.

“Sustainability” challenges us to think widely and into the future. Although it has been widely interpreted by many scholars, the WCED (1987) quoted from “The Brutllands Report defined sustainability as “development that meet the needs of present generation without compromising the ability of future generations to meet their own desires” (Palme and Tillman 2007). This provides a useful framework to evaluate present waste treatment methods within a reality of escalating urban population, urbanization, industrialization and climate change effects (Volkman 2003).

In Sweden for instance, various approaches and methods have been used to evaluate the sustainability of different urban water and wastewater treatment systems. Grönlund (2004), exemplify the various methods used to evaluate wastewater management systems for the “conventional treatment of urine separation and liquid composting using Life Cycle Assessment in three Swedish municipalities” (by Bengtsson et al., 1997); municipal wastewater treatment and electricity generation by digested sewage sludge using EMergy analysis (by Björklund et al., 2001); and the
development of a framework for sustainable urban water management” using system perspectives to (by Hellström et al., 2000).

The purpose of this study is to evaluate and raise awareness on the sustainability of the water supply and wastewater treatment systems in the LUM.

The urban and sub-urban settlements in Cameroon and the Limbe urban municipality are facing increasing environmental and public health concerns associated with the consumption of contaminated water.

Given the lack of large scale or modern wastewater treatment facilities (to handle domestic, industrial and commercial sewage as well as stormwater run-offs) in LUM by Awum et al. (2001) the following objectives will be appropriate for investigation in this research.

1.1 Objectives:

The objectives of this research are, to:

- Identify and describe the types, sources and constituents in wastewater produced within the Limbe Urban municipality;
- Examine various strategies for the collection and disposal of wastewater in the Limbe Urban municipality;
- Suggest and describe the different wastewater treatment methods relevant to the Limbe Urban municipality;
- Use sustainability criteria and indicators e.g. the framework proposed by Kärrman (2000) to assess and comparatively discuss the sustainability of the water supply and wastewater treatment systems in LUM.

2. Methodology

- Desk Research-textbooks, scientific reports, articles and web-pages
- Case studies of application and improvement on this concept and related to LUM.
- Questionnaires) were used to collect data from field experts of the “Camerounaise des Eaux (CdE) office, and the Hygiene and Sanitation department of the Limbe City Council (LCC)” and the department of water works in Östersund Kommun, Sweden.
3. An Overview of Cameroon

Cameroon is located on the West Coast of Central Africa and covers a surface area of 475,400 Km² (183,695 Square miles). It is bordered to the North by Chad, the West by Nigeria, the East by Central African Republic and to the South by Gabon, Equatorial Guinea and Congo (WaterWiki 2011).

![Fig 1 Map of Cameroon and its borders (UNEP 2010)](Image)

The world atlas (UNEP 2010) described Cameroon as a representative of Africa, with rich ecological sites, cultural diversity, splendid landscapes (mountains, highlands and semi-savanna regions) and favorable climate with two yearly seasons (raining and dry seasons).

Its total population in 2009 was estimated at 19,522,000 inhabitants, with annual growth rate of 2.4 per cent and a high rural-urban migration shift. Also, the vegetation is varied with luxuriant forests covering 50 per cent of the land area to the south, and grassland and savannah to the north.

3.1 Cameroon’s Water Supply and Sanitation Sector

Water resource management poses constraints on poverty alleviation and sustainable development in Cameroon in general and LUM in particular.

To date, significant sections of the population in towns and cities still suffer from debilitating incidence of water-related diseases associated to poor management rather than water shortage.
According to the Department on Statistics of National Accounts and UNICEF (2001), approximately 45 per cent of Cameroonians (about seven million inhabitants) do not have access to adequate drinking water. Fonteh (2003) considered this statistics striking for a nation endowed with abundant freshwater resources, estimated at about 18,536 m$^3$ per capita per year. A staggering situation is observed in the rural areas as six out of ten persons do not have access to potable water and are forced to fetch drinking water from unprotected sources (Katte et al., 2003).

Fresh water supplied is harnessed from both ground and surface water sources (e.g. springs, boreholes, rivers, streams and wells) after daily purification at 0.5 mg/l of Cl for the purpose of domestic consumption. Clean water is distributed through pipelines (polyvinyl chloride), which serve both public stand posts (taps) and individual household structures (CdE 2009).

The CSO2 (2010) report on the 2010 household survey for water supply and sanitation conducted by WHO/UNICEF, reveals that, between 1990 and 2008 the proportion of individuals with access to safe drinking water increased from 50 per cent in 1990 to 74 per cent in 2008 (with about 8 million people having access). This depicts an improvement in water access, though not putting Cameroon on-track in the Millennium Development Goals (MDGs) achievements for the drinking water sector, a target set at 75 per cent to be reached by 2015.

![Figure 2 Progress in water supply coverage](image)

The Government of Cameroon GoC, privatized the Cameroon National Water Corporation (SNEC) (Waterwiki 2011), and signed international protocols with donor organizations; World Bank, ADF, C2D relief contract, and ADB etc, to rehabilitate and heighten water supply and sanitation access for urban, semi-urban and rural areas (Nangmenyi 2007). The privatization saw SNEC Corporation which hitherto processed and distributed clean drinking water give way in December 2005 to Cameroon Water Utilities Corporation (CamWater – an asset-holding company) and sub-contract (in April 2008) to Camerounaise des Eaux (CdE) (CSO2 2010).
3.2 Sanitation Sector

Sanitation coverage remains poor both in the urban and rural settlements in Cameroon as reported by WHO/UNICEF in CSO2 (2010). The report indicates a decline in coverage rate from 65 per cent in 1990 to 56 per cent in 2010 (as represented in figure 3 below), justifying limited investments in improved sanitation facilities.

With rising population, lack of funding for the maintenance and rehabilitation of sanitation facilities, lack of operational wastewater treatment plants, the regression indicates the GoC’s inability to reach the MDGs set for sanitation coverage at 74 per cent.

![Figure 3 Cameroon’s Urban Sanitation Coverage](image)

The preponderances of latrines and septic tanks of households constructed near water sources are contributing to exacerbate pollution of water-bodies especially in the urban settlements. These latrines and septic tanks are the route cause of disease spread.

Contaminated water is proliferating water borne infections like Cholera, dysentery, malaria, typhoid and diarrhea in some major urban towns like Yaoundé, Douala, Buea, Limbe, Tiko and Mutengene etc in Cameroon (WaterWiki 2011).
4. **An overview of the Limbe Urban Municipality (LUM)**

Situated in the South west of Cameroon, it is delimited Southward by the Atlantic Ocean, to the north by the Buea Municipality, and to the west and east by the Idenau and Tiko municipalities (Awum et al., 2001) respectively. It is located between Longitude 9° and 13° east of the 180 meridians and Latitude 4° and 9° north of the equator. It has a surface of 549 km², and population density of 149 people per square km.

![Map of the Limbe urban municipality and its borders (A.I 2010)](image)

The landscape is uneven with hilly North and Low-lying South that is below sea level.

Administratively, the Limbe Urban Municipality is made up of three sub-divisions namely; Limbe I (POH), Limbe II (Mukundange) and Limbe III (Bimbia). The total population is estimates at 120,000 inhabitants (as of 2010), with an annual growth rate of 4.7 per cent (A.I 2010). Migration pattern is rural-urban with inward migration from the entire country.

The climate is equatorial characterized by a dry season (December through May) and a rainy season (between June and November) (Awum et al., 2001). Annual average temperature is 26.5°C, while the annual relative humidity is above 82.5 per cent.

The vegetation is equatorial rainforest type and relief ranging from 0 – 500 m above sea level. It is drained by two major streams: the Limbe River, which run through the
city and Njegele canal who both empty their waters into the Atlantic Ocean (LCC 2009).

The economy is highly diversified with primary, secondary and tertiary sectors. Half of the population is in agricultural (Primary sector) activities (small scale fishing, gathering and sale of forestry products and fuel wood etc) and the transformative industries (secondary sector).

Companies in the tertiary sector include the Cameroon Development Corporation - CDC (which cultivates tea, palm oil, pepper and banana) and the National Oil Refinery – SONARA (which refines crude oil for national market).

Major economic development projects in the region include; the deep sea port for ship building and oil-rig repair site. Tourism also occupies the pride of place in the Limbe economy. The region’s natural, historical, man-made as well as cultural sites are contributing enormously to visitor influx, income generation for the poor and local populations of the region.

There is a growth of housing infrastructures, permanent and semi-permanent. The permanent types (e.g. apartments, flats, single homes, and Duplex) houses are constructed with cement blocks, wood and zinc materials with internal toilets, while the semi-permanent are built with wood and zinc with external toilet systems. Wastewater generated from these both structure types are disposed of directly into septic tanks and/or into the environment (Awum et al., 2001).

The LUM is divided into three council zones with a constellation of villages and quarters (see lists attached in appendix 16). The Limbe I council area (which is more populated), is located at the center with 26 quarters. Limbe II, (averagely populated) is located to the west having 9 villages and 2 quarters; and Limbe III (with the least population) has 6 villages and is located to the east.

4.1 The Water Supply Sector of the Limbe Urban Municipality (LUM)

The LUM consists of coastal, tropical and hilly landscape with abundant vegetation. It is endowed with varied natural watersheds, the Atlantic Ocean, rivers, fresh water natural springs and wells. Despite the numerous water resources, some areas and villages in the city face shortages of portable water supply. The newly private Camerounaise des aux (CdE) is exclusively responsible for water management. They ensure the treatment, transportation, distribution and marketing of clean drinking
water; and the maintenance, extension and rehabilitation works of all assets, and work to improve drinking water quality in the leased (106) areas.

Raw water is collected from protected catchments of natural springs and surface water (rivers) from Ewongo Village (Bonadikombo – Mile 4) to the north, a distance of 15 km to the main treatment plant and treated by conventional methods in a process chain involving coagulation/flocculation, sedimentation, filtration and chlorination (0.5mg/L of Cl) to eliminate bacteria and other pathogens responsible for waterborne infections.

Two types of water quality analysis (tests) are conducted—bacteriological and physico-chemical (CdE 2009). Self (2010) describe bacteriological analysis as that which facilitates the detection of bacterial contamination of water. In this analysis type, coliform bacteria e.g. Escherichia coli can be identified, and is indicative of pollution from human or animal wastes. While the physico-chemical tests as defined by (Shittu et al., 2008) refers to water analysis carried out to determine the temperature, turbidity, odor, color, total solid, total dissolved solid, total suspended solid, pH, conductivity, and iron content in water.

To improve production, meet current demands and service efficacy, continuous water checks (i.e. types and flows of the resource, the treatment facilities and frequency of water distribution), CdE embarked on improved system services to achieve production efficiency of up to 95 per cent, appropriate and continuous transport and distribution to increase potable water access (by 82 per cent) and investing on improved methods of water purification as well as wastewater treatment within the next six years of their operation (CdE 2009).

4.1.1 Water Distribution:

In the LUM, Camerounaise des aux (CdE) operates three water treatment plants with an installed capacity of 4 x 2500m³, producing about 10,000m³/year of clean water. The plants supplied a population size of above 30,900 inhabitants in 2010. Monitoring of water flows is carried out daily and as well as hourly before distribution.

Most households and other establishment directly receive water to their homes from the municipal water system. The households have internal plumbering system,
which continuously receives water through pressurization to eliminate water storage in household tanks.

There are yard taps as well as shared community stand taps connected to meter devices, which collects monthly readings to ensure a transparent billing system. Although most urban cities in the world consume 150 to 300 liters of potable water per day, approximately 1 to 2 liters of water per day is required by humans for drinking and cooking (Nhapi 2005).

However there is a dearth of public stand taps in some areas of the LUM and the surrounding villages, whilst other are not connected to the municipal water system.

The average domestic, industrial and commercial per capita water consumption amounts to 300,000m³ (for domestic usage) 250,000m³ (for industrial) and 14,000m³ (for commercial usage) respectively, while public supply and consumption of potable water amounts to 10,500m³ in 2010.

According to Awum et al. (2001), because of rapid population and housing growth, coupled with lack of funding for water extension works, a staggering 45 per cent of the population of the municipality still lacks water or are not connected to CdE grid.

Due to wastage of clean water resulting from incidents of broken pipelines, tap heads, widespread growth of car washing points (that is accumulating wastewater in drainage systems) and the use of fresh water for home construction, the suspension and privatization (in 1999 due to huge bills owe the water utility company) of public taps by the then Limbe Urban Council (now Limbe City Council) was enacted. In addition to the poverty situation, inhabitants were compelled to purchase clean drinking tap water at 50 FCFA per bucket.

To increase the quantity of water supplied and reduce the distant search of clean water, there are on-going efforts to exploit new watershed zone at the Mile II area to the north, with anticipated extraction quantity of 2,800m³ as well as springs (through natural gravitation), boreholes and wells to meet up with communities’ increasing water demand.
4.2 Problem Statement: The Case of the Limbe Urban Municipality

Urban growth in LUM is increasing demands for housing, water supply, hygiene, public healthcare, food security and social services (Sadik 1994). The growing trends in rural-urban migration from the nearby villages and cities into Limbe is exarcebatint the problem. Unplanned landscape and uneven construction of houses contributes to difficulties in expanding both the water supply networks and installation of sewarage systems (Volkman 2003) due to the hilly nature of LUM.

In some already installed areas, extension do not keep pace with urbanization, leaving many peri-urban areas unserved. Approximately 42 per cent of the population lack access to clean drinking even with the abundant water sources

And this dire situation is not limited to LUM. According to Katte et al. (2003), none of the major cities in Cameroon (e.g. Yaounde, Bafoussam and Douala) own a centralized sewage treatment plant, and the few plants constructed by housing estates (in the 1970s) have all been abandoned. Untreated sewage from households, hospitals, commercial and industrial facilities flow directly or indirectly to the environment and water bodies downstream into the Atlantic Ocean.

Studies reveals that, about 80 per cent of sewage produced (especially in developing nations) do not undergo preliminary treatment to remove high levels of organic matter, pathogenic microorganisms, nutrients, heavy metals and toxic compounds (WaterWiki 2011) entering the sanitary systems before discharge (Metcalf and Eddy 1991 in UN 2003). These accelerates both environmetal and public health impacts from effluents rich in faecal coliforms, helminths eggs, virus, protozoa etc and other chemical and physical pollutants in some localities like Down Beach, Clerk’s Quarters, Church Street etc within the LUM.

