An Evaluation of Urban Water Systems using Environmental Sustainability Indicators

A case study in Adenta, Ghana.

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Abstract

Problems with water supply and sanitation coverage are increasing around the world today, especially in developing countries. Lack of infrastructure together with an escalating population growth is a matter of great concern in many big cities. In Accra, Ghana the problems are connected to periurban areas where planning of water services has not taken place ahead of development. In Accra development of the present urban water system is essential.

At the same time conventional urban water systems has proven to have environmental drawbacks. New sustainable solutions for water systems are necessary in order to release the pressure on water resources and on the environment. The transformation from conventional unsustainable solutions towards more sustainable solutions demands tools that can measure the degree and progress towards sustainability. Environmental Sustainability Indicators (ESI) has been suggested as such tools for a number of fields including urban water systems.

This case study applied 11 ESI to the urban water systems of Adenta, a periurban area of Accra. The indicators were chosen on the basis of previous studies made in Sweden and South Africa (Zinn, 2000; Lundin 1999). The main aim was to evaluate the present urban water system of Adenta with the help of indicators and to make scenarios in order to investigate whether alternative water systems are suitable from a sustainability point of view.

Adenta, situated in the northeastern metropolitan area of Accra represents an area of 18 000 underserved. Piping exists but was only planned for a sixth of the population. Most of the residents buy their water from tankers. No piping exists for wastewater and human excreta, the inhabitants in Adenta are using septic tanks and onsite sanitation systems.

The problems in Adenta were connected to the raw water quality, the usage of chemicals for drinking water treatment and the release of nutrients to receiving waters. Withdrawal, and wastewater production is currently not a big problem as water usage is quite low. In order to compare the present system with alternative solutions, three urban water system scenarios were set with the help of Environmental Sustainability Fingerprints (ESF).

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Abbrevations

ATMA, Accra Tema Metropolitan Area

BOD, Biological Oxygen Demand

COD, Chemical Oxygen Demand

ESF, Environmental Sustainability Fingerprint

ESI, Environmental Sustainability Indicators

GDP, Gross Domestic Product

GWCL; Ghana Water Company Limited

KNUST, Kwame Nkrumah University of Technology and Science

LCA, Life Cycle Assessment

OECD, Organization for Co-operation and Development

PWT, Private Water Tankers

SDI, Sustainable Development Indicator

USAB; Up –Flow Anaerobic Sludge Bed

UWS, Urban Water System

WHO; World Health Organization

WWTP, Wastewater Treatment Plant

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1. Introduction

Access to fresh water cannot be taken for granted by many people around the world today. It is estimated that 15 000 people die every day due to the lack of water, mainly in developing countries. By 2025, 3 billion people will live in areas lacking water due to the increasing world population (WHO/UNICEF,2000). Africa is the continent, which has one of the lowest water supply and sanitation coverage of any region. In global terms Africa contains 28%of the world's population without access to water and 13 % of people without access to improved sanitation worldwide (SIDA, 2000). African countries also face a lack of investment capital for expanding the existing water systems. The increase of urban areas is another threat to water supply due to uncontrolled growth and lack of infrastructure. It is predicted that Africa in particular will experience increased growth in the urban areas (WHO,2000). The rapid expansion of the cities creates periurban areas that do not have a regular water supply or adequate wastewater treatment. Where such exist they are often malfunctioning or designed for a much smaller population than present. One of these underserved periurban areas is Adenta, located northeast of central Accra in Ghana. Piping for water supply exists, but was originally designed for one sixth of the present population. To face the demand for water, there is a temporary solution of water tankers supplying Adenta with water. Wastewater treatment is another issue of great concern, as no piping for solid waste exists. Most of the residents use different kind of latrines for human excreta and septic tanks.

Expanding water infrastructure in developing areas is a great challenge, especially in urban areas. Pressure on fresh water resources and the aquatic environment increases dramatically. In order to develop environmentally friendly solutions of water systems, tools for measuring and assessing progress towards sustainable development are necessary (Zinn, 2000). One method that has gained a lot of interest recently is the use of Sustainable Development Indicators (SDI). These aim at making the concept of sustainable development measurable by quantifying trends in society and determining if we are moving towards sustainable development or not (Harger and Meyer, 1996). Lundin *et al* have compiled a number of proposed environmental sustainability indicators (ESI) for urban water systems, and also evaluated these in case studies in urban areas of Sweden and South Africa. The indicators were proven to be useful for assessing temporal variations of the urban water system and for the identification of change in environmental activities in both countries. A separate study that evaluates different scenarios of urban water systems with the help of indicators is the next step. This may guide decision makers at various levels so alternative solutions for different water systems can be applied. In this way a developing country like Ghana does not have to rebuild the water systems in the future, a big advantage compared to the majority of industrialized countries.

2. Aim of study

The aim of the study is to evaluate the use of indicators for sustainable development in the field of urban water systems in a developing country. The objectives are to select indicators and to analyse the current situation of the water system in a periurban area and to investigate whether alternative water system infrastructures are suitable from an environmental sustainability point of view.

3. Urban water systems and sustainable development

The aim of conventional large-scale urban water systems is primarily to protect the health of citizens and to supply water for a low operational cost. The services that the urban system should provide includes; a reliable supply of safe water to all residents for drinking, hygiene and household purposes, safe transport and treatment of wastewater and drainage of urban areas. However, today's conventional UWS are having problems with meeting the growing demand as the cities around the world are increasing in size much faster than an expansion of the system is possible. Other problems are related to the environment, such as the difficulties with recycling nutrients, increasing pressure on resources and a mixing of different water qualities that contaminates sludge and thereby complicate the recycling of nutrients further.

As awareness of the water systems influence on the environment has grown changes towards more sustainable alternatives in the future are necessary. Lundin (1999) defined sustainable urban water systems, as ′an urban water system that over a long-time perspective provides required services while protecting human health and the environment, with a minimum use of scarce resources′. A sustainable urban water system must in addition to the original objectives, consider things like reliability, efficiency, preserving the quality of raw water resources and reduce the environmental effects on the resource.

There are several publications of criteria for sustainable development concerning urban water systems. (Balkema 1998; Larsen *et al*, 1997; Karrman 2000). Lundin (1999) has compiled a list that includes technical, environmental, economic and social aspects

Technical performance can be considered from two sides, effectiveness and efficiency. Effectiveness is the extent to which the objects are achieved (drinking water quality) and efficiency is the extent to which resources are utilized optimally (use of chemicals or percent of leakage).

Reliability, flexibility and adaptability. A reliable urban water system does not break when unexpected events occur such as an electricity delivery stop. A system with frequent failures could not be regarded as sustainable. It must be capable of recovering without unnecessary effort or cost. The water system also has to be adaptive to changes in the social and physical environment in which they are embedded. Adaptation can be described as a process of modification of structure or behavior. The urban water system's potential to change (flexibility) and the ability to change (adaptability) will affect the future possibilities of approach sustainability.

Durability refers to the lifetime of the technical system. The life expectancy is usually quite long (20-40 years) so a balance between endurance and flexibility is necessary since components having a long lifetime might decrease the flexibility

Scale and degree of centralization. A small water treatment plant might be advantageous where conditions are appropriate like in an area low population density. In a larger city where economical and geographical conditions are different the potential for using more sophisticated technology is higher, and a large-scale system might be more appropriate.

Environmental protection. The UWS must fulfill the objectives of limited pollution and a sustainable use of resources. For example avoiding harmful substances in order to protect the aquatic environment and the quality of sewage sludge and protection of fresh water resources.

Recycling and reuse of resources, like plant nutrients, phosphorous, organic compounds, fossil fuels, relevant chemicals and metals. High degrees of recycling lower the total emissions on water and air.

Noise, odour and traffic needs to be considered, e.g. for the collection of sewage or transportation of sludge.

Cost-effectiveness, affordability. This can be looked upon from different perspectives; household, organization or society. Households requires a reasonably priced service, an organization a cot-effective system and a society requires a stable but flexible system.

Demographics. Population, population growth and specific water use are example of indicators that can be used to assess future and existing needs.

Social dimensions. All humans need safe water supply and an adequate sanitation. Hygiene is a major consideration and the UWS must be safe for users, operators and the ones taking care of the final products (e.g. sludge). If water management should be considered sustainable, it is necessary that the risk of infection be minimized. User friendliness and cultural acceptance is crucial if the system itself will sustain or not. Freedom of choice is important; as some individuals are willing sacrifice time and effort in order to reduce the environmental impact while others are not

Awareness and stimulation of sustainable behaviour. User behavior affects the function of the UWS. The direct use of water and chemicals are the most obvious but our lifestyle also affects the resource use and emission.

3.1 Sustainable UWS technologies

There are many opportunities for sustainable UWS technologies. Steady progress has been made in the design of water recycling/reuse technologies, some of which are already on the market. However, whilst the introduction of alternative systems is desirable from the viewpoint of policy makers and engineers, implementation remains problematic with regard to suitable technology configuration, appropriate scale and user acceptance (Jeffrey *et al*, 1997). Lundin *et al* (2000) and McCarty (2000) have identified different strategies:

Further development of large-scale, centralized systems

In traditional large-scale systems it is possible to increase the efficiency of treatment processes and decrease the use of harmful chemicals. Water use can be decreased by the installation of water saving appliances, repair of leakage and saving and reuse of water. In regions where water is scarce, wastewater can be reused for irrigation or toilet flushing. Another approach is to increase the degree of removal through mechanical, biological and chemical unit processes. Sewage sludge can be treated to extract harmful metals or substances and then be used as construction materials or for other purposes. Heat can be recovered from the wastewater and aerobic methods can be used in order to produce biogas and save electricity. To increase the biogas production organic waste can be added to the sludge.

Separation of flows

Separation of flows is a well-known concept that has been studied a lot through the years. It improves the opportunities for recycling and reuse. Separation of urine is a promising technology. Human urine contains a lot of nutrients, which can be returned to agriculture and reduce the use of mineral fertilizers. The environmental loads coming from the production and use of mineral fertilizers could thus be avoided. Separation of black water is also possible. When black water is not diluted with grey water technologies like aerobic liquid composting or anaerobic digestion is enabled to function well. The possibilities of treating different waste streams are many, but it is not yet an accepted approach. Weather the problem depends on technical, economical difficulties or people’s attitude is still to be investigated.

Anaerobic treatment

Anaerobic treatment is an old technique that lately has been re-discovered as a promising treatment system in the future. It is a natural process, which produces both energy and biosolids. A unique characteristic of anaerobic treatment by methane fermentation is that no nitrogen or oxygen needs to be present or added for the process to work, organic matter itself or the carbon dioxide resulting from it’s destruction serves this need. As a result organic loadings to anaerobic reactors can be much higher than to aerobic, because oxygen mass transfer limitations are not involved, and energy requirement for mixing is greatly reduced. Therefore, reactors can also be much smaller than in traditional systems, a big advantage especially in urban areas where space is limited. Another advantage is that the anaerobic process is capable of destroying most chlorinated hazardous compounds, and converting PCB's to less harmful forms (McCarty, 2000). Anaerobic treatment is also very suitable for tropical regions as the higher temperature permit the utilization of anaerobic reactors without heating, and thus saves energy (Wiegant,2001).There are some constraints to be overcome, which are connected to odour emissions. In some regions this has caused an unwillingness to use anaerobic reactors and authorities to be very restrictive in investing money in anaerobic treatment projects (Foresti, 2001).

