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DEVELOPING AND TESTING A RUDIMENTARY NANOTECHNOLOGY WATER FILTER FOR RURAL COMMUNITIES IN ZIMBABWE

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Abstract

Low-income earners in Zimbabwe's rural areas currently depend, to a very large extent, on water from rivers, wells, dams and boreholes. Water from all these sources is contaminated in one form or the other by the anthropogenic as well as natural pollutants and in many cases is unsuitable for human consumption. Over the past decade, an increasing number of field-based studies have been undertaken to determine the success of point – of – use (POU) treatment measures in reducing waterborne diseases. However for poor communities in rural areas of Zimbabwe such interventions have remained largely ineffective due to availability and application challenges, lack of support, resistance due to cultural stigmas and mere ignorance. The aim of this research was to provide a simple POU solution to water quality problems in the rural communities of Zimbabwe. Thermally converted magnetite particle material with nano-porosity was used to construct rudimentary filters for use by villagers. Both laboratory and village scale tests were conducted. Results revealed that filters constructed using nano-porous magnetite material were very effective for microbiological and chemical pollution control in water and can be used successfully and sustainably by poor communities in the rural areas.

Key words: magnetite particles, nanotechnology, filtration, rural communities

INTRODUCTION

According to a 2007 World Health Organization report, 1.1 billion people lack access to an improved drinking water supply, 88% of the 4 billion annual cases of diarrheal disease are attributed to unsafe water and inadequate sanitation and hygiene, and 1.8 million people die from diarrheal diseases each year [WHO, 2007:10]. In 2008, the cholera outbreak in Zimbabwe was the worst epidemic in Africa in at least the last 15 years as it reportedly killed 4 282 people out of over 100 000 infected, as wrecked health, water and sanitation infrastructure created ideal conditions for the spread of the diarrhoeal pathogen. Low-income earners in Zimbabwe's rural areas currently depend, to a very large extent, on water from rivers, wells, dams and boreholes. Water from all these sources is contaminated in one form or the other by the anthropogenic as well as natural pollutants and in many cases is unsuitable for human consumption.

Not only is potable water essential to maintaining health, it is also important for cooking, personal hygiene, sanitation, cleaning wounds, sprouting seeds and reconstituting dehydrated foods, including baby formula. Because water is so essential for survival, it is wise to have both a stored supply of drinking water and a way to acquire water for one's continuing needs.

The WHO estimates that 94% of these diarrheal cases are preventable through modifications to the environment, including access to safe water [WHO, 2007:11]. Simple techniques for treating water at home, such as chlorination, filters, and solar disinfection, and storing water in safe containers could save a huge number of lives each year [WHO and UNICEF, 2005:29].

The Millennium Development Goal (MDG) of halving the proportion of people without access to safe drinking water between 1990 and 2015 will probably not be met because some countries still face enormous challenges [Sachs *et al*, 2005:1].

Rural communities are the furthest from meeting the 2015 MDG's drinking water target. Globally only 27% of the rural population has water piped directly to their homes and 24% rely on unimproved sources. Of the 884 million people without access to improved water source 746 million people (84%) live in rural areas. Sub-Saharan Africa has made the least progress in improved water sources since 1990, improving only 9% to 2006. In contrast the Eastern Asian region saw a dramatic drop from 45% to 9% reliance on unimproved water in the same time period [WHO and UNICEF, 2005:5].

In Zimbabwe, particularly in Matabeleland, problems of drought exist. Although many boreholes have been sunk, the problem is they often dry up as a result of drought and the lack of funds and spare parts to maintain the pumps [UNEP, 2008]. Majority of Zimbabwean rural water sources for drinking are still the traditional ones that are dams, wells, rivers, streams and ponds which might harbour waterborne and vector-borne diseases. Even borehole water is not always safe to drink. Impurities in ground water maybe suspended material in the form of sediments, dissolved particles usually in the form of salts and heavy metals as well as colloidal particles which are usually microscopic particles that are difficult to sediment [Karanth, 1987:218].Lack of access to safe water is strongly correlated to poverty, and the provision of safe drinking water is considered to be a fundamental step in a community's transition out of poverty [Sachs *et al*, 2005:17].

Over the past decade, an increasing number of field-based studies have been undertaken to determine the success of point – of – use (POU) or household treatment measures in reducing waterborne diseases [Sobsey, 2002:10]. The ability of POU options to reduce disease is a function of both their ability to remove microbial pathogens if properly applied and such social factors as ease of use and cultural appropriateness. The current priority of the proponents of POU treatment is to reach large numbers of low-income households on a sustainable basis. Few POU measures have reached significant scale thus far, but efforts to promote and commercially distribute these products to the world's poor have only been under way for a few years [Sobsey, 2002:11].

In the light of this, many methods of POU have been developed by various organisations for treating water like Procter and Gamble's PuR® sachets, Vestergaard's LifeStraw, Aftim Accra's SODIS method, CWF from Potters for Peace, Stellenbosch's tea bag filter, boiling, etc but their costs have remained prohibitive for the lower income end and at times even when distributed freely, are both inconvenient and inappropriate for use [Lantagne *et al*, 2005; Sobsey, 2002]. It has become necessary therefore to investigate the possibility of adapting existing POU treatment methods for rural communities in the rural areas of Zimbabwe to conveniently and appropriately purify their water before drinking.

This paper aims at proffering a rudimentary POU water treatment method based on nanotechnology that has been successfully tested in a rural setting in Zimbabwe.

MATERIALS AND METHODS

The following materials were used for this study:

Granules were produced from iron oxide and kaolin clay (1.0 - 4.0 mm diameter) and thermally treated to generate pores within the range 0.5 – 10.0 µm in diameter. The iron oxide was processed from ore obtained from Buchwa Iron Mining Company (BIMCO) in Redcliff, Zimbabwe while the kaolin clay was obtained from WaterGlass Products in Gweru, Zimbabwe. Chemical composition of the two materials is shown in Table 1.

Table 1 Chemical composition of iron oxide and kaolin clay (%)

Chemical compound	Iron oxide	Kaolin clay
Fe_2O_3	78.4	0.99
SiO_2	12.3	49.58
CaO	0.27	0.36
MgO	0.07	4.41
Na_2O	-	0.37
K_2O	0.06	0.44
Al_2O_3	8.3	29.87

Table 2 Physical properties of magnetite powder

Property	value
BET Surface Area	42.7 m^2/g
BJH Adsorption average pore diameter (4V/A)	7.8nm
BJH Desorption average pore diameter (4V/A)	7.1nm
t-Plot Micropore Area	28.3 m^2/g

Magnetite powder used was earlier produced by chemical conversion and pulverised to 0.1 – 1.0µm particle size (Fig 1). The physical properties of the magnetite powder are detailed in Table 2.