Accordingly, a concentration of public health and hygiene problems are transferred into diffuse health problems, a situation currently affecting health situations of community members of LUM. Even the sewage collection companies based in Douala (about 70Km from Limbe) hardly carryout an effective treatment process for the collected sewage before disposing of the effluent content into water bodies. Also, the transmissive stages of pathogens excreted in the faeces of infected individuals (e.g. human and animals) may become potentially pathogenic component of the sewage. Thus, there is great need for the installation of low-cost, simple and energy
efficient sewage treatment facilities to handle the different categories of raw sewage produced to reduce associated environmental and human health impacts (Volkman 2003).

As Corcoran et al. (2010) suggested, the greatest challenges to public health and environmental problems restricting development and increasing poverty (due to increase unemployment) for the urban poor is related with the consumption of contaminated water or food. Studies by Awum et al. (2001) reported that, the privatization of water stand taps force the poor inhabitants to trek longer distances in search of clean drinking water or force them to collect from unprotected sources for domestic usage. This is increasing significant environmental and public health problems such as outbreak of infectious diseases like cholera, dysentery, diarrheal, typhoid, etc.

A major crucial problem aggravating water related situations within LUM have been the lack of sustainable management agenda particularly in the water supply sector to meet the current domestic, industrial and commercial demands. Observed frequency of water shortages, intermittent supplies, water spillage, occurrence of waterborne infectious and contaminations amongt others are daily experienced especially in the drier periods of the year. Water overflow into drains, for instance, promotes the creation of a comfortable breeding ground for mosquitos and houseflies. Thus, it is common to find individuals vending stand taps selling drinking water (at 50 FCFA per bucket). In periods of intermitted water supplies, people stay awake to fetch water at midnights or prefer uncleaned wells and boreholes for daily domestic use (Awum et al., 2001). As suggested by SAI (2010), there is urgent need to understand, and assess the cyclical pathway of water flows to promote effective management and reduce health hazards and improve sustainability in the water supply sector.

Within the LUM there opportunities and applications for the reuse of treated wastewater (as a resource) in the agricultural, aquacultural, industrial, and urban sectors, which is still to be employed. These sectors are known for their huge quantities of fresh water consumption for industrial operations and processing, a situation that could be substituted with treated wastewater. Thus, the reuse suitability must be calculated against the cost of not providing treatment at both economic and environmental level (Volkman 2003), as well as separating the different wastewater sources and treatment options to support the growing water demands for the above purposes (Corcoran et al., 2010) in the LUM.
5. Results

5.1 Sustainable Urban Wastewater Treatment in Cameroon
   The Case of the Limbe Urban Municipality (LUM)

The Limbe urban municipality consumes large volumes of fresh water and generates enormous quantities of sewage from different sources. Traditionally, the sewage produced from households, some commercial and industrial facilities (partly collected in private septic tanks), about 80 per cent is discharged directly untreated into nearby water bodies and the environment without pre-treatment (Corcoran et al., 2010), that is increasing both environmental and public health problems of many communities (UN 2003). Hence, this section describes investigations of the various wastewater types, their sources and constituents, the existing sewerage (drainage) systems as well as suggesting four appropriate sustainable cost effective treatment methods for the categories of wastewaters produced in the LUM.

5.2 Wastewater types, Sources and Constituents

Distinguishing the nature (types, sources and constituents) is fundamental for design and selection of wastewater treatment technologies for different regions (UN 2003). Although no substantial data quantified the amount of wastewater generated in LUM, studies conducted by Awum et al. (2001) in the region, however, identified four different categories or sources (in figure 5) of wastewater. Table 1 below (by Henze et al., 2000) also describes the various constituents found in wastewater, a representation of the different components produced in tropical regions and LUM. The various wastewater types are described below:

![Figure 5 Origin and Flows of Wastewater in an Urban Environment (Helmer and Hespanhol 1997)]
5.2.1 Domestic or Household Wastewater

The bulk of the wastewater is produced from this category and mainly from households (see table 1 below). Although the quantity and quality is reliant on the available water supplied, population size, standard of living and climatic conditions etc (Mara 2004), households in LUM generates an estimated 80 per cent of the total wastewater; both black wastewater (from flushing toilets) and grey wastewater (from bathroom, laundry and kitchen). Although no measurements on the total quantity and quality could be obtained for LUM, Aka 2002; Agendia et al., 1994; and Katte et al., 2003, emphasized that this source is aggravating pollution that is affecting urban water supply systems, the environment and public health infections since untreated sewage is directly disposed of into the environment and water bodies.

According to Helmer and Hespanhol (1997), an estimated 75 per cent of the tap water consumed by households is released as wastewater (in moderate climate of developing countries), whilst in arid regions, less than 50 per cent of the water consumed is typically lost, either through high evaporation, seepage or flows (see description of domestic wastewater flows in appendix 1) etc.

Mara (2004), also emphasized that, human body wastes (faeces and urine) produced from households or business facilities, consists predominantly of solids, that is the organic portion (e.g. proteins, carbohydrates and fats), and the liquid (urine) part mainly of grit, metal and salts (or the inorganic portion) of the wastewater. For instance, 135 – 270g of wet solids (faeces or organic portion) and a corresponding 1.0 – 1.3kg of urine (liquid portion) are produced per person per day in developing countries. Households with low water consumption of 40-100 l/person/day (like in Brazil and is typical for the LUM) produces about 70 per cent sewage with strong BOD of the range $\text{BOD}_5 = 300–700$ mg/l, would require more oxygen to oxidize the wastewater.

It should be noted, both the faeces and urine constitute millions of intestinal bacteria and limited number of organisms, the majority of which are harmless and some are beneficial, while others are disease causing to humans.

5.2.2 Commercial Wastewater

Commercial wastewater is the wastewater generated predominantly from business or commercial centers. It constitutes not only sewage from sanitary facilities, but also
solid wastes and wastewater (combined) originating from commercial centers. More than 60 per cent of the heterogeneous sewage is produced from restaurants, laundry business centers and service stations, night-clubs, off-licenses (bars), and eating houses etc in LUM, which do not undergo pre-treatment before disposal. Studies project future growth in commercial structures that could be deduced from the favorable business climate and increasing influx of people into the Limbe urban municipality, with increased generation of large quantities of untreated sewage (Awum et al., 2001).

5.2.3 Industrial Wastewater

Industrial facilities and processes (Manahan 2010) constitute varieties of persistent and priority pollutants present in wastewater e.g. solids, dissolve inorganic compounds, metals, hydrocarbons, solvents, polymers, oil, grease, and salts etc. Although they exist in different levels of toxicity and their characteristic varies with industrial units (Veolia Environment 2007), their widespread and contamination have not been extensively detected. Sewage generated from crude oil refinery (e.g. the National Oil Refinery – SONARA) in LUM, produce large varieties of toxic heterogeneous wastewater and chemical pollutants including aliphatic (gaseous methane), aromatic hydrocarbons (benzene, toluene, polynuclear, aromatic naphthalene and benzopyrene), heterocyclic and other nitrogen and sulphur components, are treated to reduce their accumulation in drinking water.

Cotuvo (2005) underlined that many chemical pollutants are neurotoxins at relatively high doses (e.g. hexane C$_6$) and low doses. For instance, benzene causes leukemia and benzopyrene causes skin and other cancers. Their severity for causing health impacts could escalate due to the mobile, volatile and toxic nature; hence sewage needs to be treated before disposal.

Numerous industrial sewages are toxic to microbiological sewage treatment processes; they should be pre-treated prior to discharge to sewer (WEF 1994a in Mara 2004). Although no data exists on the amount of sewage generated from industrial units, CDC oil-mills and small manufacturing companies in LUM discharge untreated industrial sewage. Hence ten to hundreds chemical pollutants enter the different ecosystems yearly without treatment (Fonteh 2002 in Katte et al., 2003) and are accumulating slowly in both surface and groundwater sources.
5.2.4 Storm water (urban run-off)

The bulk of urban water run-off generated from different sources is rainwater and discharged into sewer systems or receiving water bodies. It constitutes a mixture of rainwater, sediments, or generally solid waste materials (Haselbach 2010), typical of urban water run-offs or flows of the LUM. The high rainfall down hilly slopes, sweeps along solid waste materials and loose soil materials, through small ditches downstream (Awum et al., 2001). Scenarios occur were these materials build up and clog the river beds causing flooding.

Also, fresh water sources get contaminated with diluted sewage spills from nearby pit latrines and broken septic tanks and the diluted sewage moves directly into surface water bodies and into the Atlantic Ocean.

### Table 1 Different types of components present in wastewater

<table>
<thead>
<tr>
<th>Constituents</th>
<th>Of Special Interest</th>
<th>Environmental Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Micro-organisms</td>
<td>Pathogenic bacteria, virus and worm eggs</td>
<td>Poses risk when bathing and eating of shellfish</td>
</tr>
<tr>
<td>Biodegradable organic</td>
<td>Oxygen depletion in rivers, and lakes</td>
<td>Causes changes in aquatic life</td>
</tr>
<tr>
<td>materials</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other organic materials</td>
<td>Detergents, pesticides, fat, oil and grease, colouring,</td>
<td>Causes toxic effect, aesthetic inconveniences, and bio-accumulate</td>
</tr>
<tr>
<td>(sullage)</td>
<td>solvents etc.</td>
<td></td>
</tr>
<tr>
<td>Nutrients</td>
<td>Nitrogen, phosphorus, ammonia</td>
<td>Causes eutrophication and toxic effect</td>
</tr>
<tr>
<td>Heavy metals</td>
<td>Hg, Pb, Cd, Cr, Cu, Ni</td>
<td>Causes corrosion and toxic effect</td>
</tr>
<tr>
<td>Other inorganic materials</td>
<td>Acids, e.g. H₂S, bases</td>
<td>Causes corrosion, and toxic effect</td>
</tr>
<tr>
<td>Thermal effects</td>
<td>Hot water</td>
<td>Change living conditions of flora and fauna</td>
</tr>
<tr>
<td>Odour (taste)</td>
<td>Hydrogen sulphide</td>
<td>Aesthetic inconveniences, toxic effect</td>
</tr>
<tr>
<td>Radioactivity</td>
<td>Pose toxic effect, and accumulate</td>
<td>-</td>
</tr>
</tbody>
</table>


5.3 Strategies for Wastewater Collection, Storage and Disposal of the Limbe Urban Municipality (LUM)

Urban wastewater (sewage) systems should prevent unhygienic situations by adequately removing sewage and storm water from users, reduce incidence of pollution or contamination of urban water systems to avoid environmental and public health impacts (Hellström et al., 2000).
A diversity of different sewerage systems exists with different designs and functions (Crites and Tchobanoglous 1998), some of which do not efficiently fulfill the fundamental sustainability rules.

Examples of sewerage systems in LUM include, water canal, septic tanks and pit privy (latrines), and ecological toilets. Otterpohl, Grottker, and Lange (1997) in Kärrman (2001), emphasized that the above systems (including other traditional methods sewage treatment) can impact the environment, water supply systems and water bodies.

5.3.1 Water channels or canals

Water channels convey the total volume of storm water runoffs and sewage produced in LUM. Their size, inadequate maintenance, and efficiency (in high raining seasons - June, July and August) domestic and storm water management is increasingly been questioned.

From observation, water overflows (figure 6a) its banks, causing accelerated flooding events in houses and offices; dilution and overflow of accumulated sewage in abandoned or wrecked septic tanks and pit latrines in quarters like Clerk’s quarters, Church Street, Lumpsum quarters, and squatter areas of Dockyard, Down Beach - Mbonjo and parts of New Town East to Mabeta New layout. Hence, these can spread bacteria, pathogens, viruses, and toxic chemical and pollutants etc to impact groundwater and surface water bodies.

Owing to the uneven and unplanned landscape, Awum et al. (2001) suggested that, the installation of water canals to harmonize both storm-water and sewage are not only difficult to achieve, but rather expensive to install. Important major water canals in Limbe include, the Limbe River, Njengele, Ndongo’o canal. These systems are connected to man-made gutters (pavements) and drains (figure 6b) constructed closer road-sides in localities like Church Street, New Town, Gardens, down beach etc.

Figure 6a: The Njengele Canal, LUM  
Figure 6b: Water Canal LUM (Photos: Sebastiene Mosoke)
In addition, sediments, and solid waste materials from abandoned and on-going farmlands on hilly slopes (northern section of Limbe) move down slope into small streams, rivers and into the Atlantic Ocean. Often they clog water canal, which transports pollutant materials and reduce the free flow of water.

5.3.2 Septic tanks and pit latrines

According to Balkema et al. (2002), septic tanks traditionally store and treat (by settling) sewage from individual households, or commercial/business centers. Typically, septic tank systems in developing nations are built with concrete materials and molded blocks (see figure 7 below). Modern design (see appendix 2 below) consideration culminates with an on-site absorption field (Crites and Tchobanoglous 1998).

Approximately 70 per cent of permanent households in LUM own private septic tanks, but not connected to soil absorption fields for on-site treatment processes. Both black and grey water are treated through sedimentation, digestion (breakdown through biological processes) and flotation for the removal of pathogenic and other components (Balkema et al., 2002) to obtain sludge after 2 to 3 years.

Another widely and commonly used type of sewage collection and settling tank system is pit latrines. They are also constructed using concrete materials and rocks outside semi permanent households and schools etc. They store faecal sludge (Tilley et al., 2008) and are sometimes abandoned when filled. Approximately 75 per cent of both households located in New town, Mile Four, Mbende, Cassava farms, Lumpsu, and Church Streets in LUM adopts pit latrines (a decentralized form of sewage treatment) for sewage management (Mbom 2006).

Stored sewage is emptied (in near-by water bodies) or drained by sewage collection companies (e.g. vacuum trucks) before disposal distant from the city.
Although septic tanks and pit latrines improve sanitation and reduce forest, stream and river defecation in LUM, they are breeding grounds for cockroaches, flies, mosquitoes (which transmit malaria, bacteria and pathogens), odour and the pathway for leachate penetration into groundwater. Also, in over-crowded areas with shared kitchens are built close to pit latrine. In areas where these are absent, people make use of plastic bags (flying toilets) for defecation, which are disposed of into streams, run-offs or forests (Mbom 2006).