Natural treatment systems

Local small-scale systems often use the same type of treatment as large-scale systems. Studies have shown that large-scale systems are more efficient in terms of energy consumption and maintenance. However, the recycled product of the small-scale system is of better quality (Lundin, 1999). The natural wastewater treatment refers to the use of wetlands, ponds, sludge drying beds, aquaculture or reed beds, where biological methods are used in order to absorb pollutants. Wetlands and reeds are used for removing pollutants while aquaculture recover nutrients into biomass with the help of algae, crop or fish.

Combining different types of systems

Combinations of traditional technologies and natural treatment are common, such as combining chemical treatment and wetlands. As conventional systems are efficient in removing certain compounds (phosphorous, BOD) natural treatment systems may contribute positively in other aspects (Harremoes, 1998).

4. Sustainable Development Indicators

In order to understand the meaning of a sustainable development indicator it is important to describe what an indicator is. An indicator is a way of measuring a condition that is relevant to the overall health of a community, and it determines whether that condition is improving or deteriorating. They can also help to highlight eventual problems before they become too severe and they provide information beyond the attributes directly associated with them. An indicator is useful if it is of fundamental interest in decision-making, simplifies or summarizes important properties, visualizes phenomena of interest and quantifies and communicates relevant information. In principle, an indicator can be either qualitative or quantitative. One of the essential functions of an indicator is to quantify (Gallopin, 1997).

Harger and Meyer (1996) have compiled a list of considerations that should be taken into account when developing indicators. They are

- simplicity – the final indicators should be as simple as possible
- scope – the indicators should cover the whole spectrum of human activities related to economy and environment but overlap between particular indicators should be as small as possible
- quantification – the elements should be readily measurable
- assessment – the elements should be capable of being monitored to establish performance trends
- sensitivity – the chosen indicators should be sensitive enough to reflect important changes in the environment
- timeliness – frequency and coverage of the elements should be sufficient to enable timely identification of the performance trends

Indicators are used for different purposes. Economic indicators for example gross domestic product (GDP) have been used since the middle of last century and 30 years ago the OECD presented the first social and environmental indicators. Traditional indicators tend to focus on one aspect, such as economic considerations. However, the last year's indicators projects have been initiated to link economy with social and environmental dimensions (Lundin, 1999).

4.1 Environmental Sustainability Indicators (ESI)

To be able to compare and correlate actions undertaken in the environment there is a need of measuring, verifying and comparing. Environmental sustainability indicators (ESI) can be used for this purpose. They have been proved to be useful for comparing the environmental actions of different countries. The identified indicators can be used as a "checklist" to investigate the status of each country in relation to particular aspects of environmental health (Harger and Meyer 1996). One goal is to find a system that deals with the use of natural resources in a similar way as financial resources (Lundin, 1999). There have been two types of development of environmental sustainability indicators, one describing the pressure being placed on the environment and one describing the effects of this pressure However, the development of these indicators requires the making of explicit choices as to the types of environmental change. A reference situation, which is equated to sustainability, might be determined. This reference condition can be some past environmental state or a future one regarded as more desirable than the present (Harger and Meyer, 1996).

5. Background of Ghana

Figure 1: Map of Ghana

Formed from the former Gold Coast and the Togoland territory, Ghana became the first country in colonial Africa to gain its independence in 1957. A long series of coups resulted in the suspension of the constitution in 1981 and the banning of political parties. A new constitution, restoring multiparty politics, was approved in 1992. Lt. Jerry Rawlings, head of state since 1981, won the elections in 1992 and 1996, but was prevented from running for a third term. President John Kufour succeeded him in 2000. (CIA, 2002).

Ghana is one of the most densely populated countries in West Africa. 19,7 million people living in an area half the size of Sweden. The majority of the population is black African, where the major tribes are Akan, Moshi-Dagomba, Ewe, and Ga. Ghana lies south of Burkina Faso, between Togo to the east and the Côte d'Ivoire to the west, on the Gulf of Guinea (figure 1). Most of the country is made up of wooded hill ranges, wide valleys and low-lying coastal plains, though the northern third of the country is thick with rainforests. A big part of central Ghana was swallowed by Lake Volta in 1964, when the Volta River was dammed and the lake became one of the largest in Africa.

Well endowed with natural resources, Ghana has twice the per capita output of the poorer countries in West Africa. Even so, Ghana remains heavily dependent on international financial and technical assistance. The most important natural resource in Ghana is the soil. Of the country’s total land area, 23 % is arable and 28 % is forested. Gold, timber, and cocoa production are major sources of foreign exchange. The domestic economy continues to revolve around subsistence agriculture, which accounts for 36% of GDP and employs 60% of the work force, mainly small landholders. The GDP growth rate was 3% in year 2000 and the official unemployment rate was 20.3 %. (Ghanainfo, 2000).

Ghana’s tropical climate features distinct wet and dry seasons, with regional variations. The north experiences one long rainy season from March until November, when a hot, Saharan wind known as the harmattan blows from the north and brings the dry season. The south experiences two rainy seasons; one from April to July and the other one from September to October. The average annual temperature is 26°C. The mean annual rainfall ranges from 750-1000 mm in Accra to 1780-2080 on the southwest coast. The country experiences occasional droughts (Encyclopedia, 2001).

Environmental problems in Ghana are overgrazing, soil erosion and deforestation. Much of the hard wood forest in southern Ghana has been destroyed since the beginning of last century and about 1.3 % of the remaining forest is being destroyed every year. Other problems are connected to water supply and sanitation systems. Land in Ghana is owned and distributed by traditional family heads. Individuals who want to purchase land deal directly with the family and the land is allocated directly without reference to municipal planning authorities. As a result, long-term planning of utility services such as water supply and sanitation has not taken place ahead of development. (World Bank, 1993).

Accra, the capital of Ghana has a population of 2.2 million people and is the financial, economic and administrative center of the country. Accra accounts for 15-20 % of Ghana's GDP and 10 % of total employment (UN, 2000). Spatially, Accra is generally unplanned and characterized by overcrowding and substandard housing, especially in low-income areas. The problem of urban growth in Ghana has escalated during the last decades and the capital has a growth rate of 3.2% compared with 2.8% for the rest of the country (Acolor, 2000). The Accra Metropolitan Area (ATMA) consists of the cities of Accra, Tema and a rural district (figure 2, left of the line). ATMA covers a total area of 780 km^2 and in the early 1990's about 75% of the ATMA population lived in the periurban areas of Accra

6. The urban water system in ATMA

The ATMA region is supplied with water from two sources Weija and Kpong. Weija water works supplies Accra west and the Accra northwest districts. The water works consists of three plants, Bamang, Candy and Adam Clark. The plants of Weija are situated on a hill (83 meters above sea level) northwest of central Accra (figure 2) and because gravity is the driving force it can only serve low-pressure areas west of Accra (30-60 meter above sea level). Kpong supplies water to Tema, the eastern parts of Accra (including Adenta) and central Accra. Kpong is situated close to Akosombo, near the Volta Lake, about 75 kilometers northeast of the capital. The water works consists of a new and an old water plant. The new water plant serves Accra Tema Metropolitan Area (ATMA) region while the old is used for rural areas in Ghana. Sewage from industries and household is sent to Korle Lagoon WWTP (figure 2) and other treatment plants, where it is treated before being released to the Korle Lagoon and the sea. Many households are not connected to the water borne sewage; septic tanks and onsite sanitation systems are more common. These are emptied and the septage is taken to the WWTP for treatment. The open gutters of Accra take the storm water and some wastewater untreated into the Lagoon.

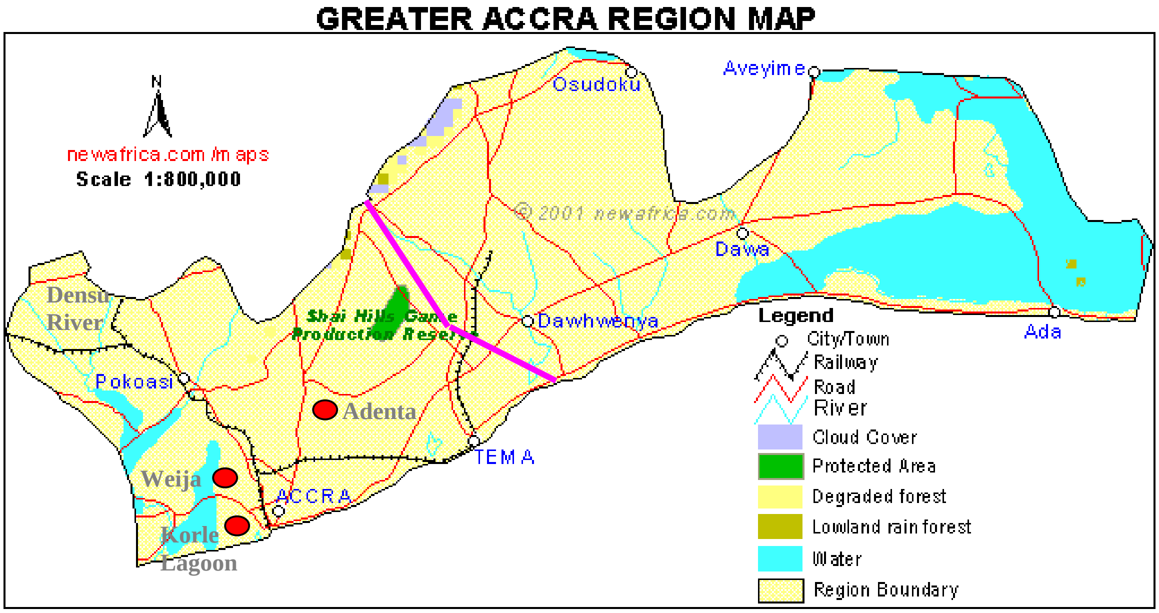


Figure 2: Map of the greater Accra region. ATMA includes Accra, Tema and Pokoasi region (left of line). Adenta, Weija waterworks and Kpong are marked as circles.

6.1 Weija

The Weija reservoir, created in 1977 on the Densu river, is about 116 km long. The dam is a rock and earth filled structure located about 10 km from the mouth of the River Densu. The catchment of the reservoir lies in the Coastal Savanna Zone where rainfall is seasonal with two peaks in June and September and the main economical activities around the area are fishing and crop farming (Asante, 1999). Raw water quality in Weija is poor (turbid water). The problem of bad water quality is partly due to the upstream towns that are releasing untreated sewage into the river There are three plants at Weija, Adam Clark, Candy and Bamang. The Adam Clark plant has recently been expanded in order to improve the water supply to the western part of Accra. The plant now produces around 136,000 m^3/day (30 million gallons per day), compared to 36,400 m^3/day before the expansion. The improvements includes and an up gradation of the treatment plant and construction of additional buildings and installation of new equipment. New pumps have also been installed at the raw water intake.

There are problems with electricity cut-offs that disturbs the operation of the plants. Other problems are the amount of sludge produced, which is much greater than expected. Today, the sludge is dumped or returned to the river reservoir.

6.2 Kpong

The Kpong reservoir was formed after the closure of the Volta dam in 1981. The reservoir has an area of about 38 km^2, and the average depth is 5 m. The quality of raw water from Volta is good due to the two dams Akosombo and Akuase dam which are used for electricity purposes but also serve as sedimentation basins for the raw water. In Kpong there are two plants one old plant and one new plant. The new plant is supplying Accra with water and the old plant pumpes water to the close-by villages. Due to the great distance a lot of energy is consumed for pumping the water to Accra.

Water that is transported to the north of ATMA, is pumped from Kpong to Tema and further to Accra Booster. From here it is transported to the north of Accra (figure 4). A number of industries, Ghacem, Coca-Cola and Ghana Aluminium in Tema are water demanding and most of the time all the water is consumed before reaching the northern regions of ATMA (figure 3). This is a big problem in Accra.