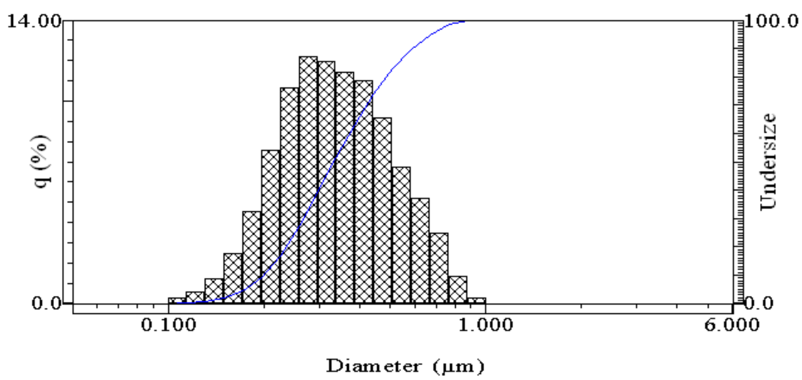

Fig 1 Particle size distribution of magnetite powder

Two 1,000ml separating funnels were used for laboratory scale filtration of water. Two 5L PVC buckets were used as demonstration vessels. One of the buckets designated filtering bucket, had its base perforated manually using a sharp piercing instrument to produce holes 0.5 - 1.0 mm diameter. The other bucket designated receptor bucket was fitted with a water spout at a distance of ¼ of its height from the base.

The two separating funnels were mounted on a clamp stand as shown in Fig 2. Cotton wool was placed first into the outlet of the burettes to prevent washing away of the material. Magnetite powder was then introduced into the burette to reach the 100ml volumetric mark. Care was taken to ensure the powder formed a compact, level bed. A bed of granules was then introduced on top of the powder up to the 300ml volumetric mark. The two 5l demonstration buckets were also lined with magnetite powder and granules in a similar fashion (i. e. powder 10% by volume and granules 20% by volume). A 5% by volume layer of washed river sand (1.0-5.0mm) was formed above the granules for pre-filtering. The buckets were mounted as shown on Fig 3.

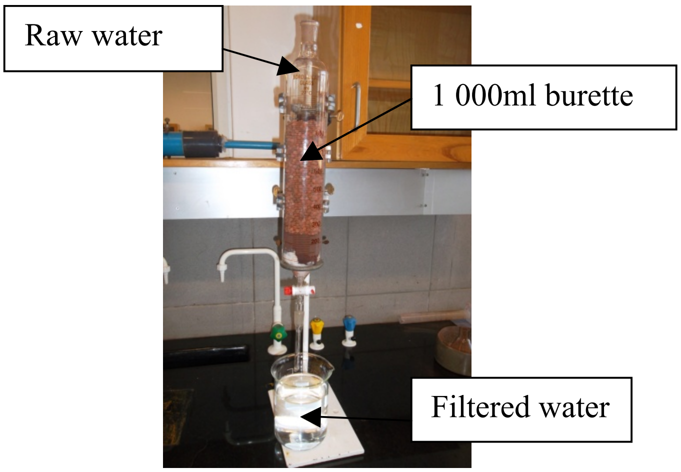

Fig 2 Lab scale filter design

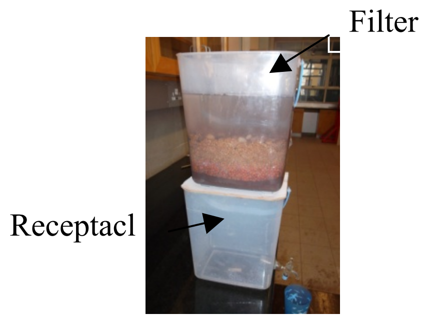

Fig 3 Filter mounting

Three demonstration units were taken to Mangwe district in Matebeleland South province of Zimbabwe and assembled for three homes and water from Simukwe River was passed through the filters as and when required by the villagers. The performance of the filters was monitored over a period of 18 months. The demonstration mini plant is shown in Fig 4.

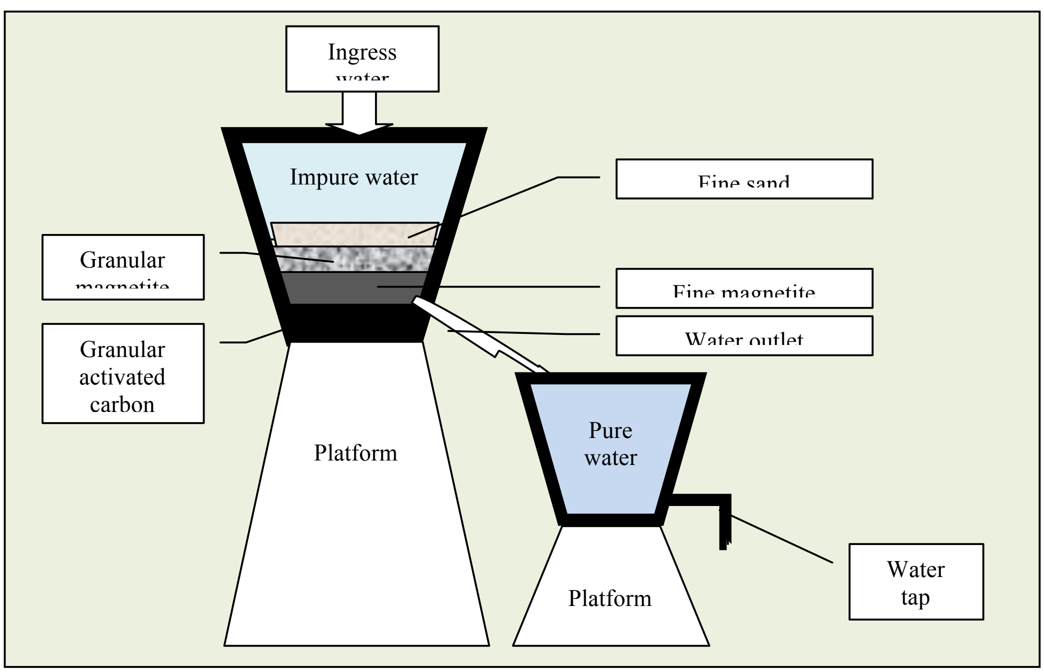

Fig.4 Rudimentary Filter Assembly

EXPERIMENTAL

For laboratory tests water samples were obtained from Khami Dam in the outskirts of Bulawayo, Zimbabwe using 20L water buckets, from a pond in the NUST campus and from a borehole at Bango Primary School in Mangwe District, Matebeleland South, Zimbabwe using 2L polyethylene containers in both cases. A grab sample was collected from the dam after manual localised agitation using an agitation stick. The same sampling procedure was employed for the pond water. Water from the borehole was allowed to run for a few seconds. The container was then rinsed twice with the water and then finally filled. The samples were then labeled and stored in the laboratory refrigerator.