5.3.3. Ecological Toilets (ET)

Ecological (eco) toilets) toilet systems according to Redlinger et al. (2002) are feasible alternative toilet systems suitable for use in water stressed areas. They pose minimal environmental and public health problems compared to above systems by reducing the spread of infections caused by fecal-oral transmission of pathogens (Esrey et al., 1998). Basically, two types of ecological toilets exist – biodegradation and dehydration systems (including the single and double vaults toilet systems) (US EPA 1995).

Studies to determine their efficacy reveal that, biodegrading ET (with no urine diversion) performs better than dehydrating systems (having urine diversion system). The former reduces pathogens e.g. fecal coliform and the occurrence of Crystoporidium and Giardia cysts, compared to dehydrating ET systems. Dehydrating systems considering the moisture content, pH and microorganisms better treats biosolids in tropical climate (hot and dry) compared to biodegrading systems. Hence, with the hot and dry tropical climate in Cameroon, biodegrading ET systems have being installed (figure 8) to control public health hazards and rising sanitation problems in LUM (Mbom 2006).

Figure 8 Ecological Toilet Systems (Photo: Sebastien Mosoke)
5.4 Four Sustainable Wastewater Treatment Methods applicable to the LUM

The significant increase of urban wastewater and release of untreated wastewater increases in developing nations means the need to provide primary, secondary and/or advanced treatment to encourage re-used is absolutely imperative (Kayombo et al., no date).

Progressively, different techniques have been hitherto applied for the treatment of different categories of wastewater (sewage) in India, Kenya, Tanzania and Uganda etc although their sustainability has undoubtedly been questioned (Helmer and Hespanhol 1997).

Studies indicate that many tropical countries are now investing in cheap and sustainable small-scale and low-cost (rather than conventional) sewage treatment technologies for sewage treatment.

Examples include wastewater stabilization ponds (WSP; also known as Lagoon systems, aerated or oxidation ponds) and constructed wetlands (CW) systems (Kayombo et al., no date), wastewater storage and treatment reservoirs, up-flow anaerobic sludge blanket reactors (UASBs), biological filters, anaerobic biogas reactor, and sedimentation/thickening ponds etc, whose suitability for application in Cameroon and LUM is discussed below:

5.4.1 Waste Stabilization Pond

Waste Stabilization Ponds (WSPs) are large, enclosed shallow earthen basins used for the treatment of raw sewage from both domestic and industrial facilities (UN 2003). They employ natural processes, combined with solar energy, algae and bacteria to breakdown sewage or nutrient (appendix 9 describes the mechanism of nutrients removal in WSP) during treatment processes. Due to its physical design (in appendix 3), arrangement (of the various types as described in appendix 4), cost-effective, reliability, and ease-operated methods (with minimum daily supervision), WSPs are excellent facilities for sewage treatment in tropical regions (Kayombo et al., no date).

Studies on the efficiency and performance of WSP systems for the removal of protozoan cysts and helminthes eggs have largely been attributed to sedimentation and retention times (Shuval et al., 1986).
As the prevalence of intestinal parasites is high in developing countries, removal efficiencies are of particular interest. For instance, Veerannan (1977) achieved 100 per cent removal efficiencies of intestinal parasites for *Giardia cysts* in pond one while investigating three WSP in India for intestinal parasites.

Other studies indicate that, both suspended solid materials and parasitic protozoan removal in WSP occurs in the primary pond (by adsorption on to the settable solids), while the concentration of protozoan parasites in effluent of subsequent pond decrease sequentially (removal achieved sedimentation and/or destruction) (Amahmid *et al.*, 2002). Furthermore, specific heavy metals, total suspended solids and BOD removals (appendix 5; nutrient removal in WSP) can also be achieved through biological activities in WSP in tropical climates (Kayombo *et al.*, no date). The WSP research group is currently using this technique to manage sewage produced from the main campus of University of Dar es Salaam, Tanzania (WSCWRG 2009).

5.4.1.1 Types of Waste Stabilization Ponds and their specific uses

(i) Anaerobic Pond

They function as septic tank systems and are often the first series of pond type (2-5m deep) that operates similar to open septic tank.

In high-strength organic wastewater (100g BOD/m³ per day), 40-60 percent BOD (their primary function) (40 per cent at 10°C, and more than 60 per cent at 20°C respectively) is removed (Kayombo *et al.*, no date) by sedimentation of settleable solids, accompanied by anaerobic digestion process to achieve the sludge layer (SAI Platform 2010).

Anaerobic pond design (described in appendix 6) and other physical design parameters such as temperature, net evaporation, flows and BOD (Kayombo *et al*. (no date), anaerobic pond do not only work well, but can achieve more than 60 per cent BOD removal at 20°C. Research at the Dandora ponds serving Nairobi indicates that, anaerobic pond’s (*figure 9 below*) effectiveness increase significantly with respect to temperature and design consider, where BOD removals of 79-86 per cent with retention times (of 2.5 – 9.5 days) was achieved. The sludge produced can be used either for restricted irrigation of crop farms or fish pond fertilization (Mara 2004).
Anaerobic ponds do not require oxygen or algae during organic load and decomposition process (Kayombo et al., no date). During treatment process, heavy metals precipitate as metal sulphides, while organic toxicants are broken down into non-toxic forms and the floating oils and scum prevents sunlight penetration that catalyzes algal photosynthesis (Mara 2004). Also, acid and methane forming bacteria, which supports the breakdown or anaerobic digestion process, cooperatively facilitate the conversion (through bacteria sensitivity functions) of organic carbon to methane (Crites and Tchobanoglous 1998), which can be obtained at temperature above 15°C, and pH <6.2, with short retention times of 1.0 – 1.5 days.

(ii) Facultative Ponds

Facultative pond systems (1-2m deep) consist of two types: the primary and secondary facultative ponds (Kayombo et al., no date). The primary facultative pond receives and treats raw sewage, while the secondary facultative pond treats settleable wastewater, usually the effluents from anaerobic ponds (SAI Platform 2010). Studies of BOD loading rates show similarities in both facultative and aerated lagoons, which differ in the rate of oxygen supply in facultative ponds.

In addition to the design pattern (appendix 7), facultative pond systems employ naturally generated oxygen (by aerobic bacteria produced during algal photosynthesis) for BOD removal processes (of the range of 100–400 kg/ha day) and the decomposition of organic matter (as described in appendix 8) is dominant in the primary facultative than secondary facultative ponds (Kayombo et al., no date).

(iii) Maturation Ponds

Maturation pond (1-1.5m deep), which are the third series of ponds receives effluents from facultative pond. They are designed primarily to remove excreted pathogens (faecal bacteria and viruses), although some quantities of BOD are removed, as in
both anaerobic and facultative ponds (Kayombo et al., no date). The removal of suspended solids and nutrients (N and P) (see nutrient removal mechanism explained in appendix 9) are relatively slow, even though the pond is well-designed, properly stratified, operated and maintained in series and is well oxygenated (SAI Platform 2010). Due to the well oxygenated nature of the maturation pond (with increasing depth) the algal diversity generally increases with a reduction in algal biomass.

Although partial removal of faecal bacteria is achieved in facultative pond, their subsequent re-appearance in maturation ponds will determine the size and abundance of faecal bacteria present in the final effluent. As in facultative ponds, the mechanisms of faecal bacteria removal in maturation ponds is activated by time and temperature, high pH (> 9), high light intensity and dissolve oxygen.

5.4.1.2 Advantages and disadvantages of Waste Stabilization Pond

WSP systems are simple to construct, operate and manage (requiring limited skilled labor).

They involve low-cost (both capital and maintenance), high efficiency (of 90 per cent) for BOD, suspended solids and ammonia (NH₃) removals. Moreover, they are robust (i.e. can treat a wide variety of industrial and agro-industrial sewage (Mara 2004).

When properly designed, operated and maintained, WSP causes odor problems when over-loaded; act as breeding avenues for mosquitoes (Kayombo et al., no date) that transmit malaria and other diseases to humans. Evaporation and salinity increases in drier climates, which correspondingly reduces its suitability for crop irrigation and production.

They are not suitable in countries where land is of high value (since they will require large portion), compared to the use of conventional systems e.g. oxidation ditches or activated sludge (Mara 2004).

5.4.2 Constructed wetlands (CWs) (“reedbeds”)

CW systems are specifically designed (design approaches described in appendix 10) and constructed to control pollution by assisting in the treatment of sewage using
vegetation or rooted aquatic plants (Aslam et al., 2004) e.g. macrophytes (*Phragmites australis*) in natural wetlands. Macrophytes are grown in soils or gravel beds that receives domestic as well as industrial sewage after primary treatment in anaerobic ponds. Other commonly used plants include *Schoenoplectus lacustris* (bulrush), *Typha latifolia* (cattail) and *Juncus effuses* (soft rush).

CWs are long, narrow and shallow reactors in which secondary or tertiary wastewater (from septic tanks or anaerobic ponds) are efficiently treated to remove pollutants such as organic material, suspended solids, nutrients, pathogens, heavy metals and other hazardous pollutants in wastewaters from domestic, industrial sewage, agricultural and storm-water run-offs. Studies present a growing interest for tropical developing nations implementing CW systems (Mara 2004). For instance, small community built-up areas, schools, and prisons in Tanzania have installed ten CW units for domestic sewage treatment; and inhabitants of Iringa Shinyanga, Malya, Bariadi, Moshi, Kibaha and Dar es Salaam Municipality with a population size of 12,700 (WSCWRG 2009).

Crites and Tchobanoglous (1998) defined two principal types of CW treatment systems based on the variation of water flows:

**5.4.2.1 Free Water Surface Constructed Wetlands (FWS)**

The FWS constructed wetland systems (marsh or swamps), consists mainly of channels or basins with natural or constructed impermeable barrier that functions to prevent the permeation of contaminated sewage coming in contact with groundwater (Bojcevska 2006). They function (as described in appendix 11) to provide additional treatment for both secondary and tertiary effluents.

![Schematic representation of the FWS CW treatment plant](Source: Wastewater treatment technologies: A general Review - Economic and Social Commission for Western Asia - UN 2003).
5.4.2.2 Sub-surface flow (SSF) Constructed Wetlands

SSF wetland systems are the rock-reed, microbial rock plant filters, and vegetated submerged beds etc (i.e. planted with aquatic vegetation), which are used primarily for the treatment of septic tank effluents, landfill leachate and other concentrations of organic materials, suspended solids, nitrate, pathogens and pollutants (Kayombo et al., no date). These systems are adapted also to remove BOD and nutrients (N and P) (see appendix 12), through a combined process involving rock filter media and plants (Mara 2004).

Two categories of SSF CW exist, - the horizontal flow SSF (hSSF) and vertical SSF (vSSF) CWs. The hSSF is the most commonly used constructed wetland systems compared to vSSF CW (Mara 2004). While in the vSSF the aerobic zone extends from the soil top layer to the end of the root zone, after which the anaerobic zone begins (Bojcevska 2006).

![Diagram of SSF CW treatment plant](Image)

*Figure 11 schematically depicts the SSF CW treatment plant (Source: Wastewater treatment technologies - A general Review - Economic and Social Commission for Western Asia (UN 2003))*

5.4.2.3 Advantage and disadvantages of Constructed Wetlands

The installation of CW involves a relatively reduce cost for construction, operation, and maintenance to improve their effectiveness and reliability in wastewater treatment. They can tolerate fluctuating hydrologic and contaminant loading rates (with respect to optimal size for anticipated waste loads), which indirectly benefit the establishment of wildlife habitats, recreational and educational areas.

The disadvantages for the use of this system include; land availability (in terms of cost and size); imprecise design and operation techniques; complex biological and hydrological functions involved and lack of knowledge of significant process dynamics; and problems with pests, mosquitoes, which might multiply infections e.g. malaria (Tilley *et al.*, 2008).
5.4.3 Up-flow Anaerobic Sludge Blanket (UASBs) Reactors

The UASBs reactor is a centralized single tank process or anaerobic digester used for the primary treatment of domestic (its application is relatively new), high-strength biodegradable industrial and agro-industrial wastewaters. It was developed in the 1970s by Gatze Lettinga (University of Wageningen in The Netherlands) and its application has recorded widespread success in tropical and sub-tropical regions (Brazil, India and Columbia) (Mara 2004).

UASBs ensure 75-90 per cent BOD and 85-90 per cent of COD reductions and achieve high organic removal efficiency. It treats highly polluted wastewater from brewery, distillery, food processing and pulp and paper waste industries. UASB reactors are relatively simple to design and construct, but would require skilled operators for monitoring and repairs in case of reactor and pump failures (Tilley et al., 2008). In addition, they require low capital and maintenance cost, low energy and minimal land requirement, proliferate their suitability for use in urban wastewater treatment of developing countries.

Although it is more adapted to function as an anaerobic process (further described in appendix 13) for the treatment of wastewater, the UASB reactor (with short detention time of 6-12 hours) produces low sludge (reduced organic loading) of high effluent quality but would require constant water supply. The anaerobic treatment process, it should be noted, does not effectively remove nitrogen, phosphorous, and pathogens. Post-treatment either in wetlands or stabilization pond (to meet discharge standards) aids the reduction of fecal and nutrient loads (Bdour et al., 2007).
5.4.3.1 Pros and Cons of UASB Reactor

The UASB reactor produces low sludge (due to infrequent desludging), ensures high organic contaminants reductions, and is capable of withstanding high organic (of up to 10Kg BOD/m^3/d) and hydraulic loading rates. The biogas (CH₄ and CO₂) produced aids as energy source to run the system during wastewater treatment process. CH₄ contains about 70 per cent biogas and is a powerful and significant Greenhouse gas that provides energy to run the UASB reactor (Mara 2004).

This system experiences difficulties in balancing the hydraulic conditions, the long time taken to start-up the reactor; it ensures unstable treatment with variable hydraulic and organic loads and requires constant supply of water and electricity for process function (Tilley et al., 2008).

5.4.4 Sedimentation/Thickening Tanks Systems

Sedimentation or thickening pond systems are simple settling ponds that treat wastewater by dewatering (Tilley et al., 2008). This low-cost sewage treatment option separates both solid and liquid fractions of faecal sludge before additional treatment (of the supernatant) can be achieved, either in a WSP, planted or unplanted drying beds or by composting (Spuhler 2011). Two types can be distinguished – sedimentation or anaerobic ponds (which treats high strength faecal sludge from latrines and un-sewered public toilets). The sludge produced is rich in organic matter, biodegrades slowly (dewatering becomes difficult to achieve stabilization), and requires long retention times. While the settling tank systems (which treats low strength faecal sludge) from septic tank or anaerobic digesters etc produce less rich organic matter (see figure 13 below). Significant anaerobic biodegradation (with short retention times of hours) and desludging are repeatedly achieved (Tilley et al., 2008).