There are plans of building a new pipeline from Kpong directly to the northeastern part of Accra (pers comm. Nyarko).

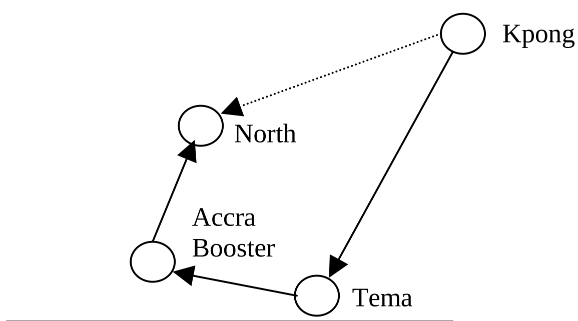


Figure 3: Present piping situation from Kpong to ATMA and planned piping (dashed arrow).

6.3 Korle Lagoon

Korle Lagoon wastewater treatment plant receives part of the wastewater from households and industries in ATMA region, from sewer and septic tanks. The only exception is the Osu district in Accra, from where sewage is pumped directly into the sea. It is estimated that 80 % of the water consumption in ATMA region goes into sewage.

The Korle Lagoon is a USAB (up-flow anaerobic sludge bed) wastewater treatment plant, the only one in West Africa. USAB plants involve anaerobic treatment of wastewater and have been used for a long time in Brazil for industrial sewage (Florencio and Kato, 2000). The USAB technique is a promising alternative for the treatment of domestic sewage especially in developing countries, since the system can be designed at very short hydraulic retention time, resulting in a very compact and low cost treatment unit. Other advantages of USAB reactors are their small size compared to the traditional methods, and their efficiency in removing COD and BOD from wastewater. The amount of biogas produced is around 80-90 m^3/h and is presently not used for any purpose, but there are plans using it as an energy source for the plant. The sludge is stabilized and dried in sun beds. Part of it is used as fertilizer at a golf course but most is taken to landfills around Accra. Parameters that are regularly monitored are BOD and COD in both incoming and outgoing water. About 88% of the COD and 95% of the BOD is removed from the wastewater. Phosphorous and nitrogen are not removed from the water. Due to unwanted influxes from industries pH can vary between 4 and 12, depending on the nature of the input. There is sometimes an emergency situation and the wastewater is pumped untreated into the lagoon. Frequent inputs are beer, diesel and gasoline from industries. Pump failures and leakage are quite common so there is still an unknown amount of wastewater that reaches the lagoon untreated.

Korle Lagoon

The lagoon receives final effluent from the wastewater plant and virtually all the runoff from the city of Accra, Ghana. Most of the wastewater from homes, fitting shops, factories and industries not connected to sewer end up in gutters that run into the lagoon. The wastewater is normally toxic, coupled with the garbage that is collected into the lagoon by rainwater. As a result it is heavily polluted.

6.3.1 On-Site Sanitation Systems

The most common form of sanitation systems in periurban areas in developing countries is on-site systems. It is commonly equivalent to household latrine, but can also include facilities shared by many households on the same plot. There are various on-plot methods that are being used. Some are flush systems that require water for functioning, while others operate without water. In Ghana 85 % of the urban households are served by on-site systems and in Adenta no inhabitants are served by water-borne sewage (Ingallinella *et al*, 2000).

Pour-flush toilets to septic tank

A septic tank connected to a pour-flush toilet receives raw sewage from the household sewer. This includes wastewater and human excreta. A septic tank needs to be emptied regularly and requires water to flush away excreta.

Pit latrines

A pit latrine is a hole in the ground with a floor/squatting slab surrounded by a latrine house. The simple pit latrine is one of the simplest and cheapest means of disposing of human wastes, but requires stable soil, as there is a risk for the pit to collapse. It is also important that the pit is well above the ground water table, as drinking water supplies can be polluted.

VIP latrines

A Ventilated Improved Pit (VIP) latrine is an improved pit latrine with a ventilation system for reducing the odours and the presence of flies. The VIP uses the movement of air across the top of a ventilation pipe to draw odors up the pipe and out of the latrine. Flies entering the pit are attracted to the light at the top of the pipe and die trying to escape.

Bucket/pan latrines

The bucket latrine method has a bucket or a container for the retention of faeces, which is removed for treatment or disposal. Bucket latrines are easy to install and have low initial costs, but can pose a health risk.

The main problems associated with on-plot systems are, odour, insects nuisance and ground water pollution (WELL, 1999). Flies are a serious problem as they spread diseases through feeding and breeding on faeces. Some types of mosquitoes breed in polluted water such as in wet latrines and may carry diseases. Another difficulty is the potential for pollution of groundwater near or under latrines.

7. Water supply services in ATMA

There are various organisations and associations related to production and supply of water in Accra. Figure 4 represents a network of associations and institutions that are related to public water supply

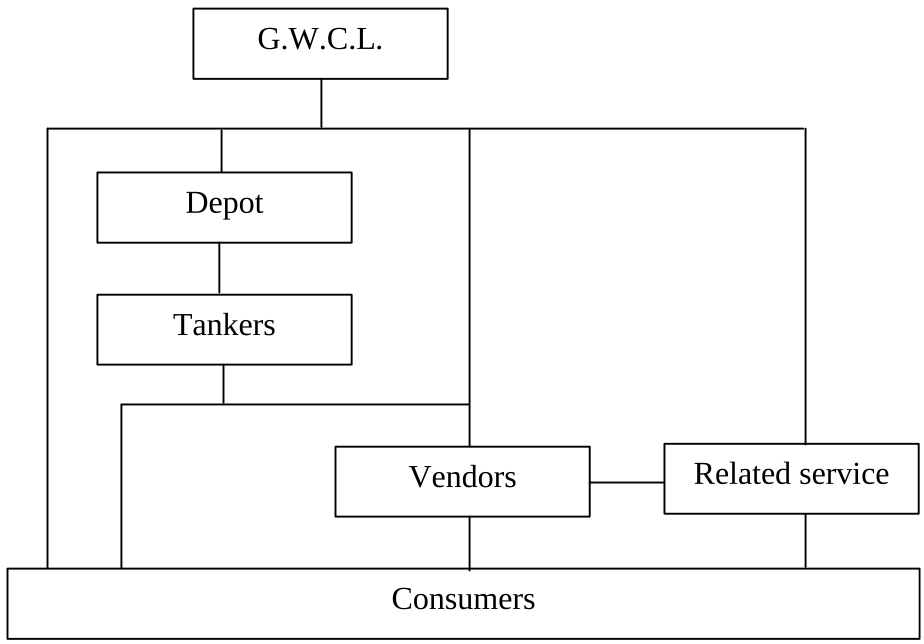


Figure 4: Water distribution in ATMA region (Agyepong, 2001).

Ghana Water Company Limited (G.W.C.L)

The G.W.C.L has been responsible for the production and distribution o water in Ghana since 1965. As mentioned before ATMA region is supplied with water from Kpong and Weija. The problem of water connection goes back to the late 60´s, when the city started to grow. In order to cope with the expansion a first system boundary for water supply through piping was developed. However, the city grew faster than the infrastructure and other boundaries had to be drawn in 1981 (2^{nd}). Between 1980 and 1990 the level of service declined due to deteriorating infrastructure, over 50 % of the water was unaccounted for water (leakage and theft), poor billing, bad meters and revenue collection. In addition, further population growth and lack of capital investment for accelerated development further widened the gap between the demand and supply of water. These factors culminated in the lack of access to potable water to a large number of people and the poor paying more money for their water. In 2000 a 3^{rd} a boundary was drawn but the unaccounted for water was still over 50 %. The area outside the second system boundary is still an under-served area (Agyepong, 2001).

Depots (filling stations)

There are six established water filling points in ATMA. They are La, Odorkor (3 filling points), Lashibi and Tema. These are provided by GWCL and used for tanker services. There are no public standpipes remaining in Accra, they have either been removed or converted into vending points.

Tankers

The growth of the city in the end of the 80's led to increased demand for water tanker services. Initially, many individual tankers transported water from local streams to construction sites. However, as the gap between household demand and GWCL water supply grew larger, water tanker services were extended to households. In order to obtain potable water, some tankers started to withdraw water from fire hydrants. Indiscriminate uses of water from fire hydrant points caused the GWCL to authorize tanker operations and establish water tanker service points at various locations.

Water tanker used for periurban areas, like Adenta

There are two types of tankers; governmental and private water tankers (P.W.T). The government tankers are owned by G.W.C.L and are used for serving government officials and institutions. The P.W.T is owned by individual entrepreneurs or institutions and provide water to all kind of consumers. The practice for government owned tankers is that they fill the tankers from the depot and pay a fixed price for the water. The private tankers buy the water from the P.W.T owners association who has bought it from G.W.C.L at an agreed price. It is then transported to either consumers or vendors. The tankers range in size from 6500-20,000 litres. The smaller ones are used for private residents while the larger tankers provide water to construction sites, schools and factories. Only a few owners actually bought their tankers for public water supply. The tankers were previously used for other purposes, such as transporting fuel. The tanker is a growing business with a high increasing rate (figure 5).

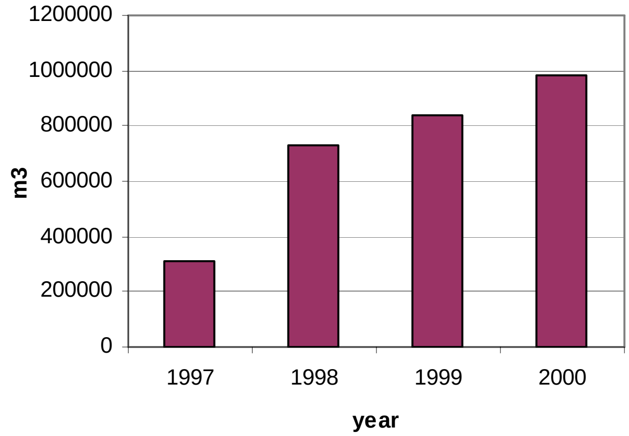


Figure 5: Quantity of water sold by PWT annually (Agyepong, 2001).

Vendors

These are people who either sell water directly from G.W.C.L systems or from reservoirs containing water supplied by tankers or both. The vendors store water in polytanks and underground concrete tanks and sell them to consumers per bucket (34 litres).

Polytank in Adenta

Related services

There are other services of water distribution in Accra. One is the power tiller (Agyepong, 2001) which is a small vehicle with a tank attached. The capacity of the tank is 1300 litres. The power tiller carry water over short distances to consumers who need water in smaller quantities and is a very popular service. The other one is tractor services. This is a tractor with a tanker attached. The capacity ranges from 4500-7000 litres. They carry water over longer distances than power tillers but the mileage is smaller compared to tankers.

Consumers

The consumers represent individual household, hotel/restaurants, hospitals, construction sites, schools, churches, mosques and small industries located in residential areas. The consumers can be classified into three categories according to their social status, High-class, middle-class and low-class. The high-class consumers only depend on GWCL The low-class consumers are the ones who mainly depend on water vendors and the middle-class depend on both types of services.

8. Adenta

Adenta is located 15 km northeast of the city center (figure 2) and has a population of 3000 families, with an average of 6 persons in each household. Most housing developments in Adenta are unapproved and the area is “unplanned”.