The microbiological analysis performed on a sample of water is an examination of the presence of coliform bacteria. The presence of coliform bacteria indicates that other disease causing organisms may also be present in the water and it may be unsafe to drink [Nollet and De Gelder 2007:102]. The total coliform count can be used to assess the safety of drinking water [ASTM 1972:65]. However due to the devastating effect of *Escherichia coli (E.coli)*, which is found only in fecal material from warm-blooded animals an examination of this coliform reinforces the analysis of water for safe consumption [Nollet and De Gelder 2007:103]. The presence of this organism in a water supply is evidence of recent fecal contamination. Both the total coliform count and *E.coli* determinations were used to assess the safety of the water samples.

2L of water was drawn from the 20L water bucket from Khami Dam via a down spout and passed through the laboratory filter column shown in Fig 1. The water was passed through the filter 4 times each time collecting 100ml of filtered water into sterile bottles. For the pond water 2L were drawn and passed through the filter column this time varying the retention time in the column by means of a bottom stopper of the burette. Retention times of 10min, 20min, 40min, 60min, 80min, 100min and 180min were used. At the end of each retention time 100ml of filtered water was drawn into sterile bottles.

An Autoclave *No25X* was used for sterilizing the culture media, pipettes, sample bottles and glass plates. Total bacterial count was determined using the pour plate method whereby 1ml of water sample was inoculated in 20ml plate count agar and incubated for 24 hours at 37^{o}C. The colonies were counted and recorded in cfu/ ml (colony forming units per milliliter). *E. coli* was determined using the Multiple Tube Furnace method as described in Standard Methods for Examination of Water and Waste Water (ASTM 9221D).

500ml of borehole water was then passed through the filter column and analysed for heavy metals, total hardness, pH, nitrates, fluorides, sulphates, chlorides, electrical conductivity and turbidity. Another 500ml of untreated water were analysed similarly. All metals were analysed using the Perkin Elmer 3110 Atomic Absorption Spectrometer and the Spec 20 Atomic Absorption Spectrometer [Zolotov *et al*, 1987:6]. Total hardness was determined using EDTA standard method [ISO 6059:1984]. A Corning pH meter 220 was used to determine the water pH. Nitrates and fluorides were determined using Perkin-Elmer UV-vis Spectrometer Lambda 2 while the Argentometric method was used to determine chlorides.

RESULTS AND DISCUSSION

Microbial analysis results for Khami Dam water are given in Fig 5 and for pond water in Fig 6. In Fig 5 **A** shows the reduction in microbial count in water collected and tested on 29/08/2012 while **B** shows reduction for water collected on 27/09/2012.

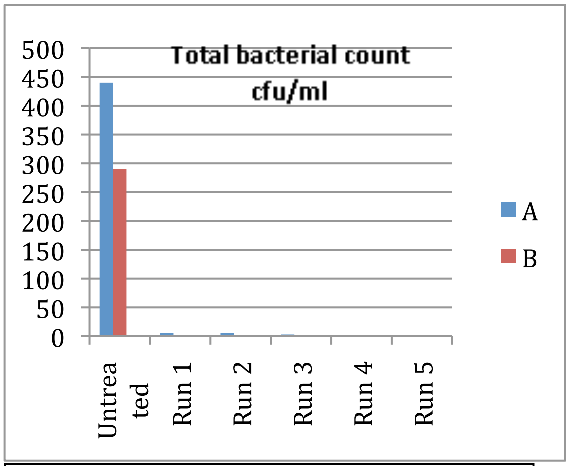

Fig 5 Dependence of microbial count on number of filtrations of Khami Dam water

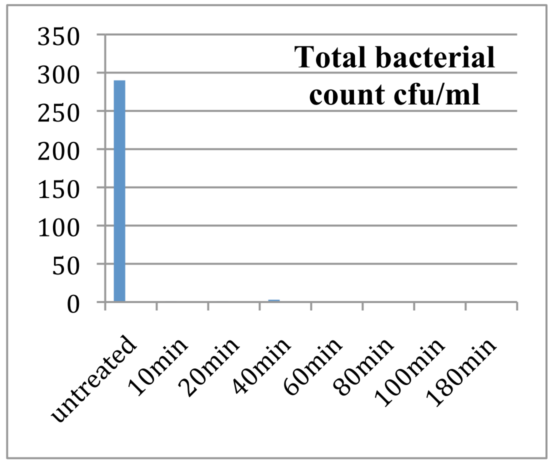

Fig 6 Microbial count versus treatment time

Table 3 E. coli count for Khami dam water sampled on 14/02/13

Sample	Faecal Coliform, E.Coli
Raw	positive
1st run	negative
2nd run	negative
3rd run	negative
4th run	negative

Table 4 E. coli count for Khami dam water sampled on 20/02/13

Sample	Faecal Coliform, E.Coli
Raw	positive
10 minutes	negative
30 minutes	negative
60 minutes	negative
90 minutes	negative

Chemical analysis of borehole water before and after filtration is shown on Table 3. Of the three demonstration units installed and observed in the rural area one required relining after 12 months of service another after 14 months and the other after 17 months of service.

DISCUSSION

Fig 5 and 6 show that there is an instantaneous reduction in microbiological count as the water is filtered through the columns. The number of passes of water through the filter beds did not exhibit a marked influence on the effectiveness of the filter material on micro biological organisms. In fact, the first pass was sufficient to reduce bacteria levels by >99%. Retaining the water in the filter did not have any marked influence on the elimination of micro organisms either as they were removed completely within 10 minutes. The mechanism by which magnetite eliminates micro biological organisms is still largely not understood. However the anti-microbial properties of magnetite most likely stem from the chemical properties of its ionized forms, Fe^{2+} and Fe^{3+}. These ions, especially the former, form strong molecular bonds with other substances used by bacteria to respire, such as molecules containing sulphur, nitrogen, and oxygen. When the Fe^{2+} ion forms a complex with these molecules, they are made unusable by the bacteria, and deprived of necessary compounds the bacteria eventually dies [Hoskins et al 2012:7-8].