![Figure 13](image_url)

*Figure 13 describes the treatment of faecal sludge and secondary treatment options for thickened sludge and liquid fraction (Spuhler 2011)*
Design considerations of both sedimentation and settling tank systems takes into account the sludge type, composition, storage volume, depth and anticipated quantity of the sludge (in a given time). Sedimentation tanks are designed analogous to anaerobic ponds in WSPs (see figure 14 in appendix 4). Unfortunately, they require more land for their installation compared to settling tank systems that is simple and require less land area, constructed with sufficient depth for the storage of the liquid portion of the sludge.

The effectiveness of solid removals differs for both systems. Sedimentation ponds can achieve approximately 60 per cent of suspended solid removals while septic tank systems can achieve roughly 95 per cent. This promotes the re-use of the effluent and sludge (e.g. for agricultural applications), though additional treatment is required to destroy pathogenic bacteria present in the final effluent.

Hydraulic loading rates are often shorter in settling tanks than in sedimentation tanks with short retention times. After desludging (after the liquid portion is removed) the removal of the solid portion is often conducted every 2 to 4 months (in settling tanks) and in after every 8 to 12 months (in sedimentation tanks), including sand, grit and solid wastes (Spuhler 2011).

5.4.4.1 Advantages and disadvantages

Sedimentation/Thickening Ponds are efficient to operate in both hot and temperate regions for the treatment of faecal sludge. Their installation requires low capital and operating cost, and can be constructed with locally made materials. No form of energy is needed to power its systems and it is a potential job creating facility.

This system requires large areas of land for pond installation (on like in WSPs), have problems associated with odour and flies (hence should be installed away from the community), involve long storage times, especially in sedimentation pond type. Front-end loader (during the desludging periods) and design and operation experts are highly needed (Tilley et al., 2008).

Investing into low-cost and energy efficient natural treatment methods for wastewater in Cameroon and the Limbe urban municipality can redress anthropogenic impacts to water, thus reducing escalating water pollution and human health (Helmer and Hespanhol 1997).
5.5 Sustainability Assessment of the LUM Water Supply System

The increasing requirement to achieve sustainable development has a profound effect on all categories of urban infrastructures. The existing gap in knowledge on sustainable development, implementation processes, and assessment methods for wastewater systems in Cameroon and LUM need to be closed. There is a need to move towards a non-toxic environment, improve health and hygiene, conserve human and natural resources and save financial resources (Hellström et al., 2000).

There is an imperative to understand the different sustainability concepts - its principles, different assessment methods, and technology (appendix 14).

Sustainability indicators and criteria considered very relevant and used in the assessment.

5.5.1 Sustainability Concept and Assessment Methods

As already defined (in the introduction) above, sustainable development is based on the principles and observations that the economy, environment and well-being cannot be alienated (WCED 1987 in Balkema et al., 2002). It provides a useful framework to assess trends in development.

Due to its multi-dimensional characteristics, sustainability concept emphasizes economic costs and benefits are not sufficient. There is a need to incorporate social, cultural and environmental aspects into the decision-making process in order to safeguard natural resources and encourage societal development (Kärrman 2000).

Several different opinions have been postulated and categorized by different authors to demonstrate the multi-dimensionality of the concept of sustainability. Balkema (2003) defined sustainable development on the basis of material well-being, social security and ecological balance; the WCED (1987) differentiate three dimensions of sustainability and sub-categorized it on the basis of environment, development and social security (i.e. income distribution and health care); and Katte et al., (2003) identify the MDGs, which directly relates to water, improved water management as significant contributor to achieve sustainable development.

The “principles” of sustainability seek to maintain economic well-being, ensure environmental protection, and the cautious use of natural resources for equitable
social progress with respect to individuals, communities and the environment, while its framework recognizes the need to design human and industrial systems to achieve negative impact reductions in the social, economic, health and the environment sectors for generations to come (Balkema 2003).

In addition, different assessment methods (e.g. Life Cycle Assessment, EMergy assessment and Cost benefit analysis etc) for sustainability have been tested to finding solutions on technological problems that balance costs and resource uses, while contributing to reducing both local and global environmental, economic and socio-cultural problems. These solutions, however, should be focused on accomplishing a long and global vision, and must strive to avoid exporting problems over time within a complex entirety (Balkema 2003).

5.5.2 Sustainability Criteria and Indicators

Sustainability criteria and indicators are significant to finding suitable solutions to environmental problems and avoid exporting these problems over time and space. Their identification and definition offers one of the best tools to conduct an assessment.

Disadvantages associated in the selection and use of indicators differ in their inability to be accepted by different group of experts, geographical diversity in both urban, sub-urban, as well as the rural sectors, lack of data and methods used for deriving the sets of sustainability indicators (Balkema 2003).

The general perception in the selection of sustainable criteria and indicators involve; chosen indicators that provides ecologically sustainable solutions, capable of determining success, sensitive and robust, and can easily be fashioned within limited number.

Similarly, they should be based on sound scientific evidence, widely accepted by the scientific community; be transparent, relevant and quantifiable with up-to-date information.

Different case studies exemplify the use of different approaches to evaluate urban water supply and wastewater treatment systems. The framework structure of Kärrman (2000), which adopts the multi-dimensional sets of sustainability criteria – e.g. environmental, economic, health and hygiene, socio-cultural, and functional
(appendix 15), sub-criteria, as well as indicators is considered suitable for evaluating contributions from sewage, sanitation, and anthropogenic impacts of different sources on the water supply systems serving the Limbe urban municipality.

Given that the LUM lacks centralized sewage treatment plants, the data input below (though not accurately collected for administrative difficulties and risks of exposure of current water crisis) was obtained from the water supply company – CdE, Limbe (see survey sheet attached in appendix 17) as keyed in table 2 below:

Table 2 Data of water supply and sanitation investigations for the Limbe urban municipality obtained from Camerounaise des Eaux and City Council Office in Limbe

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Indicators</th>
<th>Quantities</th>
<th>Impact from water and sanitation</th>
<th>Anthropogenic impacts (in Limbe)</th>
<th>Related impacts from water supply and sanitation in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground water level</td>
<td></td>
<td>Less than 30m in depth</td>
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<tr>
<td>Eutrophication</td>
<td>N to Water (Kg/ yr)</td>
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<td></td>
<td>P to Water (g/ yr)</td>
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<td></td>
<td></td>
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<tr>
<td>Spreading of toxic compounds to water</td>
<td>Cd, Hg, Cu, Pb, Fe (g/yr)</td>
<td>Cd: No data</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td>Hg: “”</td>
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<td></td>
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<td>Cu: “”</td>
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<td></td>
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<td>Pb: “”</td>
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<td></td>
<td></td>
<td>Fe: “”</td>
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<td></td>
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</tr>
<tr>
<td>Spreading of toxic compounds to arable soil</td>
<td>Cd, Hg, Cu, Pb, Fe (g/yr)</td>
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<td></td>
<td>No data available</td>
<td>No data available</td>
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<tr>
<td></td>
<td></td>
<td>Hg: “”</td>
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<td>Cu: “”</td>
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<td>Pb: “”</td>
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<td>Fe: “”</td>
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<td>Use of natural resources</td>
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<td>Use of electricity and fossil fuels (MJ/yr)</td>
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<td>Use of fresh water (m³/day):</td>
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<td>10,000 m³/day</td>
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<tr>
<td>Use of chemicals – Cl (kg/yr)</td>
<td>Cl: 8, 640 kg/yr</td>
<td>25 persons affected</td>
<td></td>
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<td>Excess quantities of Cl added to water</td>
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<td>Use of materials for construction of infrastructure (m PVC pipes)</td>
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Table 2: Social and cultural criteria

<table>
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<tr>
<th>Easy to understand</th>
<th>80% (random estimation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work demand</td>
<td>85 persons</td>
</tr>
<tr>
<td>Acceptance</td>
<td>Violation</td>
</tr>
<tr>
<td>Omission</td>
<td>45%</td>
</tr>
<tr>
<td>Ignorance</td>
<td></td>
</tr>
<tr>
<td>Availability</td>
<td>Distribution</td>
</tr>
</tbody>
</table>
Table 3: Economical criteria

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Indicators</th>
<th>Quantities</th>
<th>Impact from water and sanitation</th>
<th>Anthropogenic impacts (in Limbe)</th>
<th>Related impacts from water supply and sanitation in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total cost</td>
<td>Capital cost (fCFA/yr) (Connection charges)</td>
<td>120 - 300 million fCFA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Investment costs (Water treatment)</td>
<td>Daily treatment cost = 100,000 FCFA; Monthly = 3 million &amp; Yearly = 36 million FCFA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Operation and Maintenance (fCFA/ yr)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4: Health and Hygiene criteria

| Availability of clean water             | Drinking water quality (in mg/L)                | 0,5 mg/L of Cl       |                                  |                                 |                                                      |
|                                        | Non-access to drinking water (h/p, yr)         | 42% of the inhabitants |                                  |                                 |                                                      |
| Risk of infection                      | No. of waterborne outbreaks (no. p, yr)        | Occurred three (3) times in 2011 |                                  |                                 |                                                      |
|                                        | No. of affected persons (no. p, yr)            | 1,863 persons        | Cholera: 190 persons Dysentery and diarrheal: No data available | Six (6) deaths |                                                      |
| Exposure of water to toxic compounds   | Drinking water quality                          |                     |                                  |                                 |                                                      |

Table 5: Functional and technical criteria

| Robustness                              | Overflow (m³/ yr);                               | 6,000m³            |                                  |                                 |                                                      |
|                                        | Sewer stoppage (no. yr)                          |                     |                                  |                                 |                                                      |
| Performance                             | Out-leakage (m³/yr)                              |                     |                                  |                                 |                                                      |
|                                        | Destruction (m³/yr)                              |                     |                                  |                                 |                                                      |
| Flexibility                             |                                                 |                     |                                  |                                 |                                                      |

Note:
The grey coloured/empty columns indicates that data was not available; the light green colour shows that indicators were not able to be related to water and anthropogenic impacts; while empty columns signifies the indicators were not formulated.
6 Discussion

6.1 Environmental Criteria

6.1.1 Spread of toxic chemical compounds
There exists a diversity of pathways for the transmission of toxic chemical compounds (through untreated sewage discharged from pit toilets and septic tanks) into the water supply system (or groundwater sources), and is capable of increasing impacts and threats to humans and aquatic ecosystems.

Although no data on heavy metal measurements in drinking water was available for the LUM, studies by Karvelas et al. (2003), however, identify significant potential sources of heavy metal (e.g. Pb, Cd, Ni, Zn, Cr, and Mn) contributions from anthropogenic emissions in household effluents, drainage water, business effluents (e.g. car wash points and dental uses etc), atmospheric deposition and traffic-related emissions (from vehicle exhaust, brake linings, tires, gasoline/oil leakages, etc) (US EPA 1986; Sorme and Lagerkvist 2002). Approximately 70 per cent of pollutants emitted can be transported downstream by storm water to pollute groundwater sources or accumulate in drinking water.

A high concentrations of volatile organic chemicals, hazardous substances (Drangert 1997 in Berndtsson and Hyvönen 2002) and toxic chemical compounds (and pharmaceutical products), in untreated sewage in industrial facilities are often discharged into water bodies without treatment. They have the potential to impact groundwater reservoirs and escalate chemicals accumulation in both fish (in water ecosystems) and humans.

Owing to the lack of modern sewage treatment systems (or plant) in LUM, and as described above (in section 5.4), both septic tank and pit latrines handles sewage generated by households, commercial and small industrial units. A large majority (apart from SONARA) of industries, which produces sewage, do not provide preliminary treatment before disposal.

Alternatively, both Waste Stabilization Ponds (WSPs) and Constructed wetland systems could be employed to remove very high concentrations of heavy metals, reduce the spread of hazardous substances as well as volatile organic chemical compounds from households, commercial and industrial sewage.
Anaerobic ponds (the first series of pond in WSP), effectively remove heavy metals (from industrial sewage) through precipitation into metal sulphides. Organic toxicants (e.g. phenol), floating oil and scum are converted into non-toxic forms to facilitate sunlight penetration that catalyses algal photosynthetic processes in the ponds.

In CWs, Subsurface Flow CW systems are capable of achieving up to 99 per cent of heavy metals removal in sewage (Reed et al., 1995) through three significant processes; binding to soil particles, sedimentation and particulate matter, precipitation as insoluble salts and bacteria, algae and plants uptake from the wastewater (Kadlec and Knight 1996 in Kayombo et al. (no date)).

Studies by Dzwairo et al. (2006) while assessing the impacts of household on-site pit latrines in Marondera district in Zimbabwe observed that significant quantities of leachate (containing faecal coliforms, ammonium and nitrates and even heavy metals) are contributing to pollution of groundwater quality. They were found to microbiologically impacting the quality of groundwater within 25m lateral distance, aggravated mainly by the shallow water table, a possible phenomenon and route for groundwater contamination (by leachate) occurring in LUM.

Both anaerobic and facultative ponds (which are designed primarily for BOD removals) in well-designed WSPs have proven very efficient to treat domestic, industrial, commercial and agro-industrial wastewater for significant reductions in the BOD content before disposal.

Approximately 70 – 90 per cent of low surface BOD loadings can be achieved in the final effluent from domestic sewage. Similarly, horizontal subsurface-flow CWs are capable of achieving pollutant organic material (measured as BOD) removal through biological degradation, sedimentation, and microbial uptake processes in the wetland (Kayombo et al no date).

UASBs systems are also appropriate to achieve approximately 75-90 per cent BOD (with short detention time of 6-12 hours) for sewage originating from breweries, distillery, food processing and pulp and paper industries. They require low energy or may alternatively use biogas produced from methane (in the sludge) during treatment processes (Tilley et al., 2008).
6.1.2 Use of natural resource

Similar to other cities in Cameroon, groundwater (which flows as springs) is the main source of clean water supply in LUM. From the data obtained, 10,000 m$^3$/day of clean water was supplied for consumption (to a population of about 120,000 inhabitants). The supply rate does not meet current water demands compared with the daily consumption rates (17,000 m$^3$/day) for Östersund municipality (Sweden) with a population size of 59,300 inhabitants (appendix 18).