Adenta is outside the second supply boundaries but political pressure forced the water Ghana Water Company Limited (G.W.C.L) to build pipelines in the area. The water provided by GWCL comes from Kpong Water Works. However, most residents of Adenta are not connected to the network as the piping was only designed for a sixth of the actual population. The households that are connected only receive water once a week, usually on Wednesdays or Sundays. Most families in Adenta rely on water tankers, vendors and related services. (Acolor, 2000), i.e. middle-class consumers. Domestic vending is common practice in Adenta. A large number of domestic consumers currently sell water to their neighbours or to construction sites. When the reliability of the services from GWCL declined, many residents installed tanks to cope with the periods of water shortage. These tankers are filled up with water either from GWCL or from tankers and sold to people in need of water. The power tiller service is also very popular in Adenta (pers comm. Quaye):

In Adenta there is no functioning wastewater system, as the periurban area is not connected to a centralized wastewater system. However, there are other systems for wastewater. Most residents are connected to a septic tank, an on-site flush system, which receives raw sewage from the household sewer (including sewage and human excreta). The septic tanks are emptied by tankers and the waste is taken to Korle Lagoon

Wastewater Plant or dumpsites around Accra. Other use different types of on-site plot sanitation pit latrines, VIP latrines and bucket latrines. The grey water is poured on the ground or used for irrigation. Some people have access to a “soak away”. They are pits, sometimes made of concrete with a bed of gravel or sand, from where the wastewater percolates into the ground.

8.1 Interviews with residents in Adenta

30 persons between the age of 16 and 40 were interviewed during a two-day visit in Adenta. Questions asked were the size of the family, water consumption per day, if they were connected to pipeline or bought their water from tankers, what kind of wastewater system they used (both for black and grey water) and how much they paid for water services.

Residents of Adenta

Families in Ghana are usually large i.e. “extended families”. Extended families live close together, sometimes sharing a single dwelling. The number of individuals living in one house varies between 4-35 people, depending on the size of the house and the 'extended' family. The water consumption also varies, between 10-75 l cap^{-1} day^{-}1 with an average of 36 l cap^{-1} day^{-1}. This is due to different factors. If the household are connected to pipeline the water use is higher. The people with the lowest water consumption are poor people who buy water in buckets from vendors.

As expected, most of the households are not connected to the pipe network. The minority that are, receive water once or sometimes twice a week. They usually store the water in a polytank (different sizes) and refill it again a week later. The residents that are not connected to pipeline but own a polytank, buy great volumes of water from water tankers to fill up the polytank. Residents who don’t own a polytank buy water per bucket from markets, neighbours or power tillers. Most people use the water from pipeline or water tanker for drinking/washing and bathing. However, some households buy bottled water for drinking.

As there is no pipe network for wastewater, residents of Adenta use on-site sanitation system like latrines or septic tanks for human excreta. A few households have a ‘soak away’ for the grey water, but most residents let the grey water percolate into the ground. Others use the grey water for watering blocks or flowers. People connected to a septic tank use the grey water for flushing.

Water bought form tankers vary in price between 150.000-200.000 cedis for 9000 litres (1 USD: 7000 cedis) (CIA; 2002). The pricing depends on the urgency of delivery, how much they buy and if the pipeline is providing water or not. People who have bought water from tankers or are connected to pipeline usually sell it to other individuals for a cost of 200-500 cedis per bucket (34 litres). For those who buy bottled water the cost is about 4000 cedis for 30 bottles of drinking water.

9. Methodology

The method used for selection of Environmental Sustainability Indicators (ESI), developed by Lundin, 1999, was used in this case study. The procedure for assessing the environmental sustainability of an urban water system is presented in figure 6.

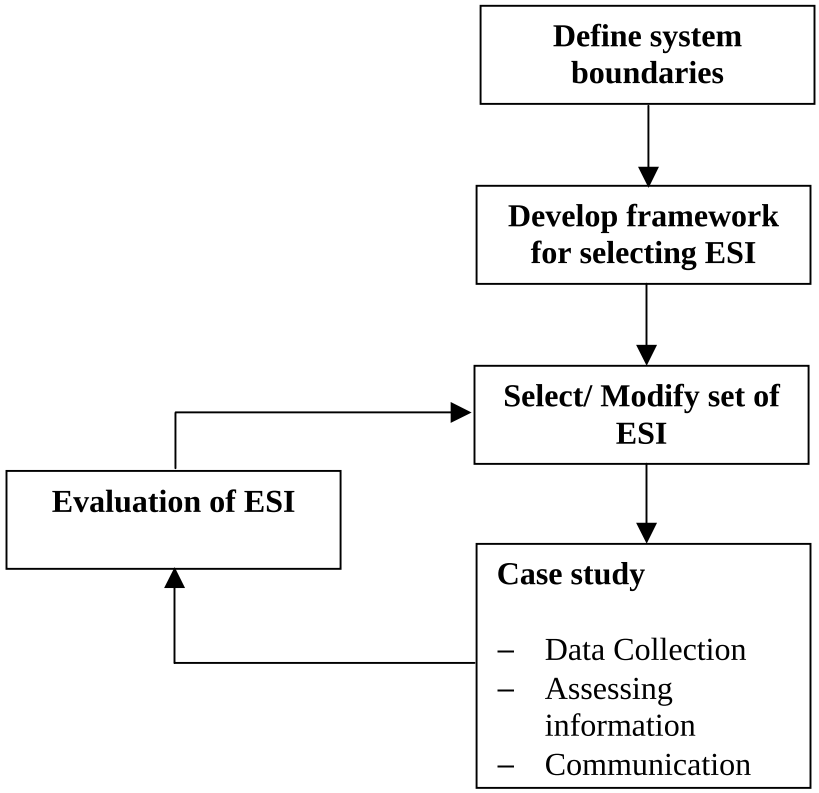


Figure 6: A simple outline of the procedure for assessing the environmental sustainability of an urban water system (Lundin, 1999).

Firstly, it is important to define system boundaries. Temporal and spatial boundaries are addressed here. Time perspective of a couple of decades is usually considered when a urban water system is planned and built, but a much longer time perspective is required when sustainability of urban water systems is considered. Geographic boundaries for an urban water system is usually limited to include the municipality and the life cycle starts with extraction of water including drinking water treatment. Wastewater treatment is also included. The cycle ends with discharge of wastewater (untreated or treated) and disposal of sewage sludge (Lundin, 2000).

The next step is to develop a framework for the selection of ESI. Examples of different frameworks are the Pressure-State-Response model developed by OECD and the DPSIR model (an extended version of the PSR model developed by the European

Environmental Agency and the Eurostat). Another approach for selecting ESI is life cycle assessment (LCA), which has been used in this study. LCA is a method aiming at analyzing and evaluating environmental impacts of products and services. The whole chain of activities, from the cradle to the grave is taken into consideration. The method has also been used for estimating environmental loads from infrastructure of water systems. The advantage of LCA is that it is well established and a standardized method which includes an impact assessment phase.

After the development of the framework the ESI can be selected. As few indicators as necessary should be selected to address the most important aspects. Several publications have dealt with the criteria for the selection of indicators of an urban water system (Lundin, 1999).

Information for the Case Study can now be collected. After the information assessment the ESI can be evaluated against their relevance of environmental sustainability of the water system.

This case study started with literature review of publications concerning sustainable development and urban water systems. A preliminary definition of system boundaries of the urban water system was drawn and a framework for selecting ESI was chosen. A list of sustainable development indicators proposed by Lundin *et al* 1999 was studied and 11 indicators were chosen for the study. The remaining of the indicators was rejected, as they were not believed to be applicable or suitable for the study. The area chosen for the case study was Adenta, a periurban setting in Ghana, situated in the northeastern metropolitan area of Accra and Tema (ATMA).

Upon arrival to Ghana in September 2001, the system boundaries were identified as starting at the Weija and Kpong dam and ending with the Korle Lagoon wastewater treatment plant. The system is partly served by a pipe network for drinking water. However, most of the residents of Adenta depend on tankers for water supply. Piping for wastewater does not exist, all inhabitants use on-site sanitation systems such as septic tanks or latrines.

Data collection at Kwame Nkrumah University of Science and Technology (UST), Ghana Water Company Limited (GWCL) and the Korle Lagoon Wastewater Treatment Plant started after arrival. Personal interviews with staff from the different institutions were performed and reports were collected with the help of professor Kwesi Andam from KNUST in Kumasi. Interviews with the people living in Adenta were also made, in order to get a better comprehension of the problem of water supply and sanitation in the area. Visits to Weija and Korle Lagoon gave an enhanced understanding of the technical performance of the water works and treatment plant.

Back in Sweden, a result evaluation of the indicators and scenarios of the indicators for different wastewater systems was done. The purpose was to investigate whether alternative urban wastewater systems are appropriate from an environmental sustainability point of view in a developing country like Ghana. The result evaluation and the scenarios were made with the help of professor Greg Morrison at Chalmers University of Technology in Göteborg, Sweden.

10. Development of the set of indicators

10.1 System boundaries

In order to define life cycle boundaries it is important that temporal and spatial boundaries are selected according to case study. Since sustainability relates to long time series, a time perspective of 50-100 years is considered. The geographical boundary for an urban water system is usually limited to the municipality, and in this case study the geographical boundaries is limited to Adenta. For the urban water system in Adenta the life cycle starts with the extraction of surface water from Kpong and Weija and includes drinking water treatment and wastewater treatment. The life cycle ends with discharge of untreated storm water, treated wastewater and disposal of sewage sludge to landfill, sea or agricultural land. The study is limited to the operation of the existing urban water system. The UWS can be divided into three sub boundaries, drinking water treatment and wastewater system (1a, 1b), Use and handling of urban water (2) the urban water system and surrounding systems (3) (figure 7).