Table 3 Analysis results of borehole water

Analyte	Untreated water, conc mg/L	Treated water, conc mg/L	WHO standards, conc mg/L
Copper	Trace	Trace	0.200
Iron	Trace	Trace	0.200
Lead	Trace	Trace	0.010
Chromium	Trace	trace	0.050
Nickel	0.250	0.000	0.020
Cobalt	0.023	0.001	-
Manganese	2.390	0.186	0.5000
Cadmium	Trace	Trace	0.003
Chlorides	279.300	193.94	250.000
Fluorides	1.958	0.275	-
Nitrates	0.446	0.317	-
Total hardness	199	165	-
pH	6.8	7.9	6.5 – 8.5

Also Fe^{2+}, by its ability to redox-cycle, will lead to production of free radicals (such as super-oxide radical O^- and hydroxyl OH^-) and other non-radical oxygen reactive species (such as hydrogen peroxide H_2O_2) which are also highly toxic to the cell through reacting with proteins, nucleic acids and lipids. The OH^- radical leads to lipid peroxidation of the cell membrane and consequently the cell becomes leaky and dies [Sharma *et al* 2012:15]. Due to nanometer pore sizes in the magnetite material (<8nm) bacteria (>100nm in size) and viruses (>20nm in size) in the water can not find their way through the material which traps them giving chance for metabolic transformations that result in their elimination.

As for chemical analysis shown on Table 3 the use of magnetite filtration has a positive removal effect on heavy metals and inorganic materials that were determined as there was concentration reduction in all cases. It has been repeatedly shown that iron oxides are good candidates for adsorption studies, as they have affinities for heavy metals, specifically Cd (II), Pb (II), and As (V) as they form complex structures with iron (D'Couto 2008:33). Magnetite, which is super paramagnetic, has continuously fluctuating magnetic moments, which average to zero below the Curie temperature. When the particles are nano-scale the moments become more pronounced [D'Couto 2008:34].

The trial at the rural area was a success as the effect of magnetite filtration was demonstrated to improve water potability and taste. The filtration system is rudimentary and can be assembled and operated by individuals with the most basic of understanding of filtration. The service life of the filters was satisfactory.

CONLUSION

The use of magnetite filtration is a POU solution for drinking water for rural communities. The magnetite is produced locally using local raw materials and villagers can be trained to produce the magnetite filters on their own. This can help empower them to control the quality of their drinking water.

The cost of producing the magnetite powder is about US$5 per kg and granules about US$3 per kg. Since each household filter requires 3kg powder, 2kg granules, 2kg GAC and two plastic buckets the total cost is estimated to not more than US$30 including labour and accessory materials which is less than the price of an ordinary goat in the rural communities. A properly assembled and maintained filter is expected to last a period of about 18 months and relining involves about half the cost of a new filter.

Therefore the developed and tested water filtration method is rudimentary, of low cost, affordable and appropriate for use by rural communities in Zimbabwe.

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Appropriate integrated water management technology transfer in the Patzcuaro Lake basin, Michoacan, Mexico.

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Abstract

This project aims to equip houses of families who live in communities where the quality and quantity of water is limited, through a training process, with the transfer of simple and low cost integrated water managing technologies in order to reduce the impacts due to lack of water and sanitation systems in rural and indigenous population of Patzcuaro Lake basin, in Michoacan, Mexico.

Over 2,600 homes have been a part of the program. Systems for ~~the~~ capture, retrieval, transport, storage, purification, energy consumption and water use have been installed. These include rainwater harvesting, bicycle pumps, water tanks, solar disinfection systems, biofilters and kitchen gardens equipped with systems of self-operating irrigation. The participation of women of the Purepecha ethnicity has been important during the transfer process.

With these low-cost and easy to implement technologies, it has been possible to positively impact the way of life of the inhabitants of the basin, thus contributing to the integration of water management at household level, without generating technological dependence.

Here, some data is presented regarding the realities in rural and indigenous communities in the basin. Since 2003, 7,311 technologies have been transferred; with activity in over thirty communities and benefits to 23,745 inhabitants. Rainwater storage has been installed with capacity for 3,470,500 liters. Catchment areas total 25,187 m^2 and installation of 824 family orchards with a total area of 22,400 m^2 cultivation took place. Treatment capacity of 65,200 liters per day of gray water, ability to treat 59,800 liters per day of black water and ability to disinfect 1,998 liters of water per day were achieved.

It is worth noting that during the transfer process, the general population has become aware of the importance of stopping the severe and rapid deterioration of water quality in the region as well as the urgent need to manage water resources with a focus on sustainability without jeopardizing the current population and future generations.

KeyWords: appropriate technology, rural areas, rain water harvesting, low cost technologies, bicycle pumps, solar disinfection, kitchen gardens.

Introduction

The Patzcuaro Lake Basin is located in the state of Michoacan, Mexico. This is an endorheic basin with an area of 929 km^2, and its elevation starts from 2,035 to 3,300 m.a.s.l, with an average elevation of 2,369 meters. The average annual rainfall is 775 mm, while evaporation is 1,393 mm. It features an interior lake of 126.4 km^2, which has an average depth of 4.9 m and has a capacity to store 619.4 hm^3. Its population is approximately 120,000 inhabitants and its economy depends mainly on tourism, forestry, fishing and crafts and more recently, remittances that come from their migrants working in the United States. For its unique beauty and its historical background, which date back to pre-Hispanic times, it is considered one of the flagship regions of Mexico (García, 2008).

In the last fifty years, due to the overexploitation of natural resources and pollution, the basin has suffered serious environmental degradation problems as summarized in the following priority issues: social conflicts and poor environmental culture; deterioration of the water quality of the lake; deterioration in the public health, public welfare and extreme poverty; deforestation; soil erosion and pollution; reduction of fisheries and aquaculture; biodiversity loss; lack of economic resources and decrease in the amount of lake water and the volume of groundwater.