With the unlimited drinking water access rate (of 42 per cent) and corresponding wastewater generated (about 80 per cent) from domestic, commercial, industrial or storm water run offs, 75 per cent of sewage generated is stored in both septic and pit toilet systems. The sewage is abandoned, drained (by mobile vacuum trucks) or discharged into surface water bodies untreated.

Sedimentation (settling) tank systems are also appropriate for use to harness and store various categories of sewage produced for preliminary treatment by dewatering. The system is capable of separating both the solid and liquid fraction of faecal sludge. It can achieve about 60 per cent removals for suspended solids before additional treatment can be employed either in WSP and CW.

This will redress incidence of contamination of existing fresh water supply sources e.g. wells, boreholes and local community water sources identified and serving households population residing in quarters like Mile II, New Town (East and West), Bonadikombo (Mile 4), Mokunda villages, down beach area and Cow fence etc.

It should be noted that, treated sewage sludge contains most of the important soil nutrients, which can replace (Drangert 1997; in Berndtsson and Hyvönen 2002) artificial fertilizers (e.g. N and P) to boost land-based agricultural practices and food production (Pimentel and Hall 1989; in Berndtsson and Hyvönen 2002) particularly in CDC palm plantations, nurseries, the tea (field) estates and small and large scale farmlands in the study area. Unsustainable agricultural systems coupled with information gap on the risks, occurrence and escalating incidences of N and P compounds accumulating in groundwater sources (in high rainfall periods) in LUM.

The nutrient loads combined with solid waste materials and sediments are conveyed through urban storm water runoffs, which pollute freshwater bodies downstream. Eutrophication may occur when high levels of urban storm water loads (suspended
solids – SS) clog small streams and rivers, a phenomenon mostly observed during the dry periods of the year in the study area.

WSP and CW are appropriate treatment methods efficient in removing both organic and inorganic loads, SS, solid wastes materials and nutrients, from urban water run-off integrating with freshwater bodies downstream.

According to Mara (1997), about 80 and 95 per cent of the total nitrogen and ammonia respectively can be achieved for nutrients (N and P) removal in WSP. Organic nitrogen is hydrolyze to ammonia (in anaerobic ponds), which is later incorporated into algal biomass and released through volatilization in both facultative and maturation ponds. While Phosphorus removals can be achieved through algal biomass uptake, precipitation and sedimentation processes (Kayombo et al., no date).

Although several stages are involved in the removal and transformation processes of nitrogen compounds (ammonia (NH₄⁺), nitrite (NO₂⁻), and nitrate (NO₃⁻) etc), CWs can be eliminate N compounds in the process of nitrification (and subsequent denitrification), uptake, transformation (with the aid of anaerobic bacteria e.g. nitrobacter and nitrosomonas) (Kadlec and Knight 1996; Kayombo et al., no date) and accumulation of organic nitrogen in sediment beds of SSF CW (Mara 2004).

Phosphorus removal from CW is attained through mechanisms such as adsorption, filtration, sedimentation, complexation/precipitation and assimilation/uptake. Their elimination prevents eutrophication and algal blooms within the wetland (Kayombo et al., no date), streams and rivers.

For Suspended Solids removal, the processes of sedimentation, filtration, adsorption (onto biofilm) and flocculation/precipitation are involved in CW. Their removals prevent re-suspension of sediment loads in the wetland, which does not only release pollutants from the sediments, but increases the turbidity and light penetration for the decomposition processes (Kayombo et al., no date). Even though SS removal efficiency ranges from 67 to 87 per cent (at a low filtration rate) and 45 – 56 per cent at high filtration rates, investigation to assess the effectiveness of CWs in Dar es Salaam, Tanzania reveals mean removal rate of 80 per cent and 50 per cent at low and high filtration rates respectively. The reduction at low filtration rate was
achieved probably due to sedimentation and filtration in the reed bed within the wetland (Mashauri et al., 2000).

6.2 Health and Hygiene Criteria

6.2.1 Clean water availability

In most part of the world, especially in developing countries, there is a huge need for water, and the water the water to meet these needs is becoming scarcer and scarcer (Mara 2004). Although an estimated 42 percent (slightly below the national estimation of 45 per cent) of inhabitants in LUM do not have access water, an estimated 1,800 households, however have access to CdE connection after SNEC was privatized. According to DSNA and UNICEF (2001), this situation is striking for a country and region with abundant fresh water resources (Katte et al., 2003).

The inadequate water distribution in LUM according to Katte et al. (2003) is central to poverty alleviation as it is capable of affecting health, food security and livelihoods.

In addition to the cost of vending water from public stand taps, trekking for long distances to fetch clean drinking water and water shortages during the dry season is pushing inhabitants at the margins to the consumption of water from unprotected sources. With this comes an increasing risk of biological pollution of water and resultant public health problems (Balkema 2003), about two-thirds of water borne diseases and 50 per cent death cases recorded in Cameroon are water related (Katte et al. (2003) in Ndjama et al. (2008).

Also, about one hundred and ninety (190) inhabitants were infected and six (6) deaths recorded in 2011 mainly linked to Cholera outbreak (Mbom 2011).

Well-designed WSP (maturation ponds) and CW treatment systems are suitable options for the removal of faecal (excreted) pathogens e.g. Giadia cysts, Helminth eggs and Ascaris eggs etc, which are primary causative agents for the transmission of infections to humans. For instance, WSPs are highly efficient to remove faecal pathogens (compared to other treatment systems, which will necessitate chlorination in tertiary treatment process) and destroy about 99 per cent E. coli; while sedimentation processes in anaerobic or primary facultative ponds aids the removal of Helminth eggs (Kayombo et al., no date).
According to Reed et al. (1995), CW systems on the other hand are capable (with additional treatment) of removing faecal pathogens from influent inflows into vegetated wetlands through die-off, sedimentation, filtration, ultra-violet light ionization etc processes (Kayombo et al., no date).

6.3 Functional and Technical Criteria

6.3.1 Robustness of the System
Water overflows and loss (along the supply chain) from damaged pipes were identified and associated with constant water supply problem and shortages. From observation, damage to pipelines (during road construction and in rocky terrains) contributes to clean water spill out from broken pipes. An overflow of approximately 6,000m³ of water was recorded in 2010, which demonstrates ineffectiveness of supply infrastructure and materials used in water distribution.

Although the sewage treatment systems (e.g. pit latrines and septic tanks) in LUM are robust and stores different categories of sewage produced from domestic, industrial, and commercial facilities, they were observed to inappropriately treating but facilitate the breakdown of biodegradable organic and inorganic materials etc. The sludge content produced after decomposition does not favored re-used applications (for agricultural and aqua-cultural practices), but were observed to proliferate infections in humans.

Alternatively, WSP, CW, UASB and Sedimentation tanks were identified very robust especially in handling different categories of wastewater. According to Moshe et al. (1972), owing to the long hydraulic retention time, WSP can withstand both organic and hydraulic loads during treatment process compared to other treatment systems. For heavy metals removal, they can cope with high levels (of up to 60 mg/l) and can treat a wide variety of industrial, strong wastewater from agro-industrial processes considered toxic for other processes (Mara 2004).

Moreover, these cost effective and simple treatment methods can thrive in hot or warm climatic conditions, which have been tested for the removal of various pollutants in many developing countries (with land availability) such as Tanzania, Kenya, India, and Australia with water stress zones and are reliable for application in the Limbe urban municipality.
7 Conclusion

The failures to achieve sustainability in water supply, sanitation and wastewater treatment systems in Cameroon could widely be acknowledged as a major developmental problem. Accelerated demographic growth, simultaneous increase in demand for water consumption and sewage produced within quarters of LUM translate the existing systems do not provide integral solutions to rising contributions of untreated sewage (pollution incidence) to both environmental and public health situation affecting the population.

About 75 per cent of sewage generated from domestic (septic tanks and pit latrines), industrial, commercial, hospitals as well as storm water run offs is disposed-off into near-by existing water bodies without pre-treatment as the study area seriously lack wastewater treatment facilities. It is common to find a proliferation of pit and septic tank systems in both permanent and semi permanent households that collect and stores the sewage produced compared to ecological toilet (or biodegrading systems), which to a certain degree effectively reduces excreted or faecal pathogens, *Giardia cysts* and the biosolids etc. Most household constructed nearby water bodies have adopted the habit of draining sewage into water bodies (when full during the raining periods) than paying for mobile vacuum trucks.

In the context of stemming the on-going situation and proliferation of infections, four (4) sustainable sewage systems (such as WSP, CW, USABs reactor and Sedimentation/Thickening tanks) were evaluated within the sustainability viewpoint and assessed with current treatment systems (pit latrines and septic tanks).

WSP, CW, USAB reactors and Sedimentation/Thickening tanks investigated and if well-designed and carefully operated and maintained, are effective in providing positive solutions for the treatment domestic, commercial, industrial sewage and urban run-offs; the favour re-use options of the sewage for agricultural, aquacultural, groundwater recharge, etc. Previous investigations, coupled with assessing the effectiveness of the above treatment method, comparatively with pit latrines and septic tanks, reveals that WSP and CW are highly efficient for the treatment of all categories of high strength sewage.

The systems are simple to construct (require less skilled labour), cost effective (i.e. they require low capital cost for construction, operation and maintainace), use
preferably zero chemicals and energy during treatment processes. Also, they mostly depend on solar radiation that speeds up reactions for the breakdown process. Moreover, the methods do not ensure non-dilution of high strength wastes, but maximizes recovery and re-use of the treated effluents compared with conventional methods e.g. activated sludge, which consumes electricity to power the system.

Well-designed WSP are efficient to achieve more that 90 per cent BOD, suspended solids, and ammonia removals. They are most suitable and particularly efficient to remove excreted pathogens and heavy metal (in anaerobic ponds).

CW if properly designed removes BOD through biological degradation, sedimentation and microbial uptake processes; destroy faecal pathogens, remove approximately 99 per cent of heavy metals through binding to soil particles, sedimentation and particulate matter precipitation as insoluble salts and bacteria, algae and plants uptake. SS removals can range from 67 to 87 per cent (at a low filtration rate) and 45 – 56 per cent at high filtration rates. N breakdown is achieved in a stepwise process that involves nitrification and denitrification and with the help of anaerobic bacteria e.g. nitrobacter and nitrosomonas; and Phosphorus removal occur through algal biomass, precipitation and sedimentation etc.

The UASBs reactors are capable of achieving BOD removal of 75 – 90 per cent. Secondary and tertiary anaerobic processes such as in WSP or involving CW processes support the treatment of high strength biodegradable industrial and agro-industrial sewage. Biogas is harnessed and used as alternative fuel to power treatment processes.

Thickening tank systems are simple and treat wastewater by dewatering. The system also segregates both the solid and liquid components of the treated sewage to produce rich organic sludge, and can achieve up to 60 per cent SS.

With the availability of land space, favorable warm climatic conditions in tropical countries such as Kenya, Tanzania, India, and Australia, investing in the above low cost, simple and energy efficient treatment methods in Cameroon and LUM will adequately anthropogenic impacts to groundwater reservoirs and reduce rising water borne impacts in local communities and quarters such as New town (East and West), Mbonjo, Mabeta New layout, dock-yard etc.
Consequently, for the urban water supply and wastewater treatment systems to be characterized as sustainable, they should involve low capital and maintenance cost, simple to operate and maintain, be efficient to produce low, preferably zero use of chemicals and energy, free from water borne infections, demonstrate high performance for quality effluent produced, produce low sludge, be adapted to local environmental conditions and easy to understand.

**Further research:**

The following topics and areas are considered for future research:

- There is need to investigate and quantify possible effects of pit and septic tank systems for groundwater pollution as compared to biodegradation and dehydrated ecological toilet systems.

- Assess the relationship between water quality and human health. A Case study of water bodies (streams and rivers) in the Limbe urban municipality.

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List of references


Appendix

Appendix 1 Domestic Wastewater Flows and Loads

Wastewater flows from households can be determined from water consumption for domestic usage using the equation below:

\[ Q_{ww} = 10^3kqP \]

Where \( Q_{ww} \) is wastewater flow (m³/day); \( q \) is the water consumption, l/person/day; \( P \) is the population connected to the sewerage system; and \( k \) is the “return factor” (fraction of the water consumed that becomes wastewater). \( K \) value = 0.8-0.9, which lower in rich areas and high in poor areas in car washing and gardening watering. Hence, the mean domestic wastewater flow based on income levels can be derived for developing countries, as Campos and Von Sperling (1996) calculated the mean wastewater flow for Brazil:

\[ Q_{ww} = 58 + 8N_{ms} \]

Where \( N_{ms} = \) Household income expressed as the number of minimum salaries/month (US$100/month in Brazil in 1996).

The above equation presents the “dry weather flow” (DWF) for domestic sewage, a term principally used for sewerage systems which receive both sanitary and storm water flows (combined sewers) commonly found in city centers of developing countries. The DWF is the average wastewater flow per day over seven consecutive days without rain falls.

To determine the BOD contributions for domestic sewage, the BOD concentrations in mg/person/day should be divided by the sewage flow in l/person/day. The flow (as well as loads) of sewage from households vary weekly and yearly. At night (when people are asleep), the flows are lower compared to daytime when it rises sharply (during breakfast, lunchtime and evening or clothes washing at weekends).

Also, more water is consumed during the hot seasons as individual consumption increases either when showering or toilet flushing. It is necessary to determine the daily maximum flows in cases when the wastewater flow is connected to the preliminary wastewater treatment plants. The peak daily flows could be obtained by multiplying the mean daily flow by a “peak factor”, which depends on total population served (i.e. the higher population, the lower the peak factor) and flow fluctuations (Mara 2004).
Thus, as the urban populations of the LUM escalates with sewered populations, the wastewater flows and loads correspondingly increases with time. An increase in per capita water consumption leads to the generation of higher BOD contributions (Mara 2004).