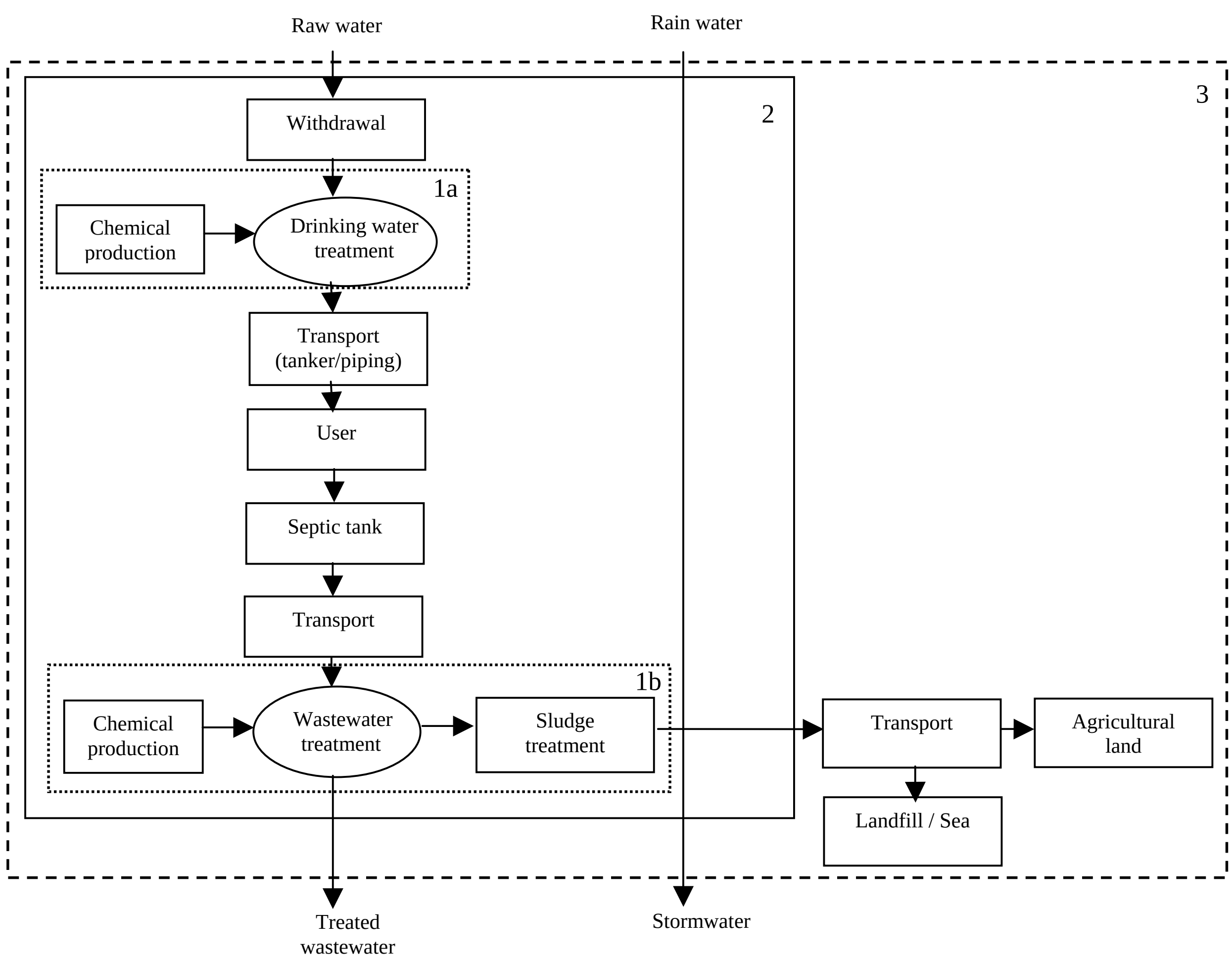


Figure 7: System boundaries from case study in Adenta

10.2 The applied indicators

Lundin *et al* initially suggested 20 ESI for urban water systems. The selection were based on five criteria

- Move towards or away from sustainability
- Availability of data of sufficient quantity and quality to provide spatial and temporal variations
- Representatives of one or more aspects of the sanitary system
- Applicability to a range of sanitary systems
- Ease of use

After testing the 20 selected ESI through a case study in Göteborg 14 were demonstrated as useful in assessing variations for the urban water systems in a industrialized country. Another case study in South Africa performed by Zinn (2000) tested 17 of the indicators developed by Lundin. After evaluating the indicators 15 proved to be of use in a developing region (Morrison *et al*, 2001). In this case study performed in Ghana 11 indicators were chosen (table 1), as the remaining of the indicators were not believed to be applicable or suitable for the study.The indicators were chosen based on the following criteria:

- Comparability of environmental sustainability of different urban water systems
- Availability of data
- Representatives of environmental aspects of the UWS
- Ease of use

The indicators were tested in the purpose of evaluate the sustainability of the existing water system in Adenta and for making scenarios of alternative water systems and evaluating these in terms of sustainability.

Table 1: List of indicators that was used in the case study

Suggested Indicator	Parameters	Relevance for environmental sustainability
Freshwater resources		
Withdrawal	$km^3\ y^{-1}$ Total withdrawal compared to annual amount	Resource depletion
Raw water quality	$Kg\ p^{-1}\ y^{-1}$ Conc of N, P, BOD, heavy metals and coliform	Contributes to eutrophication and contamination
Drinking water		
Water use	$l\ cap^{-1}\ d^{-1}$ compared to WHO recommendation	Resource depletion
Electricity use for drinking water treatment	$KWh\ p^{-1}\ y^{-1}$	Use of fossil and non-renewable resources
Chemical use for drinking water treatment	$g\ p^{-1}\ y^{-1}$	Contamination
Leakage	%	Resource depletion
Quality of drinking water	Conc. Of N, P, BOD, chlorine and heavy metals	Contributes to eutrophication and contamination
Transport		
Transportation o water to user by tanker	$km\ p^{-1}\ y^{-1}$	Diesel use and related emissions
Wastewater		
Wastewater production	$m^3\ p^{-1}\ y^{-1}$	High WW production can cause overflows and decreased efficiency
Discharges of BOD, N and P to receiving water	$g\ p^{-1}\ y^{-1}$	Contributes to eutrophication
Electricity and chemical use for wastewater treatment	$KWh\ p^{-1}\ y^{-1}$ $g\ p^{-1}\ y^{-1}$	Use of fossil fuels

Withdrawal

The withdrawal indicator is calculated by dividing the annual fresh water withdrawal by the annual available amount. It shows whether the withdrawal is within an acceptable level from a sustainable point of view. Only estimations are possible for the available volumes of surface water. The indicator depends on several factors like climate, season and population.

Raw water quality

This indicator is important for the environmental sustainable future of fresh water ecosystems. The parameter gives information about activities that may affect the raw water quality for example agriculture; release of untreated wastewater, industrial discharges, urban runoffs and landfills. It also indicates the amount of treatment necessary to produce drinking water of acceptable standard.

Water use

As the population enhances, increasing volumes of water will be needed for domestic and industrial use. The consumption of drinking water not only affects amount of water available but also the use of energy and other resources.

Electricity use for drinking water treatment

The sustainable use of energy requires an efficient use, but not at the cost of drinking water quality. Ground water or water treatment plant situated far from consumer requires more energy due to pumping.

Chemical use for drinking water treatment

In order to reach sustainability it is important to regulate the amount of chemicals added to the water. Uncontaminated groundwater water requires little or no treatment, while surface water usually requires higher amounts of chemicals added to the water. The raw water quality affects this indicator. It in turn affects the quality of drinking water.

Leakage

Leakage occurs in volumes in decaying pipes, and leads to increasing pumping costs, loss of water, loss of pressure and increased risk of contamination by bacteria and corrosion products. Decreasing leakage decreases costs and increases revenue, but most important the withdrawal can be lowered if the leakage is minimized.

Quality of drinking water

In order to protect human health, the quality of drinking water is of great importance. It should have, tolerable levels of bacteria or chemicals. Drinking water quality is measured at the treatment works.

Transportation of water to user by tanker

In areas like Addenda where the majority of the households depend on tankers for their water supply, transportation of water is an important indicator. Emissions from the vehicles are causing environmental problems such as smog formation and global warming. They also cause health problems like respiratory diseases. Calculating the km p^{-1} y^{-1} can give a good estimations of the magnitude of the emissions of air pollutants.

Wastewater production

An increased wastewater production can be caused by enhanced water use or increased leakage of infiltration water or storm water. Overflows may cause emissions of harmful substances to the environment. Minimization of the amount of wastewater produced is therefore necessary in order to decrease the risk.

Discharges of BOD, N and P to receiving waters

In wastewater there is normally a high amount of BOD, N and P. If the water is not purified enough before released to the environment, problems like eutrophication in fresh water systems can occur. Therefore it is important to lower the emissions to an acceptable level in order to reach sustainability.

Electricity and chemical use for wastewater treatment

The chemical and energy use should be decreased due to contribution to environmental effects such as contamination and global warming. A sustainable society requires a limited use of non-renewable resources.

10.3 Assumptions and limitations

Lack of data for certain activities has resulted in limitations of the case study. The water in Adenta that is supplied by piping originates from Kpong and the water bought from tankers comes from both Weija and Kpong reservoir. Half comes from Kpong and the other half from Weija (Agyepong, 2001).

In the study the residents are using septic tanks or on-site sanitation systems for septage. These are emptied and the waste is taken to the Korle Lagoon treatment plant. The transportation of the sewage from septic tank to Korle Lagoon is included in the system boundaries but due to lack of data it has not been taken into consideration in the case study. The transportation is believed to contribute to environmental impacts, such as use of fossil fuels. In the calculations it is assumed that 100 % of the sewage ends up at the treatment plant in Korle Lagoon and that the number of people connected to the wastewater plant is 23 500 persons (based on calculations). The amount of chemicals added for wastewater and sludge treatment has been excluded from the study due to lack of information. The transportation of sludge to landfills, sea and agriculture have not been considered and the reuse of sludge for agricultural purposes is very low and has therefore been excluded.

10.4 Data quality

The data in the case study was collected from authorities, Ghana Water Company Limited, Korle Lagoon wastewater plant, the Kwame Nkrumah University of Science and Technology in Ghana. The quality and the quantity varied a lot depending on source and type of data. Where no data could be found, estimations were made on basis of interviews and on written reports (Bengtsson *et al*, 1997:Agyepong, 2001). In some cases data was obtained from similar case studies done in Sweden. It is important to remember that the situation in different countries varies a lot, which results in a difference in indicator values.

A great deal of background information and data about the tanker system was obtained from KNUST in Kumasi. An investigation of a master's student was made in early 2001 and the report was very complete. GWCL provided data for the water distribution network and Korle Lagoon WWTP for the wastewater treatment. However, the latter data was very limited and estimations and assumptions were made. Data was missing for certain time periods and sometimes gaps were found. Extreme values were excluded when calculating the results.

11. Results and evaluation

11.1 Present system

Withdrawal

In Ghana the global renewable water resources are 53 $km^3\ y^{-1}$, where 30.0 $km^3\ y^{-1}$are internally produced water resources and 22.9 $km^3\ y^{-1}$ are runoff from other countries. The total water withdrawals in Ghana are 0.3 $km^3\ y^{-1}$, which is less than 1 % of the internal renewable water resources. The problem in ATMA is not the available amount of water, it is the non-uniform distribution of water and limitations of pumping. This results in frequent shortages of water supply in periurban areas like Adenta. It is estimated that the annual available amount of water for the total population in Accra is 840,96 $km^3\ y^{-1}$. In Adenta the total annual water withdrawal can be estimated to 236,5 $km^3\ y^{-1}$, i.e.28 % of the available amount of water.

Raw water quality

The Ghana Water Company Limited (GWCL) is responsible for the monitoring of the raw water quality from both Weija and Kpong. The quality is measured regularly for both dams.

The major problem in the raw water is the high amount of nutrients. Investigation made by Asante (1997) shows high concentrations of nitrate, phosphorous and BOD. The nutrient input for Weija is higher than in Kpong (figure 8). Calculating that 60 % of the people in Adenta receive their water from Kpong results in a nutrient input of 33,9 kg p^{-1} $y^{-}1$.

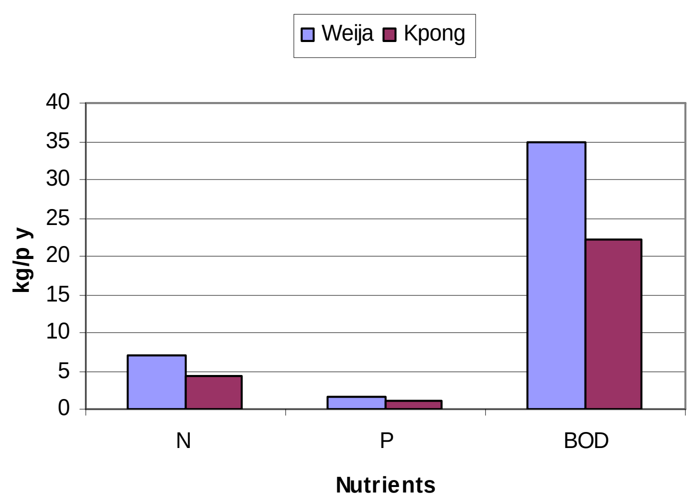


Figure 8: Nutrient inputs from settlements in Weija and Kpong 1997 (Asante, 1997).

The high nutrient levels may be due to sewage, runoff from from agricultural activities and the overland. Human settlements are releasing untreated sewage upstream the Denzu River in Weija. Agricultural activities have also increased in the catchment areas around Weija and Kpong during the last years. As the population in the surrounding villages will continue to grow, situation is likely to worsen in the future. Estimations of nutrient input show a 25 % increase between 1997-2010 (Asante, 1997).