In order to contribute to the solution of the environmental problems of the Patzcuaro Lake, on February 26th, 2003 the Program for the Environmental Rehabilitation of the Patzcuaro Lake was implemented. This program gathered efforts and resources from Federal and State level governments, municipalities of Pátzcuaro, Quiroga, Tzintzuntzan, Erongarícuaro and Huiramba; universities, non-governmental organizations, including the participation of Gonzalo Río Arronte Foundation and, most especially, the civil society that has been participating since the implementation of the program. This agreement remained valid and has been ratified five times, the last one for the period 2013-2017.

Integrated water management was promoted through the transfer of appropriate technology to rural and indigenous communities to mitigate the problems associated with health disease problems, extreme poverty and public welfare; particularly to communities that were highly marginalized. This initiative aimed to provide families living in communities where the quality and quantity of water is limited, with simple and inexpensive technologies in order to reduce the impact of water pollution, lack of food, disease and environmental degradation suffered by the rural and indigenous population of Patzcuaro Lake. These actions where implemented following a systematic training process that helps to empower the local communities, diversifying and increasing their capacities related to water management.

These appropriate and ecofriendly systems are technologies that allow people to easily meet their water needs at the household level and are characterized by their low cost and easy installation. These technologies are grouped in a package consisting of eight concepts: i) rainwater harvesting system ii) rainwater storage system, iii) family garden, iv) bottom discharge tank, v) solar disinfection, vi) ecological laundry, vii) ecological toilet and viii) bicycle pump. Through these devices, at the household level one can capture, store and disinfect water and treat and reuse wastewater (gray and black) in home gardens (Table 1). These devises allow the capture, storage and disinfection water at household level.

The results indicate that with these low-cost, easy to apply technologies, it is possible to improve the lifestyle of the inhabitants of the basin. It becomes an important contribution to the activities of collection and storage of water, extraction and / or pumping water, food production and primary and secondary water treatment at household level, without highly technological systems dependence.

Table 1. Appropriate technologies for water.

Technology	Function
Rainwater harvesting system	Collect rainwater
Rainwater storage system	Water storage
Ecological toilet	Bathroom and sewage treatment
Ecological laundry	Laundry and greywater treatment
Solar box	Disinfection ~~for~~ of drinking water
Backyard Garden	Productive use of water for the production of vegetables
Bottom discharge tank	Self-operating irrigation system
Bicycle pump	Water pumping

Source: Ortega, 2007

Methodology

The institute has developed a manual to make the technology transfer, in which the methodology applied in the communities of the basin was systematized. The manual is organized into 5 sections plus appendices (Ortega, *et al*, 2007). After the introduction, the first section discusses the site preparation to execute the transfer of each technology, possible scaling up issues and the personnel and tools needed to carry it out. The next three sections take you through the steps in the process of carrying out the installation of the technologies in the selected locations, the transfer strategy and the monitoring process. Finally, the appendices provide details for some further steps such as instruments of control, monitoring, general data surveys among others.

Appropriate technologies for water, developed by the Mexican Institute of Water Technology (IMTA) have been designed so they can be integrated into the daily lives of families living in marginalized rural areas with minimal disturbance to their customs, while seeking to improve their quality of life through the provision of water resources. It is widely recognized that the lack of water creates cycles of poverty that lead to more inequalities between men and women, increases disease and, eventually, even death.

The following describes each one of the appropriate technologies transferred in the Patzcuaro Lake basin:

Rainwater Catchment - Collecting rainwater from the roof into a storage tank; the system includes gutters, pipes and traps for solids. The size of the system depends on the separation of the storage tank to the ceiling of the house and the materials used for its construction vary depending on the characteristics of the roof. The particular characteristics of each house are taken into account during the transfer process.

Vertical brick tank type - Structure for water storage, installed at ground level, consisting of a cylindrical structure made of brick placed vertically (known locally in Mexico as *capuchino* type), reinforced with wire mesh and plastered with cement. The external dimensions for an 11m^3 tank are 3.0 m in diameter by 2.4 m high.

Solar Box - Device for exposing the water to sunlight for a period of time to disinfect it, the solar box inactivates bacteria at levels up to 99.99%. The device does not alter the organoleptic characteristics of water. The treated water is fit for human consumption; it includes a flat solar concentrator made of an structure of 0.35 m x 0.35 m, that can be wood and mirrors, and the size is enough for disinfect the volume of 3 Polyethylene Terephthalate (PET) bottles of 2 liters each, during a whole insolation day.

Eco Laundry - Biological system to treat water from the laundry, dishes, cooking, body shower and wash basin (gray water); consists of a grease trap, with anaerobic bio filter packing rings made of PET and an artificial wetland. It has a hydraulic retention time of 4 days and a treatment capacity of 200 liters per day.

Ecological Toilet - Is an appropriate technology that is used to treat, through a biological system, the water from the toilet contaminated with fecal matter and urine (black water); consists of two structures reinforced with mesh and plastered with cement, the first structure is a septic tank for sedimentation of solids; the second, consisting of two chambers, is formed by an anaerobic filter followed by an artificial wetland. If housing does not have bathroom, it is possible to build one and connect it to the system.

Bottom Discharge Tank - It is a device for irrigation, self-operating system, which is used to irrigate small areas with low flow discharge. The device operates as an amplifier of hydraulic gradient by the accumulation of water entering a storage tank of 200 liters with a height of 1 meter. Water discharge is controlled by an internal mechanism using PVC pipe 2" diameter. With this device it is possible to optimize the irrigation of 72 m^2 with water efficiency levels of up to 75% compared to non technified irrigation.

Bicycle Pump - Allows small flows to be handled by mechanical pumping action while pedaling a bicycle; consists of a pump supported in a base iron structure with an adaptation which allows to support a bicycle; the back wheel of the bicycle rests in the main pump axis; the iron structure is not fixed to the ground so it can be moved and connected in any point where it is necessary to pump water inside the household.

The process of transferring the Appropriate Technologies was made following this scheme:

a) A first phase forms the basis for the initial field activities, which depending on the nature and scale of the project (number of beneficiaries), makes it necessary to form one or several team fields to gather communities information in order to quantify the building materials that are necessary to begin the transfer process of the technologies. Also in this phase is necessary to get approval from each beneficiary, because they must be involved in the construction process.
b) The second phase consists in the definition of the strategy in order to reach the total amount of beneficiaries in the minimum space of time, in order to optimize the schedule for visiting each family to be beneficiated.
c) Then the third phase is essential in order to get the complete transfer and appropriation of the technologies, during this phase it is necessary to start the technology transfer to each family, by implementing the training course given to the beneficiaries so they can be capable of self-constructing the systems, this way they can be able to know and understand the basis of each system making possible to replicate them locally.

d) The last phase consists in monitoring the use of the transferred technologies to each community, the training course given during the third phase is necessary to ensure the correct use and maintenance of the systems.