Appendix 2 Septic tanks and Pit latrines design considerations

Septic tanks and pit latrines are the most common methods used to reduce sanitation problems in urban populated areas. Modern designed septic tanks should be connected to sewer systems (to facilitate effluent pumping for advance treatment) or on-site treatment fields for wastewater treatment (Crites and Tchobanoglous 1998). In this system, sewage collected is divided into four layers (1) an upper layer of scum (2) a sedimentation zone (3) a sludge digestion zone and (4) a sludge storage zone at the bottom (Balkema et al., 2005). Caution should be taking to avoid their installation in areas prone to flooding or where the groundwater table is high (Tilley et al., 2008).

Other suitable materials such as steel, fiberglass, PVC and plastics are suitable can be used for construction. The choice of septic tank must be water-tight and structurally sound to ensure proper functioning (Crites and Tchobanoglous 1998).

Ideally it should comprise of two chambers; the first chamber receives the incoming wastewater and facilitates settling of solids. The T-shape outlet pipe structure helps to reduce and separate both solids and the scum. Well-designed septic tank systems are efficient and remove about 50% solid matter, 30 to 40% BOD and 1-log of E. coli in hot climatic regions, than in temperate regions (Tilley et al., 2008).

2.1 Performance of Septic tanks and Pit Latrines

Heavy metal particles settle by gravity at the bottom of the tank, while oil and grease including other light materials floats on top of the liquid surface. This increases the wastewater inflow rate faster than the rate of decomposition (Tilley et al., 2008). The organic portion of the wastewater is broken down by facultative and anaerobic processes (with short retention times of 48 hours) to produce CO₂ CH₄ and H₂S (Crites and Tchobanoglous 1998). It should be noted that, the number of individuals per household, the total amount of water usage, the average temperatures and characteristics of wastewater etc determines the performance or breakdown rate of sewage.
It is advisable to empty septic tanks after every 2 to 3 years (using vacuum trucks) to avoid long-term scum and sludge accumulation, which may reduce settling and decomposition effectiveness, odor and leakage problems (Tilley et al., 2008).

Appendix 3 Physical design of Waste stabilization Ponds

The design of the WSP is not based on nutrient removal; rather, it is based on BOD and faecal coliform removal (Kayombo et al., no date). According to Mara (2004), a wide range of different parameters should consider during the design process of waste stabilization ponds for domestic wastewater treatment in developing countries. These include:

Appendix 3a The location of pond
A preferable distance of about 200m (or 500m) is required for the installation of WSP away from the community they serve and from any likely future expansion. This will prevent people visiting the pond and odour problems.

Even in well-designed and properly maintained systems, the planning phase should include a high degree of certainty and a minimum distance respected to stop people living adjacent to WSP. The site should have suitable soil, be flat or gentle sloping, and accessible with a vehicle (in and around the pond) to reduce earthworks during maintenance.

Appendix 3b Geotechnical Considerations
Below-ground investigations are very important during the preliminary phase of WSP installation.

The main objectives during the investigations are to ensure accurate embankment designs are made, to determine soil’s impermeability (i.e. if pond lining is required), and the maximum height of the groundwater table etc. Also, particle size distribution, maximum dry density, optimum moisture and organic matter contents and coefficient of permeability etc are important parameters to consider during soil properties measurements at site location.

One soil sample should be collected per hectare for analysis of soil profile representation and the envisaged pond depth (of 1m). It is not, however, advisable to use organic and plastic soils and medium-to-coarse sands for embankment construction. Suitable local soils (or excavated local soils from site) could be used and
must be brought to the site at extra costs for the construction of embankment slopes. The soils should be compacted (with 10-30 per cent shrinkage with an \textit{in situ} permeability coefficient of $<10^{-7}$m/s) in 150-250mm layers to 90 per cent of the maximum dry density as determined by the modified Proctor test.

Slope dimension should range from 1 to 3m internally and 1 to 1.5-2m externally; slope steepness may be considered for use if the soil is suitable; while the slope stability must be determined by standard soil mechanics procedures for small earth dams, and planting of grass (especially a slow-growing rhizomatous species – Bermuda grass) be applied to increase stability and reduce maintainace.

Also, adequate drainage systems should be provided to enable the external embankment to protect the pond from storm water erosion, while lean concrete cast \textit{(in situ)}, precast concrete slabs (\textit{figure 14a and 14b}) or stone rip-rap placed at top water levels should be used to protect internal embankments against erosion by wave action. This further prevents vegetation growth (into the pond) and shade habitats for mosquito or snail breeding.

\begin{figure}[h]
\centering
\includegraphics[width=0.4\textwidth]{figure14a.png} \hfill \includegraphics[width=0.4\textwidth]{figure14b.png}
\caption{Embankment protection by pond cast in situ \hfill Embankment Protection by Precast Concrete Slabs}
\end{figure}

\section*{Appendix 3c Pond lining}

There exist different categories of lining materials e.g. plastic, thick-clay liners etc (dependent on local availability and cost), which could be used to line ponds in cases when the soil is too permeable. For soils having an \textit{in situ} coefficient of permeability ($k$) of $k>10^{-6}$ m/s – this indicates that the soils are too permeable and will required lining. $k<10^{-7}$ m/s – not sufficient seepage may occur within soils, but pond should be lined; $k <10^{-8}$ m/s, the ponds should be naturally sealed and when $k <10^{-9}$ m/s – indicates that no risks of groundwater contamination will occur (but hydrological studies are required).
Appendix 3d Pond Geometry

Persson (2000) emphasized that, very little accurate work had been realized in determining the geometry or optimal shapes of WSPs. Although different shapes exist, the length-to-breath ratio, relative position of inlet and outlet, and the rectangular shape are the most common variations that minimize hydraulic short-circuiting. For instance, the anaerobic and primary facultative ponds have rectangular shapes with length-to-breath ratios of 2-3 to 1. This prevents sludge banks forming close to pond inlet. Meanwhile, Pearson et al., 1995 suggested that the secondary and maturation pond geometry will require higher length-to-breath ratios of up to 10 to 1. This dimension better estimates plug flow conditions.

The top and bottom of pond dimensions could be calculated from the equation below:

\[ V_a = [(LW) + (L - 2sD)(W - 2sD) + 4(L - sD)] [D/6] \]

Where \( V_a \) = anaerobic pond volume (m\(^3\)), \( L \) = pond length at top water level (TWL) (m), and \( W \) = pond with TWL (m), \( s \) = horizontal shape factor (a slope of 1 in \( s \)) and \( D \) = pond liquid depth (m). As suggested by Oswald (1975), the dimensions (freeboard) and levels could be derived from the base and top of the embankments. Depending on site considerations for instance, small ponds (of <1 ha in area) 0.5m freeboard is required and ponds between 1ha and 3ha would require a freeboard of 0.5-1m. Also, the pond liquid depths could be obtained considering the following ranges: Anaerobic ponds (2-5m), facultative ponds (1-2m) and maturation ponds (1-1.5m).

According to Stalzer and von der Emde (1972), for WSP serving more than 10,000 inhabitants, the site topography should encourage the installation of two or more series of ponds, which must be connected in parallel to increase their operational flexibility in receiving the same flow and are adapted to split the raw sewage flows into equal parts after preliminary treatment is made.

Appendix 3e Inlet and outlet structures

A wide variation of designs for the inlet and outlet structures of WSP exists, although certain basic criteria facilitate their precise design. These structures should be simple, inexpensive and not complex and expensive structures and should permit the collection of effluent samples from the pond with ease. Hence, to minimize short-circuiting (especially in deep anaerobic ponds), secondary facultative and maturation ponds; and scum reduction (primary facultative ponds) their inlets should be designed to discharge well below the liquid level.
Single inlets and outlets should be diagonally located at opposite corners while multi-inlets and multi-outlets are assumed to improve pond hydraulic. In poorly constructed ponds, one of the outlets settles and its discharged level is then lower than those of the other, hence, the effluents produced (from all the ponds) are discharged (through the outlet) and left literally high and dry. Scum guards are needed to protect all outlets against the discharge of scum.

Outlets located at the final section of the pond in a series, should the effluent into a simple flow-measuring devise e.g. a triangular or rectangular notch. This permits the calculation of evaporation and seepage levels.

Other important parameters to consider during construction are by-pass pipe work, security fences, notices and operator facilities.

Appendix 4 Arrangement of Waste Stabilization Ponds

WSPs are designed with an inlet (ensures the inflow of sewage) and outlet (ensures the outflow of treated effluents) channels (Kayombo et al., no date). Mara (2004) also emphasized the arrangement in series of the different categories of WSPs in sequence (anaerobic, facultative and maturation ponds described above in 5.3 and represented in figure 14 below.

Thus, to achieve higher effluent quality using the WSP systems, two or more maturation ponds can be included. Also, more than one series of WSP with each
receiving equal proportion of the wastewater flows can be aligned (at any one site) in parallel. This design option produces effluent of better quality than when a single type system is used even if of the same total size (Mara 2004).

Appendix 5 Nutrient Removal mechanism in Waste Stabilization Pond

According to Kayombo et al., (no date), the significance of nutrients (N and P) removal from wastewater in WSP is to prevent the occurrence of eutrophication in the receiving water bodies. However, the common practice and design considerations of WSP systems basically consider BOD and faecal coliform removals from wastewater rather than nutrient removals.

This could be achieved from the hydrolysis of organic nitrogen to yield ammonia. The resulting effluent produce in anaerobic ponds often contains a high amount of ammonia compared to the raw influent sewage, which gives algal biomass in facultative and maturation ponds. It is later released from the pond at high pH by the process of volatilization. Unless the wastewater contains high nitrate constituents, for instance, little evidence of nitrification (and hence denitrification) can be observed because of the low population of nitrifying bacteria within the aerobic zone. As a result, total N and NH$_3$ removals from WSP can be achieved at 80 and 95 per cent respectively.

The removal of phosphorus can be achieved due to the presence and uptake by the algal biomass, and in the processes of precipitation and sedimentation occurring within the WSPs. Also, increasing the number of maturation ponds is outstanding to achieving a high phosphorus removal in the wastewater.

Appendix 6 Anaerobic Ponds design

Anaerobic ponds (2-5m deep) are designed based on the volumetric BOD loading ($\lambda_v$, g/m$^3$d), calculated using the equation:

$$\lambda_v = \frac{L_i \times Q}{V_a}$$

Where $L_i$ is the influent BOD, mg/l (= g/m$^3$), $Q$ is the flow, m$^3$d; $V_a$ is the anaerobic pond volume, m$^3$ and $\lambda_v$ the permissible design value. $\lambda_v$ increases with temperature although few data sets exist to enable the development of suitable design equation. Hence, when $\lambda_v$ value has been selected, the volume of the pond can be calculated using the above equation (Mara 2004).
To maintain anaerobic conditions, Meiring et al. (1998) suggested that, the recommended loading should be between 100 – 400 g/m³/day. Hence, when the organic loading is obtained, the volume of the pond can be determined from $QV_{tan}$. For anaerobic ponds, with retention time of less than one day the volume of the pond can be recalculate (Kayombo et al., no date).

Appendix 7 Design of facultative ponds

Facultative ponds are designed on the basis of surface loading $\lambda_s$ (Kg/ha/day), since solar radiation required for photosynthesis arrives from the sun at the pond’s surface according to the equation below:

$$\lambda_s = 10L_iQ/A_f$$

Where $A_f$ = facultative pond area (m²), and $L_iQ$ = mass of BOD entering the pond (g/day). Since the algal oxygen production is a function of the area, the BOD loading equates to the functional area. Hence, once $\lambda_s$ is determined, the pond area can be calculated from the equation below:

$$A_f = AfD/Q_m$$

Where $D$ = pond depth (m) usually 1.5m, and $Q_m$ = mean flow (m³/day). Thus, the mean influent and effluent flow can be obtained from ($Q_i$ and $Q_e$)

Appendix 8 Decomposition rate in facultative Ponds

The processes associated with sewage decomposition in anaerobic, primary and secondary facultative ponds occur at the same time.

![Figure 17 Pathways of BOD removal in primary facultative ponds (After Marais, 1970)](image)

During sewage breakdown (by photosynthetic algae), an estimated 30 per cent of the influent BOD is released from the ponds as CH₄, while a high proportion that is retained is being consumed by algae. This normally takes about 2-3 weeks water
retention times rather than 2-3 days as in the aerobic pond systems, were the “sewage BOD” is converted into “algal BOD”. This occurs in the primary (in the upper layers) and secondary facultative ponds. A well-designed WSP system in series produces about 70 – 90 per cent BOD in the final effluent in relation to the algae they contain.

Meanwhile, in the secondary facultative ponds that receives anaerobic effluent (that is particle-free sewage) from the anaerobic ponds, the heterotrophic bacteria (such as Pseudomonas, Flavobacterium, Archromobacter and Alcaligenes spp) oxidizes non-settleable BOD in the presence of oxygen that is obtained from the photosynthesis of micro-algae that grows naturally and profusely in the facultative ponds (Kayombo et al., no date).

8a Performance
Although facultative pond systems they are designed to primarily remove BOD on a relatively low surface loading range of 100 – 400 Kg BOD/ha per day, this favors healthy algal population growth, since the oxygen required to galvanize the removal process is generated by algal photosynthesis. Accordingly, the increased algal population in facultative ponds amplifies the production of a dark-green color that characterizes the pond’s water color, even though it may occasionally appear red or pink when slightly over-loaded, and in the presence of anaerobic purple sulphide-oxidizing photosynthetic bacteria (Mara 2004). Hence, motile algae (e.g. Chlamydomonas and Euglena) tends to prevail (in the turbid water) compared to non-motile algae (e.g. Chlorella) within the facultative pond.

Studies indicate that, facultative ponds rely on naturally-growing algae population to speed-up the rate of decomposition of sewage, and their concentration is found to increase in the presence of nutrient loadings, temperature and sunlight in the range of 500 - 2000 μg chlorophyll a. These factors are known to accelerate algae photosynthetic activities in the pond with a simultaneous increase in the diurnal variation in dissolve oxygen concentration. During photosynthetic activities, increasing sunlight increases the concentration of dissolve oxygen in water (to a maximum level in the afternoon), which automatically drops to a minimum levels at night, when photosynthesis ceases.

As a result, the algal population (as well as bacterial) automatically begins oxygen consumption for their respiratory activities. At the maximum level, the algae
stimulate the reaction between carbonate and bicarbonate ions, to produce \( \text{CO}_2 \) (for the algal intake) and, releasing an excess of the \( \text{OH}^- \). The water \( \text{pH} \) then rises to above 9 and can kill faecal coliform bacteria. Good water mixing (by wind, heat and inlet design of the pond) with the upper layer of the pond, favors a uniform distribution of \( \text{BOD} \), dissolve oxygen, bacteria and algae, which finally leads to a better degree of waste stabilization (Kayombo et al., no date).