Neither of the plants have problems with coliform bacteria or high content of heavy metals in the raw water (pers comm. Mensah).

Water use

Water use in Ghana has increased over the years, due to the rapid growth of the country. ATMA region is the fastest growing in Ghana, population increased from 1,2 million (1990) to 2,2 million (1995). Water consumption is currently about 130 liters cap^{-1} d^{-1}in ATMA. In Adenta the water use is much lower. Interviews with residents show that the average water use varies between 10-75 l cap^{-1} day^{-1}. The people with access to pipeline have a higher consumption than the people that buy water from tankers, still it is lower that for the rest of the region. This probably depends on the fact that the water flows in the pipelines once a week. Estimating that 20 % of the population in ATMA uses 60 l cap^{-1} day^{-}1 and 80% use 30 l cap^{-1} day^{-1}results in a water consumption of 36 l cap^{-1} day^{-1}in Adenta. This is a third of the water use for the rest of the region. The minimum recommended water use by WHO is 36 l cap^{-1} day^{-1} (WHO; 2000). Even though the water consumption in Adenta is low today, it is increasing in the future together with population growth. As mentioned before there are plans of constructing a pipeline from Kpong to northeast of ATMA, which would increase the water use even more.

The estimated water use in ATMA region can be seen in figure 9. The water use is expected to increase together with population growth.

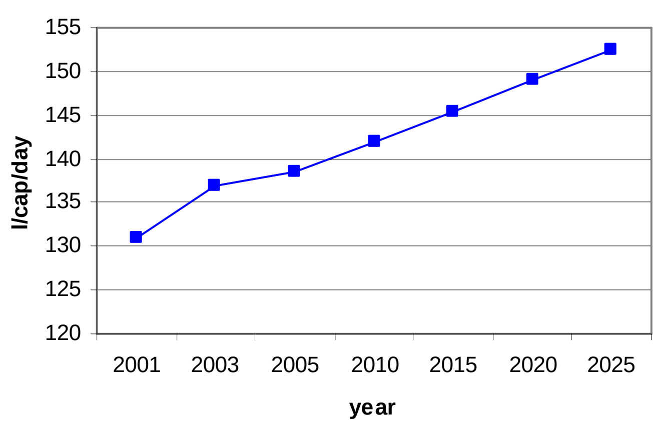


Figure 9: Predicted water use in ATMA 2000-2025.

Electricity use for drinking water treatment

The electricity use for the drinking water treatment varies a lot between the water sources. The electricity use per person in ATMA is 23,8 kWh p^{-1} y^{-1} if the water comes from Kpong. The same number for Weija is 7.6 kWh p^{-1} y^{-1}. The high-energy consumption in Kpong is due to the pumping of water from Kpong to Accra (75 km). In Adenta the numbers are different as the water is first pumped from Kpong to Tema and Accra Booster before it reaches the northeastern parts of Accra. This results in a high-energy consumption for the people who receive their water through pipelines, 30,2 kWh p^{-1} y^{-1} (figure 10). Calculating that 20% uses water from pipelines (high energy use) and that 40% buys tank water that originates from Weija and 40% from Kpong (lower energy use), results in an electricity use of 18,6 kWh p^{-1} y^{-1} in Adenta today.

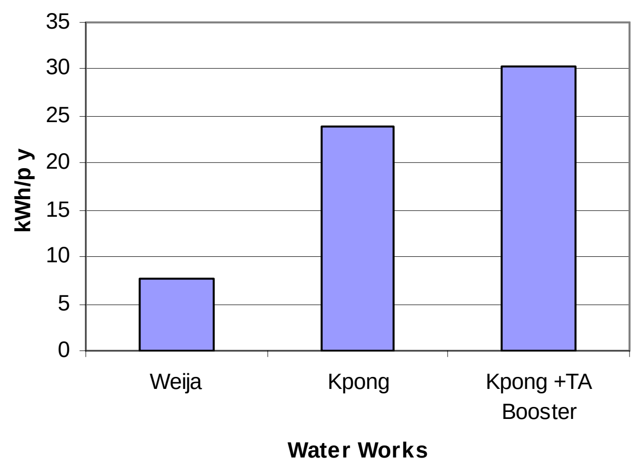


Figure 10: The difference in electricity use per person and year depending on from where the water originates.

Chemical use for drinking water treatment

Data on the use of chemicals were obtained from GWCL the year 2001. The chemical of primarily interest is chlorine. The amount of Chlorine added in Weija is 116 tons y^{-1}. The same number for Kpong is only 30 tons y^{-1}, which is a fourth of the chlorine added to the drinking water in Weija (table 2). As mentioned before the raw water quality is poorer in Weija than in Kpong. In ATMA 50 % of the water is taken from Kpong and 50% from Weija which results in an average chlorine addition of 25 g p^{-1} y^{-1}. For Adenta this number is slightly smaller, the chlorine use in Adenta is 22 g p^{-1} y^{-1}.

Table 2: Chlorine usage in Kpong and Weija.

	Added Cl^- (tones year)	Added Cl^-in ATMA (g p^{-1} y^{-1})
Kpong	30	10,2
Weija	116	39,6

Leakage

The leakage of the water supply system through pipeline is estimated to over 50% (pers. Comm. Nunoo). This is due to three factors, real leakage (30%), bad meters and illegal connections. This is quite high compared to a study made in an urban area in Sweden , where leakage was estimated to 20% (Lundin, 1999). The leakage for the tanker system is hard to estimate as the water is piped to the filling points and then transported by tankers.

Quality of drinking water

Regular water quality tests are performed by GWCL at Weija and Kpong for drinking water. Parameters like phosphorous, nitrogen and BOD are monitored at both plants, but the only data available in this study is nitrate in tap water from Kpong. The level is 0.04 mg l^-1, well below the WHO recommendations of 45 mg l^{-1}. The concentration of chlorine in final water from Weija is quite high compared to Kpong. The average in tap water from Weija is 1.66 mg l^{-1} and 0.44 mg l^{-1} in Kpong. This can be compared to Swedish regulations of maximum 0.4 mg l^{-1}(Zinn, 2000). Heavy metals like mercury and lead are monitored but they are below detection limit. However, small concentrations of these contaminants may be harmful for the human health and environment. A problem in Adenta is the storage facilities of drinking water. These are many times poor and many residents store drinking water and rain harvesting in the same tank, which leads to contamination of water.

Transportation of water to user by tanker

There have not been any previous studies on how much the tankers travel in km p^{-1} y^{-1}. The distance between the closest filling point (Lashibie) and Adenta is about 9 km (Agyepong, 2001). The population of Adenta are approximately 18 000 persons, and 80 % of the population depends on tankers services i.e. 14 400 residents. The water consumption for the people that buy water from tankers is estimated to 30 l cap^{-1} d^-1. The Lashibie PWT (the association that serves Adenta) operates 6 days a week from Sunday to Friday and the most common capacity of the tankers is 2500 gallons (Agyepong, 2001).

The calculated distance is 11,9 km p^{-1} y^{-1}. Power tillers and tractors are not included in the calculations as well as tankers that travel from other filling points than Lashibie. The road to Adenta is a high intensity road and traffic jams are very common, which enhances the emissions from the vehicles even further.

Wastewater production

It is estimated that about 80 % of the water consumption goes into sewage in ATMA region including Adenta (pers comm. Nunoo). In Adenta the average water consumption is 36 l cap^{-1} $d^{-}1$ or 236 520m^3 y^{-1}. The wastewater produced in Adenta can be estimated to 189 216 m^3 y^{-1}or 10,5 m^3 p^{-1} y^{-1}, which is rather low, compared to the rest of ATMA 37,9 m^3 p^{-1} y^{-1} (figure 11).

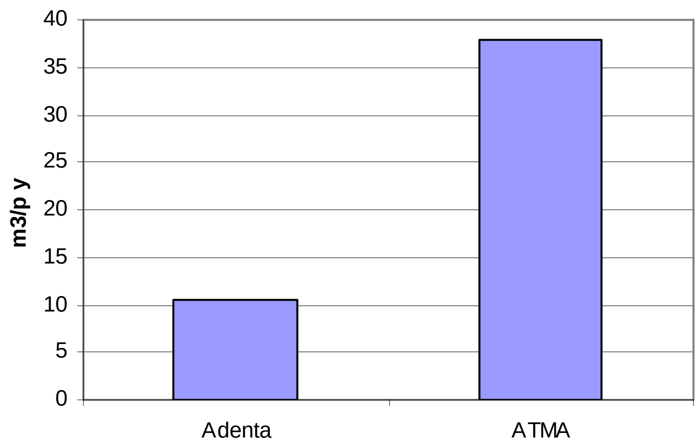


Figure 11: Wastewater production in Adenta and ATMA (GWCL, 2001).

Discharges of BOD, N and P to receiving water

Korle Lagoon is an anaerobic plant, which uses USAB reactors for purifying the water. It has a very high capacity of removing BOD (95%). The following values were calculated by multiplying the measured concentrations in the outgoing effluent by 80 % of the incoming volumes of wastewater, which is the estimated volume of treated wastewater being released to the Korle Lagoon. The calculated amount of BOD that is released to the environment is 780 g p^{-1} y^{-1}. There is no treatment for nitrogen and phosphorous at the wastewater plant, and no data has been found concerning release of N and P to receiving waters. The data used in this study are extrapolated from studies made in Sweden.(Bengtsson *et al*, 1997). It can be assumed that about 70 % of the incoming P and 80 % of the N is present in the final effluent to the aquatic environment. The rest is presumed to be caught in the sludge. If the incoming sludge contains 712 g p^{-1} y^{-1} phosphorous (Bengtsson *et al*, 1997), about 498 g p^{-1} y^{-1} will be released to the recipient. For nitrogen the release is 3920 g p^{-1} y^{-1}. This is of great concern as phosphorous and nitrogen contributes to environmental problems like eutrophication. The release of nutrients to receiving water can be calculated to 5198 g p^{-1} y^{-1} in Adenta.

Electricity and chemical use for wastewater treatment

Numbers from publications about anaerobic treatment has been used in the calculations. Electricity use for an aerobic wastewater treatment plant can be estimated to 29,8 kWh p^{-1} y^{-}1. The same number for an anaerobic plant is 19,4 kWh p^{-1} y^{-1}. This is 35 % lower than for aerobic plants. (Florencio, 2000). The net energy balance becomes even more positive when the biogas production is considered. The anaerobic treatment plan produces energy that may be reused for the operation of the plant. As mentioned before, there are plans to use the biogas as energy source in the future in Korle Lagoon.
No data could be found on the usage of chemicals in Korle Lagoon wastewater treatment plant.

Table 3: Summary table of the results of the applied indicators

Indicator	**Results (Adenta)**	**Highest value**
Withdrawal	236,5 km^3 y^{-1}	840,6 km^3 y^{-1}
Raw water quality	33,9 kg p^{-1} y^{-}1.	43,6 kg p^{-1} y^{-}1.
Water use	36 l cap^{-1} day^{-1}	130 l cap^{-1} day^{-1}
Electricity use for DW treatment	18,6 kWh p^{-1} y^{-1}	30,2 kWh p^{-1} y^{-1}
Chemical use for DW treatment	22 g p^{-1} y^{-1}.	39,6 g p^{-1} y^{-1}
Leakage	50% for pipeline	
Quality of DW	Nitrate low concentrations Chlorine high especially in Weija	
Transportation of water with tanker	11,9 km p^{-1} y^{-1}.	14,9 km p^{-1} y^{-}
Wastewater production	10,5 m^3 p^{-1} y^{-1}	37,9 m^3 p^{-1} y^{-}
Discharges of BOD, N and P	5198 g p^{-1} y^{-1} in Adenta.	6237 g p^{-1} y^{-1}.
Electricity use for WW treatment	19,4 kWh p^{-1} y^{-1}	80 kWh p^{-1} y^{-1}

11.2 Environmental Sustainability Fingerprints (ESF)

Environmental Sustainability Fingerprints (ESF) is a new method that collates indicators into visual presentation. The calculated values from the case study are divided by the highest value, resulting in number between zero and one, but without units. Table 4 lists the indicators, the highest values and the units that are used in the ESF. Figure 12 shows the ESF of the existing system as it is today in Adenta.