This process considers a participative approach of the local population: the basic feature is to promote the participation of local people in the whole process of the project. As a starting point, it is necessary to have the opinion and knowledge of the rural population, the goal is to increase their skills, driving a process of knowledge and decision making through active and purposeful participation. Training manuals were designed with the aim of providing the theoretical and practical elements for the beneficiaries. The manual provides simple explanation of the installation process, emphasizes the benefits, performance, user practices and maintenance. For installation, the project provides all the required materials and the recipient provides the necessary labor.

After the scale of the project was defined, the team was trained, strategy defined, the process was conducted in field divided into the following phases.

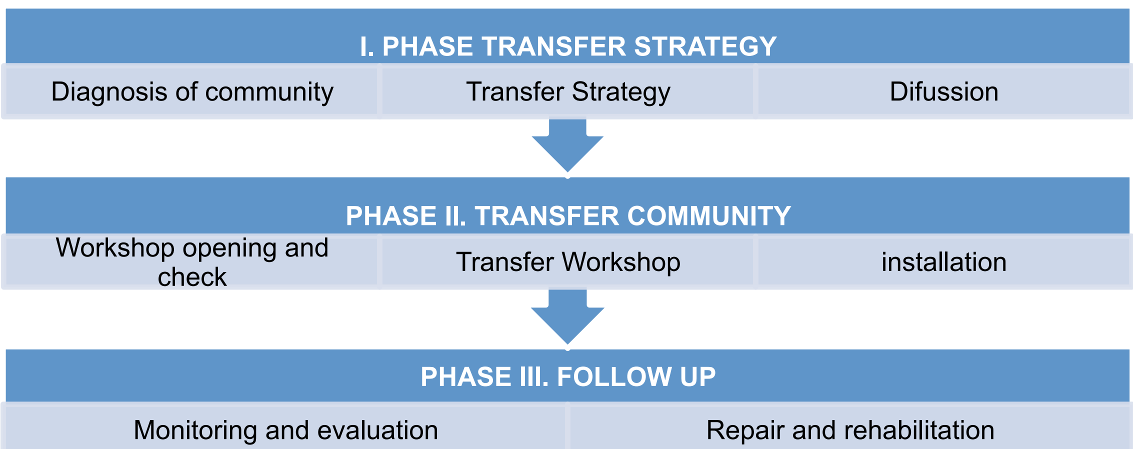

Figure 1. Transfer Strategy

Throughout the process, the following principles must be observed:

- Efficient use of water
- Quality of service
- Efficiency in the use and allocation of resources
- Respect to communities traditions, beliefs and habits
- Equity and fairness in the selection of beneficiaries
- Caring for the environment
- Gender equity in the transfer process
- No political or religious preferences
-

Results

As a result of this project, 7,311 appropriate technologies were installed covering over 30 localities of the four municipalities, directly benefiting 23,740inhabitants in the basin. During this process, the methodology for technology transfer in rural communities, installation manuals, and a Geographic Information System (GIS) program were developed. The GIS System concentrate all the information generated during the transfer process and it is systematized, which makes possible to consult and monitor specifically each appropriate technology installed in the communities within the lake basin.

This means that there is a capacity to store 3,470,500 liters of rainwater; 25,187 m^2 of installed catchment area, 824 home gardens installed with a production area of 22,400 m^2; 65,200 liters per day capacity to treat gray water; 59,800 liters per day capacity to treat black water and the possibility to disinfect 1,998 liters of water per day.

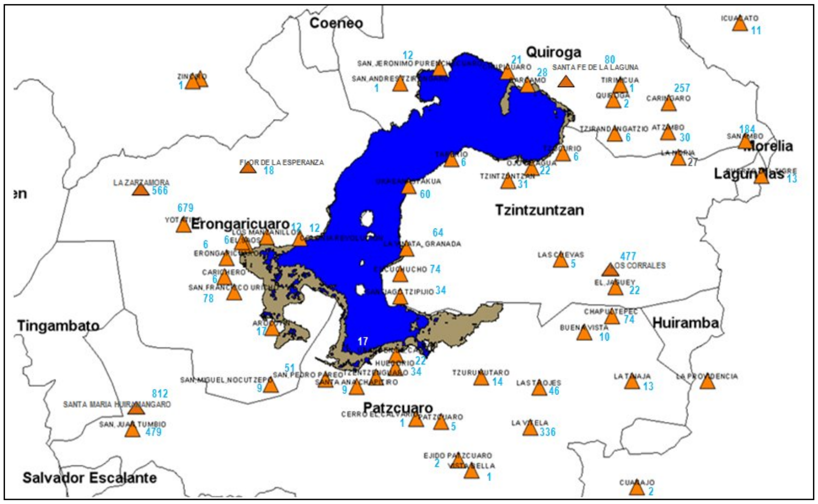

Figure 2. Communities with appropriate technologies installed.

The results indicate that with these low-cost easy to implement technologies it has been possible to improve the lifestyle of the inhabitants of the basin. The local population get involved in the activities of data collection, storage, extraction and / or pumping of water, food production, primary and secondary water treatment at household level, without dependence on external agencies or technologies.

Figure 3. Installation process of appropriate technologies.

Finally, this process can empower beneficiaries since the technologies are built by themselves, thus generating knowledge for proper operation and maintenance that can also be replicated with other beneficiaries and / or localities. By these actions, the integrated water management concept is encouraged in homes and beneficiaries promoting use of water sustainably.

Table 2. Appropriate technologies transferred during the period 2003 – 2011.

Number of	Vertical brick tank capacity installed (m3)					Rainwater	Solar box	Family	Bottom	Bicycle	Ecological	Ecological	Dry
Locations	5	11 to 12	15 to 17	20 to 35	50	Catchemnts	disinfection	Gardens	discharge tank	pump	laundry	Toilet	Toilet
55	305	641	12	2	1	701	1301	824	824	777	1201	648	23

Source: GIS of the Program for the Environmental Rehabilitation of the Patzcuaro Lake.

Figure 4. Examples of appropriate technologies finished

This year (2014) monitoring of technology transfer in compliance with the outcomes and objectives of the project will be evaluated. This assessment will be made based on indicators that reflect the efficiency of the installation of appropriate technologies and their impact on users and their environment. Once the results, conclusions and recommendations are established, efforts to improve the technology transfer process and increase the project area will take place.