Appendix 9 Mechanism for faecal bacteria removal in Maturation ponds

Further describing the major mechanism and corresponding factor for faecal bacteria removal in maturation ponds time and temperature parameters are known to leverage maturation pond design and determine faecal bacterial die-off. The \( \text{pH} \) value of above 9 (which can kill faecal bacteria except \textit{Vibrio cholerae}) occurs when the pond algae undergoes photosynthesis and consumes \( \text{CO}_2 \) than it is replaced by bacterial respiration. Consequently, the carbonate and bicarbonate ions are breakdown to yield \( \text{CO}_2 \) and \( \text{OH}^- \) as show below:

\[
2 \text{HCO}_3^- \rightarrow \text{CO}_3^{2-} + \text{H}_2\text{O} + \text{CO}_2
\]

\[
\text{CO}_3^{2-} + \text{H}_2\text{O} \rightarrow 2 \text{OH}^- + \text{CO}_2
\]

The resultant \( \text{CO}_2 \) is fixed by the algae while the \( \text{OH}^- \) accumulates and raises the \( \text{pH} \) to 10. Light intensity (with wavelengths range between 425 – 700nm) has been found to destroy faecal bacteria through absorption by humic substances and in the presence of high dissolve oxygen concentration and increases \( \text{pH} \) values (Kayombo et al., no date).

Appendix 10 Constructed Wetlands Design Approaches

Kayombo et al. (no date), emphasized that when planning for the design of CWs, the following characteristic parameters e.g. \( \text{BOD} \), \( \text{COD} \), heavy metals, suspended solids (SS), nitrogen compounds, phosphorus compounds and pathogenic organisms should be considered for removal. There exist three important approaches by Reed et al., 1995; Kadlec and Knight 1996 to be considered during the design phase of CWs. These are empirical approaches that are based on two different “rule of thumb”.

According to Reed et al. (1995) and Kadlec and Knight (1996), wetland systems are attached-growth biological reactors, which uses a first-order plug flow kinetic model as the basis for their performance equations. For instance, the removal of soluble
BOD in SSFCW systems can be achieved through microbial growth attached to plant roots, stems, leaf litter and substrates.

Hence, both Reed et al. (1995) and Kadlec and Knight (1996) described BOD₅ removal in SSFCW using the first-order plug flow kinetics. The first-order kinetics could be defined as the rate of removal of a particular pollutant is directly proportional to the remaining concentrations at any point within the wetland cell.

Appendix 10.1 Reed’s Method

Reed et al., (1995) equation for CW design is based on the first-order plug flow assumption for pollutants that are removed primarily through biological processes e.g. BOD, ammonium (NH₄) and nitrate (NO₃). For CWs, separate equations have been suggested for total suspended solids (TSS) and total phosphorus (TP) using regression analyses (Knight et al., 1993). Below are the design equations based on Reed et al., (1995):

For BOD, NH₄ and NO₃ removal in CW:

\[
\ln\left(\frac{C_i}{C_e}\right) = K_T t
\]

and

\[
t = \frac{V_f}{Q} = \frac{LW_Y}{Q} = \frac{nLW_Y}{Q} = \frac{A_s vn}{Q}
\]

In CW systems, the actual retention time is considered as a function of the porosity of the substrate used as defined by the 3rd and 4th equation above. Thus, the substrate porosity could be obtained from \( n = V_s/V \); where the value \( n \) is the cross-sectional area that is available for flow as indicated below:

\[
K_T = K_R \theta_R (T_W - T_R)
\]

and

\[
A_s = LW = \frac{Q_t}{vn} = \frac{Q \ln\left(\frac{C_i}{C_e}\right)}{K_T vn} = \frac{Q(\ln C_o - \ln C_e)}{K_T vn}
\]

Alternatively,

\[
C_e = C_i \exp\left(-\frac{A_s K_T vn}{Q}\right)
\]
and

Where \( A_s = \frac{100Q}{HLR} \)

Wetland treatment area (m\(^2\)); \( C_e \) = outlet effluent pollutant concentration (mg/l); \( C_i \) = influent pollutant concentration (mg/l); \( HLR \) = hydraulic loading rate (cm/day); \( K_R \) = rate constant at reference temperature (day\(^{-1}\)); \( K_T \) = rate constant at temperature \( T_W \) (day\(^{-1}\)); \( L \) = wetland length (m); \( n \) = porosity (expressed as a decimal fraction percentage); \( Q \) = average flow rate through the wetland (m\(^3\)/day); \( t \) = hydraulic residence time (day\(^{-1}\)); \( T_w \) = water temperature (°C); \( T_R \) = reference temperature (°C); \( V_f \) = volume of wetland available for water flow (m\(^3\)); \( W \) = width of the wetland (m); \( y \) = wetland depth (m); \( Q_R \) = temperature coefficient for rate constant; and \( V_v \) and \( V \) = volume of the voids and total volume respectively.

For TSS removal:

In SSF CW systems, \( C_e = C_i (0.1058 + 0.0011 HLR) \)

While in FWS CW systems, \( C_e = C_i (0.1139 + 0.00213 HLR) \)

For Total phosphorus removal in both SSF and FWS wetlands

\[
C'_e = C_i e^{\left(-\frac{K_T}{HLR}\right)} \quad \text{Where } K_T = \text{the first-order phosphorus reaction rate (2.73 cm/day)}
\]

Appendix 10.2 Kadlec and Knight design method

Kadlec and Knight (1996) method consider the first order decay rate, plug flow model for pollutant removals including BOD, Total Suspended Solid (TSS), Total phosphorus (TP), Total nitrogen (TN) and Organic nitrogen (OrgN), ammonium nitrogen (NH\(_4\)-N), oxidized nitrogen (NO\(_x\)-N) and faecal coliform (FC). Although it is less sensitive to different temperature, their model is based on real rate constants, independent of temperature following the equation below:

\[
\ln \left( \frac{C_e - C^*}{C_i - C^*} \right) = -\frac{k}{q} \quad q = \frac{365Q}{A_s} \quad A_s = \frac{365Q}{K} \ln \left( \frac{C_i - C^*}{C_e - C^*} \right)
\]

\[
C'_e = C^* + (C_i - C^*) \exp \left( -\frac{A_s k}{365Q} \right)
\]
On the other hand;

Where \( A_s \) = wetland treatment area (m\(^2\)); \( C_e \) = effluent concentration target (mg/l); \( C_i \) = Influent concentration target (mg/l); \( C^* \) = pollutant background concentration (mg/l); \( K \) = first order aerial rate constant (m/yr); \( q \) = hydraulic loading rate (m/yr) and \( Q \) = average flow rate through the wetland (m\(^3\)/day).

Kadlec and Knight (1996) advocated for a global and specific parameters determined from plug flow analysis performance and prior to investment in a full-scale system respectively, to ensure the suitability of design option.

These parameters include;

10.3) System layout

The various components of the system layout to be considered include the preliminary/primary treatment unit, CW cells, substrate, vegetation, and biological organisms contained in the physical configuration.

10.4) Configuration

The arrangement of CW systems should increase effective distribution of wastewater to maximize contact between the wastewater, substrate, and vegetation by reducing short-circuiting. The configuration should consider pre-treatment degree, required treatment area, available land/space (shape and slope), length-to-width ratio, desired bed slope, the amount of excavation and grading (to obtain depth and slope), substrate type, collection pipes, and operation and maintenance flexibility.

Three configurations for CW cells that can be used for the treatment of wastewater include: parallel, series or combination of both. Parallel cells are often aligned to provide flexibility and redundancy in operation and facilitate removal of individual cell lines for repairs and maintenance. Water is re-directed into other cells allowing ongoing treatment process in the wetland.

When configured in series, water flow sequentially from one wetland to the next forming a chain of wetland cells. The cells arranged in series minimize short-circuiting, leading to better overall treatment in the system.
Kadlec and Knight (1996) concluded that, the choice of configuration should provide a clear understanding of the objectives, influent water quality, desired effluent water quality, hydraulic regimes and site specific constraints and opportunities.

10.5) Preliminary treatment

The use of CW systems for wastewater treatment must be preceded with screening. Imhoff tanks, septic tanks or waste stabilization ponds could be used as primary treatment units. For small communities with water flow rate of 380 m$^3$/day septic tank systems may be used as primary treatment unit for the reduction of organic solids.

Appendix 11 Free Water Surface Constructed Wetlands (FWS)

During the treatment of wastewater in the FWS constructed wetland systems, pre-clarified wastewater (both black and greywater) are continuously added into the wetland to be treated (Kayombo et al., no date). This is later allowed to flow horizontally (with a hydraulic retention time in a range of 7 – 50mm day$^{-1}$) over the soil surface and through the stems and roots of the vegetation that is rooted into the sediment layer in the water column (UN 2003) (figure 10 above).

Physical, chemical and biological actions simultaneously take place, which filter soils, degrade organics and facilitate nutrient removal from the influent wastewater (Tilley et al., 2008). Worth-noting is the fact that, the roots of the growing vegetation provides the surface for the attachment of bacterial films, facilitate filtration and adsorption of wastewater constituents, oxygen transfer in the water columns, and the penetration of solar energy that favors the growth of algal population (UN 2003).

After pre-treatment of the wastewater, the heavier sediments settle out while nutrients (N and P) uptake is conducted by plant roots. However, chemical reactions will facilitate the precipitation of other elements, while pathogens removal is conducted either by natural decay process, predation from higher organisms, sedimentation and UV radiation (Tilley et al., 2008). These create an aerobic (near the water surface), as well as anaerobic environment (near the sediment), (Bojcevska 2006), which favors high removals of BOD and TSS (UN 2003) with the help of bacteria activities (on the plant surface) as the main process of pollutant removals in wastewater (Kayombo et al., no date).
This technique is most suitable for the treatment of low strength wastewater and can be efficient for small sections of urban and sub-urban communities and rural areas with primary treatment facilities such as septic tank systems (Tilley et al., 2008).

Appendix 12 Subsurface-flows (SSF) Horizontal Constructed Wetlands

12a Description
As mentioned above, the horizontal subsurface flow (hSSF) CWs consists of large gravel and sand-filled canal planted with aquatic vegetation plant types for the treatment of wastewater. They allow primary treated wastewater to flow horizontally and through the channels and filters, before degradation (by microorganisms) of organic matter occurs.

In this wetland system, the water depth and bed are kept at 5 to 15cm (to guarantee subsurface flow) and wide and shallow (to maximize water flow path) respectively, and as shown in figure 11 above. Pre-treated wastewater flows through the wide inlet zone into the bed, which is lined with impermeable clay material. In addition, small, round, evenly sized gravel material (of 3-32mm in diameter) is filled on the bed to a depth of 0.5 to 1m. The use of the gravel filled bed offers a comparative advantage over the sand filled bed and redress incidence of inlet clogging and efficient treatment of effluent.

12b Performance:
During the effluent treatment process occurring in the hSSF wetland systems, the rock-filter media filters solid materials, provide a fixed surface for bacterial attachment and activities and forms a support for the growth of vegetation cover. The vegetation provides oxygen to the root zones to ease the effective degradation of the remaining organics from facultative and anaerobic ponds by aerobic bacteria. In maintaining the permeability of the filter media, plant roots with deep and wide roots that can thrive in wet, nutrient-rich soils environments e.g. Phagnites australis (reed), play a significant role in increasing permeability and nutrient adsorption (Tilley et al., 2008).

In hSSF CWs, pathogens removal mechanisms from the effluent can be achieved through natural decay, predation by higher organisms and sedimentation processes. Suspended solids removals is accomplished by entrapment in the gravel interstices and sedimentation, while several factors such as nitrification (and subsequent
denitrification), plant uptake and organic matter accounts for ammonia removals in the sediment beds (Mara 2004).

Alternatively, this wetland system is not a suitable option for untreated domestic wastewater (e.g. blackwater), as clogging of the inlet will be a common problem. As such, the wastewater should undergo primary treatment (e.g. in septic tanks or WSPs) before it is allowed to flow into the SSF wetland to achieve higher effluent quality. It application is suitable for small urban, sub-urban and rural communities with warm climates. Mosquitoes breeding risks is reduced compared to the risks associated with FWS Constructed wetlands (Tilley et al., 2008).

Appendix 13 Up-flow Anaerobic Sludge Blanket (UASBs) Reactors

In the USAB systems (explained in section 5.4.1.3), raw wastewater, after screening and grit removal is distributed to the base of the reactor. It flows upward through the sludge layer (sludge “blanket”), and reacts with anaerobic bacteria, (by anaerobic biochemical reactions), to increase the effectiveness of BOD removal in the reactor. The wastewater (collectively with the active sludge particles) rises through the reactor and further ensures more BOD removal to occur during the process.

In the “phase separator” (divides the reactor into a lower digestion zone and an upper settling zone into solid, liquid and gas), the wastewater-sludge suspension rises through the settling zone reducing the up-flow velocity due to the outward inclined surface of the phase separator. This causes the flow area to enable the suspended sludge particles to settle out mainly on the inclined sides of the phase separator. A high concentration of the sludge particles is therefore maintained in the phase separator within the lower zone of the reactor to facilitate the discharge of effluent with low concentration suspended solids from the reactor. The deflector, (found under the phase separator zone) helps to prevent the flow of biogas bubbles into the settling zone to hinder sedimentation.

Biogas with high concentrations of methane produced as by-product is captured under the phase separator and used for energy source (electricity generation) of the facility (Mara 2004). The construction of the above types of wastewater treatment systems will increases awareness of the operation of such low-cost, low-energy efficient treatment techniques.
Appendix 14 Sustainable Technology

Sustainable technology (or appropriate technology) is technology that is compatible with or easily adapted to function with natural, economic, technical, social, and environmental resources that can readily offer both long-term and global possibilities for development.

Sustainable technology does not degrade the diversity, quantity and quality of resources, but strives to provide sustainable solutions through lowest costs involvement and with respect to the different environmental systems. It can either be of high-tech or low-tech (as long as it is appropriate to handle a particular circumstances), effective, efficient, and capable of providing real solution with minimal costs. For instance, as the quantity and quality of resources, and coupled with the flexibility of the environmental systems to assimilate emissions over time and space differs, achieving sustainable solutions will include balancing the different economic, environmental and socio-cultural costs with respect to different choices for actors.