Table 4: Indicators in ESF. One is equivalent to the highest value for each indicator.

Indicator	Highest value	Unit
Freshwater resources		
A. Withdrawal	1 ⇔ 840,9	$km^3 y^{-1}$
B. Raw water quality	1 ⇔43,6	$kg\ p^{-1}\ y^{-1}$
Drinking water		
C. Water use	1 ⇔130	$l\ cap^{-1}\ day^{-1}$
D. Electricity use DW treatment	1 ⇔30,2	$kWh\ p^{-1}\ y^{-1}$
E. Chemical use for DW treatment	1 ⇔39,6	$g\ p^{-1}\ y^{-1}$
Transport		
F. Transport with tanker	1 ⇔14,9	$km\ p^{-1}\ y^{-1}$
Wastewater		
G. Wastewater production	1 ⇔37,9	$m^3\ p^{-1}\ y^{-1}$
H. Discharges of BOD N and P	1 ⇔6237	$g\ p^{-1}\ y^{-1}$.
I. Electricity use for WW	1 ⇔80	$kWh\ p^{-1}\ y^{-1}$

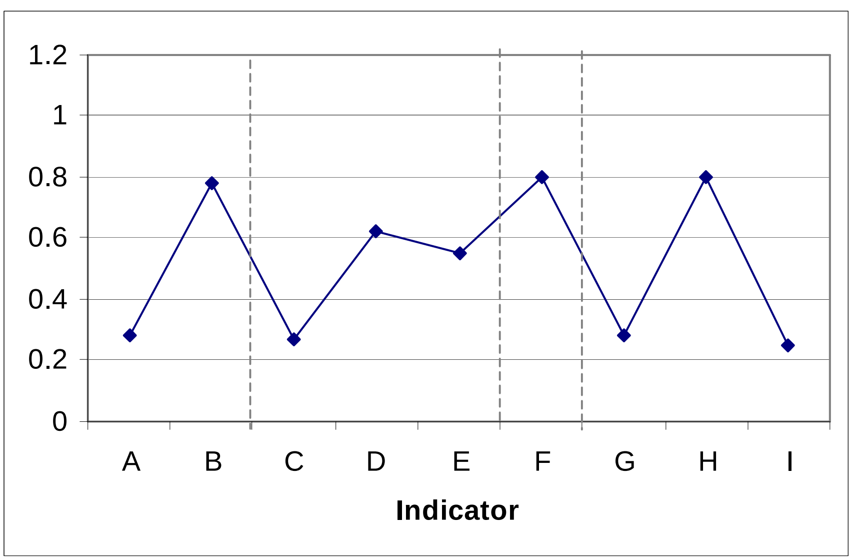
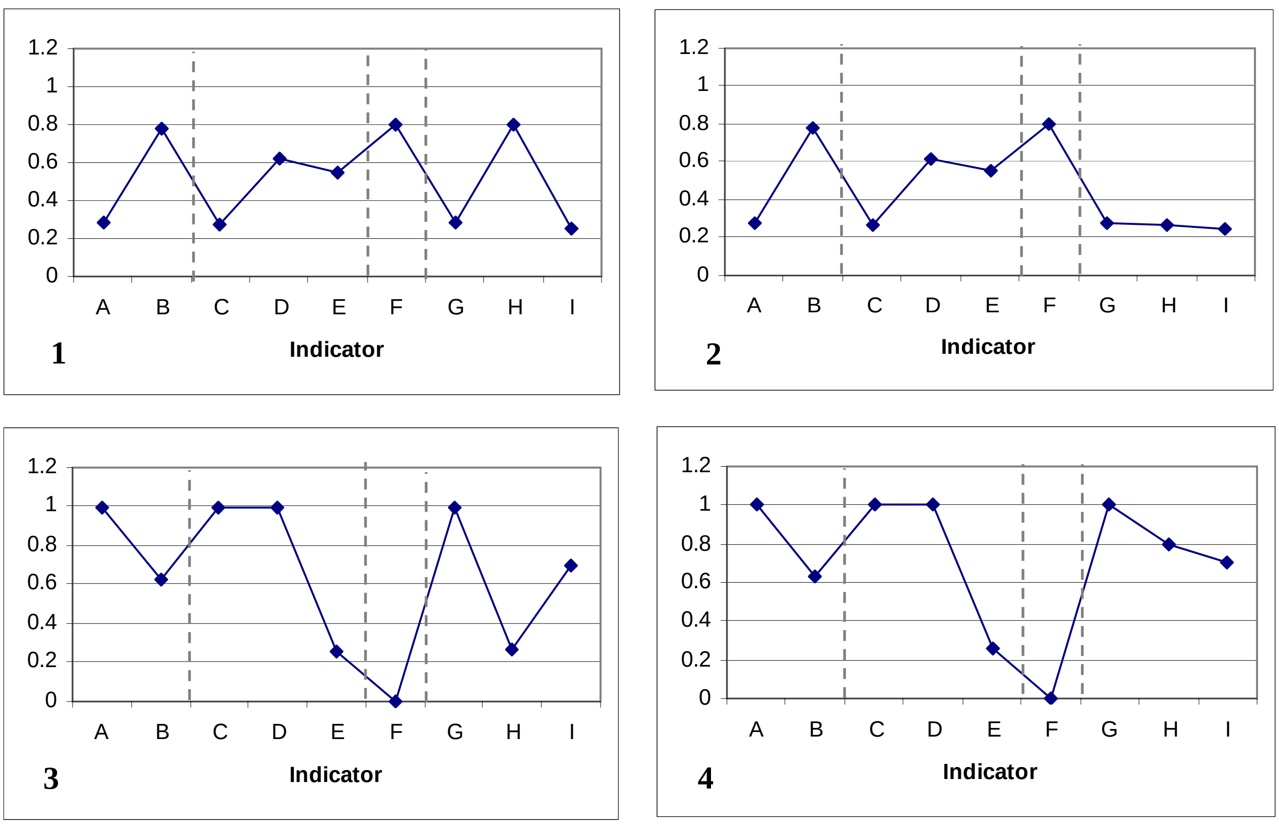


Figure 12: ESF for the urban water system in Adenta today

Figure 13 shows the present system in Adenta and three alternative urban water systems. The scenarios are:

1. Present urban water system in Adenta
2. Present system for water supply (tanker 80% and piping 20%) and source separation of wastewater.
3. Piped water for water supply and source separation of wastewater.
4. Piped water and regional treatment of wastewater.

The four scenarios enable comparison between the systems, in order to evaluate the environmental sustainability of the infrastructures. The values are not comparable between different indicators, the ESF only show relation between UWS for each indicator.



A. Withdrawal	F. Transport with tanker
B. Raw water quality	G. Wastewater production
C. Water use	H. Release of BOD, N and P
D. Electricity use for DW treatment	I. Electricity use for wastewater treatment
E. Chemical use for DW treatment	

Figure 13: Environmental Sustainability fingerprints for UWS scenarios.

Comparing the present system in Adenta (1) and scenario (2) it is clear that they are almost identical; the only ting that differs is the release of nutrients to receiving waters, which is lower in the separation alternative. However, as the fingerprints only takes into account three aspects from wastewater treatment this is not really the case. In a source separation alternative there would be other advantages compared to the conventional treatment. One would be the recycling of phosphorous and nitrogen to agricultural land. A case study in Sweden made by Bengtsson *et al* (1997) showed that more P could be used for farming in the source separation case. The percentage of P available to plants is also higher in the separation alternative. Chemical usage for wastewater treatment would also be much lower.

The ESF for energy consumption is the same in both figure 1 and 2 (or 3 and 4). The amount of electricity needed to treat the sewage differ little between the source separation and the conventional alternative. This has to do with an assumption that there will be no difference in wastewater production between the scenarios. Since the demand for electricity depends to a large extent of the wastewater volumes, this will lead to small differences between demands of electricity. Both a conventional and a source separation wastewater system produce biogas that can be used as an energy source for the wastewater plant. Presently there is no energy recovery at Korle Lagoon but there are plans for using the biogas in the near future for operational purposes.

Scenario 3 and 4 are representing piped water for water supply. Scenario 3 is the source separation alternative while scenario 4 is the conventional treatment of wastewater. These graphs look very different compared to the first two. Here the withdrawal, water use and electricity use for both drinking water treatment and wastewater treatment is much higher. As more water is used per person (130 l cap^{-1} d^{-1}) there is also an enhanced wastewater production. The high electricity use for drinking water treatment is due to the pumping of water from Kpong to Accra and Tema Booster and finally to Adenta. As mentioned before there are plans of building a pipeline from Kpong to the north eastern parts of Accra (where Adenta is situated). This would lower the energy use in a conventional system. In scenario 3 and 4 all water would originate from Kpong. As the raw water quality is better in Kpong than in Weija the chemical use would decrease for treating the drinking water. The water would be pumped through pipe lines to Adenta, and no transports of water through tankers would be needed, therefore the low values for tanker transport.

It is interesting to compare graph 1 and 3. Even though there would be a source separation of the wastewater in the latter alternative, the present system appears to be more sustainable from an environmental point of view. This is mainly due to the fact that people in Adenta have very low water consumption and that the energy consumption for drinking water treatment is low. The most preferable option is number 2 with the existing system for water supply and a source separation of wastewater and the least environmental sustainable option would be scenario 4, the conventional system used in industrialized countries.

For making the scenarios the urine separation numbers were taken from Swedish case studies which is a industrialized country where conditions are very different from Ghana. Installing urine-separating toilets is very expensive and a better option might be compost latrines (Johansson and Wass, 1994) with a separating system where part of the sludge produced could be used as fertilizer. However, this would require a very well planned logistic system for collecting and transporting the excreta to the farmlands.

As mentioned before the wastewater system in Adenta consists of onsite sanitation systems and septic tankers that are emptied and taken to Korle Lagoon for treatment. There are several problems connected with this type of solution. As the distance is large between the treatment plant and Adenta, illegal dumping in ditches, inland water etc is common practice. Traffic congestions prevent efficient emptying and haulage and the emptying services are often poorly managed. The transportation also results in emissions of air pollutants and use of fossil fuels, which is not a sustainable solution (Montanegro, 2002). Today it is not realistic that a western type of centralized system would be built for the whole city of Accra, due to the rapid growth of the city and financial limitations. An option would be to construct many small treatment plants, decentralized system (figure 14). It requires less land for individual plants and leads to shorter haulage distances than for centralized plants. Costs and haulage volumes could be reduced and dumping of faecal sludge could be avoided. Another option is to have a neighbourhood septic tank. This is especially suitable for densely populated periurban areas like Adenta. With fewer tanks the transportation would decrease. Other alternatives could be sedimentation tanks, ponds or drying beds. This allows handling and treating separately the relative large solid loads of faecal sludge, which is a valuable agricultural resource. Constructed wetlands have been proven to be a feasible treatment alternative characterized by low investment, operation and maintenance cost. However, a problem is that it requires a considerable area of land, which may not be available in a densely populated metropolitan area. (Wilderer and Schreff, 2000). It is important that the treatment options are determined on a case-to-case basis taking into account the specific conditions in the area (economic, climatically, legal etc.), the existing excreta management system and the characteristics of the sludge.