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Evaluation of sand biofilters as rainwater disinfection system used for drinking water

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Abstract

The lack of access to drinking water, especially in rural communities, makes people susceptible to waterborne diseases to meet their daily needs. In Mexico the most common waterborne diseases are intestinal infectious diseases, which are among the top 20 causes of general death and are the leading cause of mortality in children under five years (SINAIS, 2008).

In order to remedy the problem of water scarcity, rainwater harvesting has been implemented; however, it is necessary to disinfect the water before consuming. Alternatively disinfection at the household level arises the sand biofilter, which is an adaptation of the traditional slow sand filter, whose main advantages lie in its simple construction, operation and maintenance.

The aim of this study was to evaluate a sand biofilter as rainwater disinfection system used for drinking water in the community Felipe Neri, Tlalnepantla, Morelos. The biofilter was constructed based on the model developed by the Centre for Affordable Water and Sanitation Technology (CAWST).

The biofilter was monitored for three months, analyzing the pH and microbiological parameters marked in the current regulations for drinking water in Mexico (NOM-127-SSA1-1994). Monitoring results indicate that the biofilter can be coupled to a rainwater collection system for disinfection showing removal efficiencies of total and fecal coliforms over 99%.

Keywords: Biofilter; disinfection; rainwater; drinking water.

Introduction

Drinking water is the one that can be consumed by people and animals without risk of disease. The term applies to water that has been treated for human consumption according to quality standards determined by the local and international authorities. It is estimated that by 2012, the coverage of drinking water in Mexico was 92% covering 95.5% in urban areas and 80.3% in rural areas (CONAGUA, 2013). As shown, it is presented more coverage in urban areas than in rural areas, however, the fact of having this service does not necessarily mean that the water is safe for human consumption. This is a serious problem because generally in rural communities there is no other source of supply that meets the required standards for consumption.

On the other hand, people in rural areas that do not have drinking water, often use sources as rivers and lakes that may have a high degree of pollution due to the discharge of untreated wastewater from industries and households. This results in an increase in the incidence of waterborne diseases.

Water-related diseases

When water destined for human consumption or crop irrigation has a high degree of pollution, particularly of pathogens, waterborne diseases can be contracted. In Mexico the most common waterborne diseases are intestinal infectious diseases, which are among the top 20 causes of general death, are the leading cause of mortality in children under five years and ranks fourth among the main causes of infant mortality (under one year) (SINAIS, 2008).

Treatment alternatives for water disinfection in rural areas

Water disinfection is part of the purification process, and refers to the inactivation of microorganisms, especially pathogens that are responsible for diseases. Because that installing water treatment plants in rural areas is not always possible, techniques that enable people to carry out the disinfection of water in a simple way and low cost are used. Some of these techniques include solar disinfection (SODIS), boiling, chemical disinfection (such as chlorine and iodine), and sand biofilters.

Sand Biofilters

The sand biofilter is an adaptation of the traditional slow sand filter which allows its build on a small scale and can be operated intermittently. These modifications make the filter to be a good choice for use at the household level or for small groups. It can be produced locally anywhere in the world because it is constructed with readily available materials. In addition, does not present energy dependence making it a viable alternative for rural communities. This filter is packaged with three media types: fine sand, coarse sand (fine gravel) and coarse gravel, in which are carried out transport, adhesion and biological mechanism. The biological mechanism is the most important in this system, and it’s performed through a layer consisting of materials of organic origin formed in the surface of the media, known as the "schmutzdecke" or "biolayer ".

It is necessary for the filter to operate as a true "disinfection system" to have produced a robust and sufficient schmutzdecke, which is known as stabilization stage. Only when it has reached that point, the filter can operate correctly. Then we say the filter "is ripe" (Solsona and Mendez, 2002).

During the filtration, there are four processes to help the elimination of pathogens that are:

a) Trap mechanical: The pores or spaces between the grains of sand trap sediment and pathogens.
b) Predation: Pathogens are consumed by other organisms in the overlying water and the biological layer.
c) Adsorption / attraction: Pathogens are attracted to each other, to sediments and sand grains.

d) Natural Death: Pathogens finish their life cycle or die because there is not enough food and oxygen to survive.

Removal efficiencies

For several years have been conducted studies, both at laboratory and field level, about the efficiency of biofilters to remove certain contaminants. The results of some of these studies are presented in Table 1.

Table 1. Reported removals.

Author	Parameter	Effluent concentration	Average removal efficiency (%)
Stauber (2007)	*E. coli*	25 MPN/100ml	>99.9
	Turbidity	1.7 NTU	11
Aiken et al. (2011)	*E. coli*	28.3 MPN/100 ml	88.4
	Turbidity	1.1 NTU	29.5
Sisson et al. (2013)	*E. coli*	87 MPN/100ml	92
	Turbidity	4.7 NTU	82
Stauber et al. (2012)	*E coli.*	437 MPN/100 ml	97
	Turbidity	47 NTU	67
Aiken (2008)	Total coliforms	1181 MPN/100 ml	88.7
	E coli.	28.3 MPN/100 ml	88.4
	Turbidity	1.1 NTU	29.5
Mudie (2013)	Fecal coliforms	647 MPN/100 ml	96.95
Horne (2012)	Total coliforms	104 – 21.6 MPN/100mL	99 - 86

Methods

Sand biofilter construction

During July 2013 was carried out the construction of a sand biofilter, guided by the manual included in the final report of the project "Evaluation of sand biofilters as single family disinfection systems in rural communities" HC1105.1, of 2011. This guide is based in the model developed by the Centre for Affordable Water and Sanitation Technology (CAWST).

Biolayer stabilization and rainwater characterization

The stabilization stage for this biofilter was one month, starting on 6 September 2013 (day zero). During this time the biofilter was fed every third day with rainwater, and was carried monitoring the formation of the biolayer through three samplings in the storage tank of rainwater (influent) and outlet of the biofilter (effluent), carried out at 0, 15 and 30 days of operation.

Day zero samples were used for the characterization of rainwater. For this, the corresponding analyzes were performed for all the parameters listed in the Official Mexican Standard NOM-127-SSA1-1994, “Environmental health, water for human use and consumption - permissible levels of quality and treatment to which must undergo the water for purification”.