However, different dimensions of sustainability should be considered when analyzing or finding technological solutions both in the long-term and global viewpoint that can contribute to reducing local and global economic, environmental and socio-cultural problems.

With respect to finding suitable technological solutions to problems in the water sector for instance, the sustainability (taking as the starting point) of the different technological solutions should be analyzed. Analyzes of the different interactions of the technology with the environment is represented in figure 18 below. The first important step involves achieving a translation of the end-user’s demand into functional criteria, which must be achieved by the technology.

This is vital as the choice on the functional level is achieved. Also, the request for safe drinking water can be translated into drinking water standards. As such, the actual problem associated with drinking water alone, may not have been solved, as hygienic sanitation and hygiene in food are also incorporated.
Thus, an integrated approach of how the problem is embedded and interrelated with other problems is important to be considered in achieving a realistic technological solution.

Moreover, in order to fulfill the function, the technology uses resources from the environmental systems that affect the environment through emissions. The different resources that can be used for instance include money from the economic environment; natural resources e.g. water and energy from the physical or ecological environment, and expertise from the socio-cultural environment (Balkema 2003).

Appendix 15 Description of Sustainability Indicators and Criteria

15a Environmental Criteria
According to Balkema (2003), to conduct an assessment using environmental criteria, analyzes of the optimal resources and emissions should be considered. The optimal resource use can be expressed in indicators such as water use, energy use, bio-gas production, space requirements, the quality of the utilized space and nutrients use alternatively as fertilizers or soil conditioner.

For water use, the total water use, drinking water use, household water use, rainwater use and reuse possibilities for treated wastewater for households or for irrigation or infiltration purposes should be investigated.

Emissions are expressed as discharges; combined sewer overflows and wastes (i.e. the quality of effluent and sludge, combined sewer overflows and gaseous emissions (Balkema et al., 2002). Emissions originating from air and the use of chemical could be used to develop indicators, but due to data scarcity, they are often not included.

When conducting future assessments using the environmental criteria, suitable methodologies applicable for evaluating the environmental criteria to consider include: conducting a Material-flow analysis, Life Cycle Assessment, Environmental
Impact Assessments and Exergy Analysis (Kärrman 2000) throughout the water supply chain.

15b Social-cultural Criteria

The socio-cultural indicators play an important role during technological implementation (for instance in the case of water use, sanitation and on-site treatment) although often they are often not quantified and addressed. Indicators in this criterion include:

- **Acceptance**: Different people as well as cultural have different perception of both wastewater and sanitation arising from different habits. Thus, the implementation of new sanitation concepts or wastewater treatment methods will obviously encounter socio-cultural difficulties in their acceptance by the community.

- **Expertise**: Adequate knowledge is required for selecting technologies that provide sustainable solutions during their installation and operation. Lack of knowledge locally would require importing or training individuals on the functioning of a particular technology.

- **Institutional requirements**: There exist different wastewater treatment systems that require different regulations and control mechanisms for different standards. What is important is to ensure the existing institutional infrastructure of the region fits into current global regulations and standards.

- **Participation**: It is imperative to take into account the major key players that should be included in a particular management approach. The participation of different actors, end-users for instance, creates ownership, responsibility and awareness.

Valuable methods suitable for use in evaluating the water supply sub-sector with the support of the socio-cultural criteria include observation, focus-group discussions or interviews and action-oriented research.
## Appendix 16 List of quarters and villages in Limbe Urban Municipality

### Limbe I (More populated)

1. Church street  
2. Half mile  
3. Mile one  
4. Nambekke street (Gardens)  
5. Bota – Middle farms  
6. Bota Road Layout  
7. Bota annex  
8. G.R.A Bota  
9. Cassava farms  
10. New town – East and West  
11. Livanda Congo  
12. Down Beach – Dog-yard  
13. Mabeta New-layout  
14. Mile 2  
15. Lumpsum  
16. Bonadikombo – Mile 4  
17. Clerks quarters  
18. Limbe Camp  
19. Middle farms  
20. Federal Quarter (Customs quarter)  
21. Indian Quarter  
22. Cat Quarter  
23. Layout behind Nurses Quarter  
24. Towe Quarter  
25. Cité SONARA  
26. Cité SIC

### Limbe II

1. Bota Land  
2. Wovia  
3. Bobende  
4. Mukundange  
5. Isokolo – Mokindi  
6. Batoke  
7. Mukunda  
8. Botaland  
9. Limbola  
10. Kie village  
11. Ngeme

### Limbe III

1. Bimbia  
2. Bonangombe  
3. Dikolo peninsular  
4. Man O WAR Bay Road Layout  
5. Bonabile  
6. Mabeta fishing port

Source: Awum et al. (2001)
Appendix 17 Status of water supply and sanitation in the Limbe urban municipality – Fact finding survey sheet

Department of Engineering and Sustainable Development
Mid Sweden University, Östersund – Sweden

STATUS OF WATER SUPPLY

Name of city/town: Limbe

1. General

b) Area covered by Camerounaise des eaux connections (in sq. km.) (in 2009)

(c) Population living in various quarters (If applicable):
   New Town Church Street Down Beach Lumpsum
   Cassava farms GRA Bota Coconut Island
   Gardens Mbende Mile II

2. Institutional Arrangements for Water Supply
Name the company or groups responsible for:
   a) Water supply in the Limbe municipality: MIES, CAMWATER, CDE
   b) Planning, designing and execution of capital works: CAMWATER
   c) Operation and maintenance: CAMWATER
   d) Collection of revenue (water tax, charges, connection fees etc.): CDE
   e) If water is purchased, which organization/group is responsible for bulk water supply, operation and maintenance and others: CDE

3. Quantity of Water (please specify the unit of measurement)
a) Installed capacity of the system
   b) Quantity of water produced
   c) Quantity of water supplied i) Treated

   d) Give the total quantity of piped water supplied for various uses? (Please specify unit of measurement used where applicable)?
   a) Domestic consumption: 2009 290,000 m$^3$ 2010 300,000 m$^3$
   b) Industrial consumption: 2009 250,000 m$^3$ 2010 250,000 m$^3$
   c) Commercial consumption: 2009 14 000 m$^3$ 2010 14 000 m$^3$
   d) Public consumption: 2009 10,500 m$^3$ 2010 10,500 m$^3$
   e) Water losses due to system losses, leakages, theft etc: 6000 m$^3$
   f) Total hours of water supply/day: 24 hrs
   g) Number of times supplied daily: 2 times daily
4. Total No. of metered connections:
   a) Domestic (household): 2009 5800 2010 6000
   b) Industrial & Commercial: 2009 200 2010 240
   c) Others (specify): 2009 __________ 2010 __________

5. Source of Water:
   a) Name the present source of raw water supply (surface/groundwater/spring)?
      ____________________________
      
      **Evongo Village (Mile II)**
      ____________________________
   b) Present distance from treatment tank to source (km) __15km__
   c) Are there any proposals for obtaining water from new sources? Yes/No __Yes__
      If yes, ____________________________
   d) Name the source(s) ____________________________
      Mile II
   e) Quantity to be obtained __2800 M³__
   f) Distance to source (km) __300m__
   g) Anticipated year of obtaining water __Approx. 1yr, depending on availability of material__

6. Quality of Water:
   a) Name the type of treatment provided to raw water before supply i) Alum ii) Chlorine iii) others
      (specify): ____________________________
      Chlorine
   b) The agency responsible for water quality monitoring: ____________________________
      CDE, MIHEE
   i) Indicate whether laboratory testing is conducted before water supply? Yes/No ____________________________
   ii) If no, give future plans for improvement of water quality: ____________________________

   c) How is periodic monitoring of water quality conducted (daily/hourly/yearly):
      i) Raw water __Daily__
      ii) Treated water - At treatment plant __Daily__ At distribution network __Daily__

7. Treatment plants (Please specify unit of measurement used where applicable):
   a) Name the No. of treatment plants available: __One__ and location __Mile II__
   b) Give the total installed capacity of treatment plant(s): __3 treatment plants__
   c) Indicate the total present production: __10,000 M³__
   d) Give the number of houses connected to Camerounaise des eaux distribution network?
      More than a thousands.
8. Please indicate how Water Tariff is distributed in the following situations:

<table>
<thead>
<tr>
<th>Domestic</th>
<th>Industrial</th>
<th>Commercial</th>
<th>Others (specify)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Metered</td>
<td>364Fr/m³</td>
<td>364Fr/m³</td>
<td>364Fr/m³</td>
</tr>
<tr>
<td>b) Unmetered</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(if applicable)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c) One-time water</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>connection charge</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

d) In which year was water tariff was established and last revised: ________________________________

f) Is water tax imposed to inhabitants or it falls within company income generating policy? Yes/ No

If yes, water tax distribution rate? 19.25%

9. Revenue Income and Expenditure on Water Supply (Actual):

i) Total Water tax collected (2009) 113,700FCFA (2010) 17,000FCFA

ii) Water charges from collection point (if applicable) (2009) not applicable (2010) not applicable

iv) Connection charges (2009) 120,000 - 300,000FCFA (2010) 120,000 - 300,000FCFA

v) Total cost for water treatment daily 700,000FCFA monthly 3,000,000 yearly 36,000,000FCFA

10. Staff Position:

a) No. of managerial staff: 56

b) No. of technical staff: 15

c) No. of staff allocated for Operations & Management: 20

d) Total staff of the department: 85

11. Privatization - Water Supply

When was SNEC privatized to Camerounaise des eaux? 2008

12: Indicate the year and incidence of water borne diseases that has been witnessed and the area affected by water contamination:

<table>
<thead>
<tr>
<th>Year(s)</th>
<th>Water borne disease type(s)</th>
<th>Area of Occurrence</th>
<th>Casualties (dead etc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>Cholera</td>
<td>Isoko</td>
<td>6 deaths</td>
</tr>
<tr>
<td></td>
<td>Cholera</td>
<td>Makoto</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cholera</td>
<td>Limbe</td>
<td></td>
</tr>
</tbody>
</table>
13. Please give the environmental impacts that have been witnessed during water management and supply (water treatment and distribution)?

Environment (Water Impacts)

<table>
<thead>
<tr>
<th>Year</th>
<th>Impacts</th>
<th>Solution</th>
<th>Casualties</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>Road destruction</td>
<td>Rebuild</td>
<td>Public</td>
</tr>
<tr>
<td>2010</td>
<td>Pipe leakage</td>
<td>Maintain immediately</td>
<td>none</td>
</tr>
<tr>
<td>2011</td>
<td>Pipe leakage</td>
<td></td>
<td>none</td>
</tr>
</tbody>
</table>

Other related Impacts identified during water handling water?

<table>
<thead>
<tr>
<th>Year</th>
<th>Impacts</th>
<th>Solution</th>
<th>Casualties</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>Too much chlorine in water</td>
<td>Main collection emptied</td>
<td>none</td>
</tr>
</tbody>
</table>

Thanks for responding!!!!!
A SURVEY OF STATUS OF WATER SUPPLY, SANITATION AND WASTEWATER MANAGEMENT IN THE ÖSTERSUND MUNICIPALITY - SWEDEN

Four Wastewater Treatment Methods Evaluated from a Sustainability Perspective in the Limbe Urban Municipality - Cameroon (Central Africa)

D – Thesis Research 2012

Name and Designation of respondent(s) _Jenny Haapala_study and investigation engineer___

Name of the responding organization ________Östersunds Kommun______________________

Address of the organization __Rådhuset 831 82 Östersund____________________________

1. General

a) What are the current total population, area and households of water coverage in Östersund municipality?

Total population:____59300____________________________

Area of water coverage: Households: _____31 000 _________________

2. Institutional organization for water supply

Name the company or authorities responsible for:

a) Water supply in the Östersund municipality_Östersunds kommun Vatten Östersund_

b) Planning, designing and maintenance of water works_ Östersunds kommun Vatten Östersund_______

Planning___ Östersunds kommunVatten Östersund________________________

Designing___ Östersunds kommunVatten Östersund________________________

Maintenance:___ Östersunds kommun Vatten Östersund______________________

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3. Quantity of water supply

a) What is the total yearly and daily water supplied per person (if applicable) for household uses?


b) What is the total installed capacity of water treatment plant? _Distributes 17 000 m3/dygn Minnesgärden___

c) Number and Location of water treatment plant? _______6____Minnesgärden, Lit, Häggenäs, Lillsjöhögen, Fåker och Tandsbyn_____________

d) Source of water collection? __2 lakes and 4 groundwater____________

e) Distribution material (pipes) used to serve households? _concrete, plastic and stainless________

f) What is the current population or household non-access rate to drinking water?

_The households that don’t get drinking water from the municipality has own water from lake or ground water_

f) What is the total yearly and daily amount of water losses (if applicable)?


4. Water quality

a) What is the type of treatment method applied to raw water before distribution e.g. Ozone, Chlorination or others? _For Minnesgärdets vattenverk. Alkalinity increase, sand filter, Ozone, chlorination and UV_____________

5. Please indicate the year, occurrence and incidence of water borne infections, toxic Chemical and heavy metals in drinking water and total population infected due to water contamination

a) Water borne infections?

<table>
<thead>
<tr>
<th>Year(s)</th>
<th>Water borne disease type(s)</th>
<th>Town or location of occurrence</th>
<th>Casualties</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010___</td>
<td><em>cryptosporidium</em>____________</td>
<td>Östersund____________________</td>
<td></td>
</tr>
</tbody>
</table>

b) Chemical compounds accumulation in drinking water?
c) Heavy metal occurrence or accumulation in drinking water?

d) Please give the year and occurrence of eutrophication events and nutrients accumulation in lakes or rivers (If applicable?)

<table>
<thead>
<tr>
<th>Year (s)</th>
<th>Nutrient (substance) accumulation</th>
<th>Town or location of occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6. Wastewater treatment

a) Please give the number of wastewater treatment plants in Östersund municipality?

8

b) What is the yearly and daily quantity of wastewater treated by one plant (if applicable)?

i) Daily quantity (in 2010) 21700 m³

ii) Yearly quantity (in 2010) 7 909 884 m³

c) Please estimate access to sanitation and coverage rate?

Thank you for your time.

Stamp, Signature and/or Name

(If applicable)