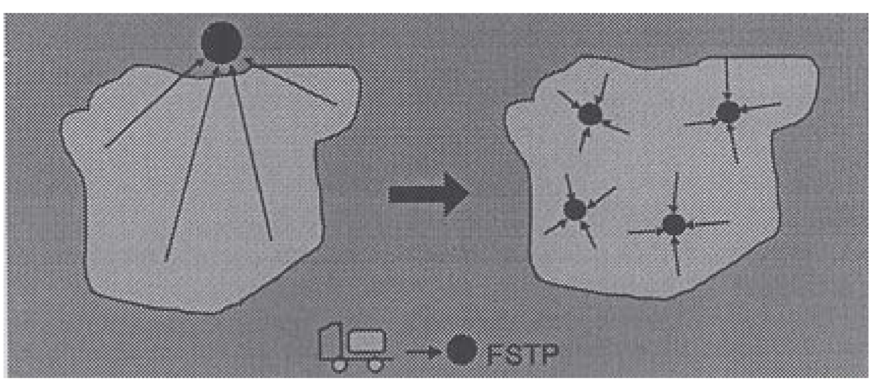


Figure 14: Decentralized sludge treatment. A tool to indiscriminate dumping, minimize costs and the risk for water pollution. FSTP = Faecal sludge treatment plant. (Ingillanella,2001)

11.3 Evaluation of the indicators

The ESI were evaluated against characteristics such as their relevance of environmental sustainability of the UWS and the availability and quality of information. It is important to remember that the importance of indicators depends on local and regional factors. In Adenta indicators like water use is of special interest as the demand is growing faster than the supply. In another part of the world other indicators might be considered more significant, it is therefore important that indicators are carefully chosen and evaluated for each specific case.

The criteria for suitable indicators are:

- Comparability of environmental sustainability of different urban water systems
- Availability of data
- Representatives of environmental aspects of the UWS
- Ease of use

Comparability

The comparability of environmental sustainability for the different UWS scenarios is good for the indicators. However, Transportation of water through tanker is only related to the tanker system, which gives a very high value for present system. Indicators that are applicable for both tanker and conventional systems are preferable. In order to compare the environmental sustainability of UWS it is very important that there is a good range of representative indicators. This is for making the study more accurate.

Availability of data

Data for most of the indicators concerning fresh water resources and drinking water was accessible. However, many important parameters for drinking water quality were not measured. Estimations are only made for leakage and there is no data available for the leakage concerning transportation of water with tankers. Measurements of phosphorous and nitrogen emissions was missing at the Korle Lagoon treatment plant. The data for electricity use in the wastewater treatment was available but not accessible. Availability of data of sufficient quantities is a condition for suitable indicators and some indicators in the case study requires further investigations.

Representatives of environmental aspects of the UWS

The indicators connection to environmental aspects is good for all the indicators. Some indicators are also related to health effects, such as raw and drinking water quality.

Ease of use

It is important that the indicators and the information they contain are easily understood by researchers, professionals and the general public. The indicators can then be used for decision-making, when planning an urban water system. The ease of use of the indicators is considered good. The ease of use also depends on the availability of data and the comparability of the different UWS, which has already been discussed.

12. Conclusions

The case study showed that environmental sustainability indicators (ESI) can be used for not only evaluating an existing urban water system in terms of sustainability but also for making scenarios of alternative solutions. However, the Environmental Sustainability Fingerprints (ESF) is a new method and needs to be further developed.

The present urban system of Adenta with tankers as the major water supplier was shown to be more sustainable than a conventional western type of solution. This is mainly due to the low water consumption in the area. If the water consumption would increase the results might be different. Further studies have to be done in this area.

For waste water systems source separation was the preferable alternative. As implementing a source separation alternative in Ghana is rather difficult, other wastewater systems could be of interest. Natural treatment systems such as ponds and wetlands could be good alternatives. Decentralized wastewater treatment plants are preferable to centralized plants. Advantages would be shorter distances, lower haulage volumes, less transportation, lower costs and reduction of illegal dumping.

In order to improve the indicators and the results it is essential to have access to more and long time series of data. As data was missing for some indicators, efforts should be done in making more measurements in the environmental field. This would improve the accuracy of the study.

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Appendix 1

Withdrawal

Annual available amount of water: In ATMA: 82 m gallons d^{-1}= 373 m l^{-1} d^{-1}=128 l cap^{-1} d^{-1}=2 304 000 l d^{-1}= 840 960 000 l y^{-1}= 840,96km^3/year
Annual fresh water withdrawal in Adenta: Average Water consumption 36 l cap^{-1} d^{-1} = 648 000 l d^{-1}= 236 520 000 l y^{-1}= 236,5 km^3/year
The total water withdrawals today in Adenta are 28% of the available amounts of water.

Raw water quality

Number of residents in Kpong catchment area: 20232
Number of residents in Weija catchment area: 7121

Kpong
N^{input}: (242,8 kg d^{-1} *365) = 88622 kg y^{-1}= 4,38 kg $p^{-1}y^{-1}$
P^{input}: (60,7 kg d^{-1} *365) = 22155 kg y^{-1}= 1,1 kg $p^{-1}y^{-1}$
BOD^{input}: (1222,9 kg d^{-1} *365) = 446358 kg y^{-1}= 22,06 kg $p^{-1}y^{-1}$= 27,54 kg p^{-1} y^{-1}

Weija
N^{input}: (136,1 kg d^{-1} *365) = 49676 kg y^{-1}= 7,0 kg $p^{-1}y^{-1}$
P^{input}: (34 kg d^{-1} *365) = 12410 kg y^{-1}= 1,7 kg $p^{-1}y^{-1}$
BOD^{input}: (680,8 kg d^{-1} *365) = 248492 kg y^{-1}= 34,9 kg $p^{-1}y^{-1}$ =43,6 kg p^{-1} y^{-1}

Nutrient input for Adenta: (0,6*4,38)+(0,6*1,1)+(0,6*22,06)=16,5 kg $p^{-1}y^{-1}$
(60% Kpong, 40% Weija) (0,4*7)+(0,4+1,7)+(0,4*34,9)= 17,4 kg p^{-1} y^{-1}
= 33,9 kg p^{-1} y^{-1}

Table XX: Raw data for nutrient input in raw water reservoirs in Weija and Kpong 1997 (Asante, 1997)

	Nitrogen (kg d^{-1})	Phosphorous (kg d^{-1})	BOD (kg d^{-1})
Kpong	242,8	60,7	1222,9
Weija	136,1	34	680,8

Water consumption

Residents in Adenta:	18000
Number of residents with pipeline:	3600
Number of residents who buy from tanker:	14 400
Water use in Adenta (interviews):	10-75 l cap^{-1} day^{-1}.
Residents with access to pipeline (average):	60 l cap^{-1} day^{-1}.

Residents who purchase water from tankers (average): 30 l cap^{-1} day^{-1}.

Average consumption =(14400*30+3600*60)/18000= 36 l cap^{-1} day^{-1}.

<u>Electricity use for drinking water treatment</u>

Electricity use in Weija:	22 460 274 kWh y^{-1}
Electricity use in Kpong:	69 923 923 kWh y^{-1}
Electricity use in Accra and Tema Booster:	18 077 042 kWh y^{-1}
Electricity use for pumping the water to Adenta:	88 566 233 kWh y^{-1}
Residents in ATMA:	2 936 833

Electricity use (Kpong):	23,8 kWh p^{-1} y^{-1}
Electricity use (Weija):	7,6 kWh p^{-1} y^{-1}
Electricity use for people, NE part of Accra:	30,2 kWh p^{-1} y^{-1}

Estimation Adenta: 20% uses pipeline, 40% tanker (water from Weija), 40 % tanker (water from Kpong).

Electricity use in Adenta: (3600*30,2)+(7200*23,8)+(7200*7,6)=334800/18 000= 18,6 kWh p^{-1} y^{-1}

<u>Chemical use for drinking water treatment</u>

Average added Cl^- (Kpong)= 0,45 mg l^{-1}
Average added Cl^- (Weija)= 1,67 mg l^{-1}

Amount of water produced in Weija: 40 m gallons d^{-1}=182 million l d^{-1}= 66 430 km^3 y^{-1}
Amount of water produced in Kpong: 42 m gallons d^{-1}=191 million l d^{-1}= 69 715 km^3 y^{-1}

Tonnes of Cl added in Kpong: ((0,45*10^{-6}) kg dm^{3-1}) * (66 430*10^6 dm^3 y^{-1})=29 893 kg y^{-1}= 29,9 tonnes y^{-1}
Tonnes of Cl added in Weija: ((1,67*10^{-6}) kg dm^{3-1}) * (69 715*10^6 dm^3 y^{-1})=116 424 kg y^{-1}= 116,4 tonnes y^{-1}

Chlorine addition in Kpong per person in ATMA: 29 893/2 936 833= 10,2 g p^{-1} y^-
Chlorine addition in Weija per person in ATMA: 116 424/2 936 833= 39,6 g p^{-1} y^-
Average: 25 g p^{-1} y^-

Chlorine addition in Adenta (60% receives their water from Kpong and 40 % from Weija): (10 800*10,2)+(7200*39,6)=395 280/18000= 22 g p^{-1} y^-
Average: 22 g p^{-1} y^-

Transportation of water by tanker

Distance between the closest filling point (Lashibie) and Adenta = 9 km
Population in Adenta= 18 000
Number of residents depending on tanker service = 14 400
Tanker operation = 6 days a week.
Water consumption from tanker (average) = 30 l cap^{-1} d^{-1}
Water consumption from tankers in area: (14 400*30)= 432 000 l d^{-1} (94 945 gallons day)
Number of tankers with the capacity of 2500 gallons (most common)= (94 945/2500)= 38 tankers
Each tanker travel 18 km =(38*18)
= 684 km d^{-1}=(684*313(6 days a week))=214 092 km y^{-1}=(214 092/18000)= 11,9 km p^{-1} y^{-1}

Wastewater production

80% of water consumption goes into sewage in ATMA.
Water consumption in Adenta = 36 l cap^{-1} $d^{-}1$ = 236 520 m^3 y^{-1}.
Wastewater produced = 189 216 m^3 y^{-1}= 10,5 m^3 p^{-1} $y^{-}1$.

Discharges of BOD, N and P to receiving water

Percentage of BOD that is removed: 95 %
Outgoing BOD (average) = 26 mg l^{-1}
Volumes of wastewater = 100 m^3 h^{-1}= (0,8 * 100 = 80 m^3 h^{-1} = 1 920 000 dm^3 d^{-1}.
Amount of BOD = (26 * 10^{-6}) * (1 920 000) = 49,9 kg d^{-1} * 365 = 18 213 kg y^{-1}= 18 213/23500 = 780 g p^{-1} y^{-1}
Percentage of P that is removed: 30 %
Incoming P (average) = 712
Amount of P in effluent: =(712*0.7) = 498 g p^{-1} y^{-1}
Percentage of N that is removed: 20%
Incoming N (average) = 4900
Amount of N in effluent: = (4900*0,8) = 3920 g p^{-1} y^{-1}
Sum: (780+498+3920)=5198 g p^{-1} y^{-1}

Electricity use for wastewater treatment

Electricity use aerobic plant = 29,8 kWh p^{-1} $y^{-}1$. Anaerobic plant 65% =19,4 kWh p^{-1} $y^{-}1$.