Monitoring

After the stabilization phase, were conducted two samplings at 60 and 80 days from the initial date, to track the percentage of contaminant removal in the biofilter.
Four of the samplings were performed at the certified laboratory of water quality, and the remaining was conducted in the laboratory of Appropriate Technology, at IMTA.

Calculation of removal percentage
Once obtained the results of the analysis, we calculated the percentage removal of total coliform, fecal coliform and pH, using the following formula.

% Removal= Concentration If−Concentration EfConcentration If∗100

Where: If = Influent; Ef = Effluent

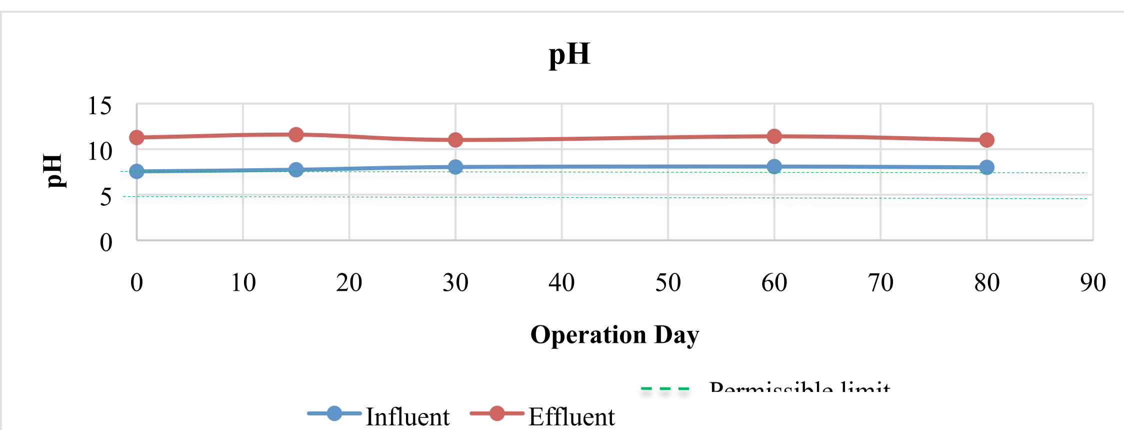
Results and discussion

Rainwater characterization
During characterization was found that rainwater used to fed the filter comply most of the parameters marked on the Official Mexican Standard NOM-127-SSA1-1994, except those for total coliforms and fecal coliforms (Table 2), this may be due to the pets are in the home have access to the area for capturing rainwater (roof).

Table 2. Characterization of rainwater. Parameters out of permissible limits.

Parameter	Units	Analysis results	Permissible limits.
Fecal coliforms	MPN/100ml	9,300	Absence
Total coliforms	MPN/100ml	15,000	Absence

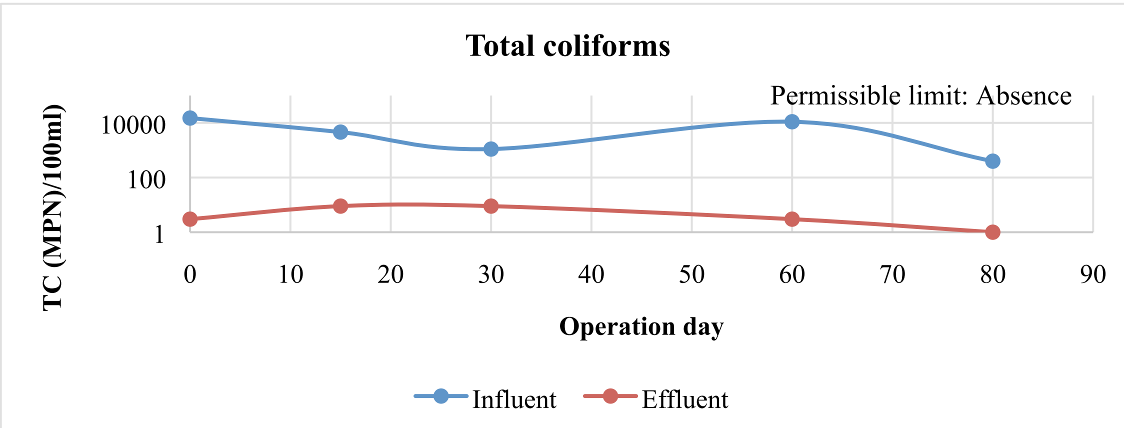
Stabilization and monitoring stage



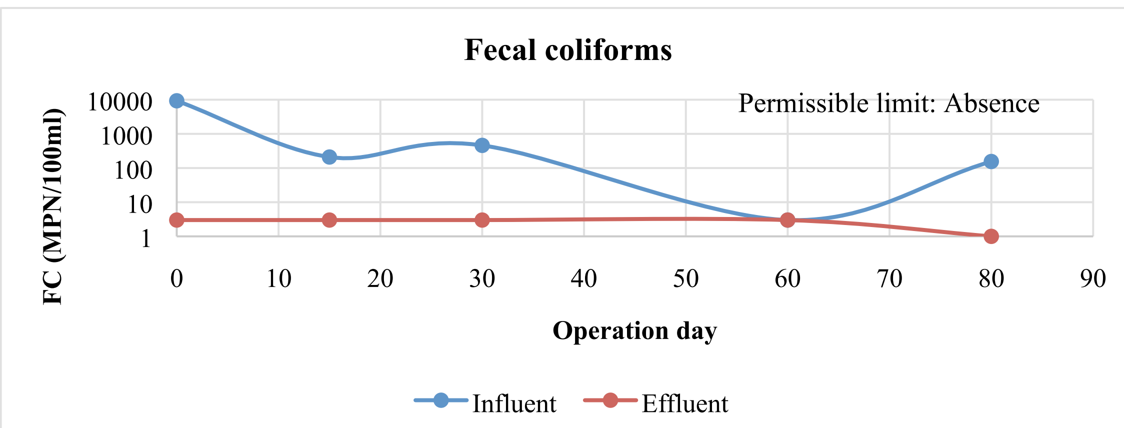
Graph 1. Influent and effluent pH in the biofilters

Graph 1 shows that the influent pH was between 7 and 8 units and the effluent values were above 11 units, exceeding the permissible limits (6.5 to 7.5 units). Possibly the sand used is not 100% silica sand and it comes with limestone trace compounds that upon contact with water allow the partial hydrolysis of carbonate generating OH-, increasing the pH.

$$CO_3^{2-} + H_2O \rightleftharpoons HCO_3^- + OH^-$$



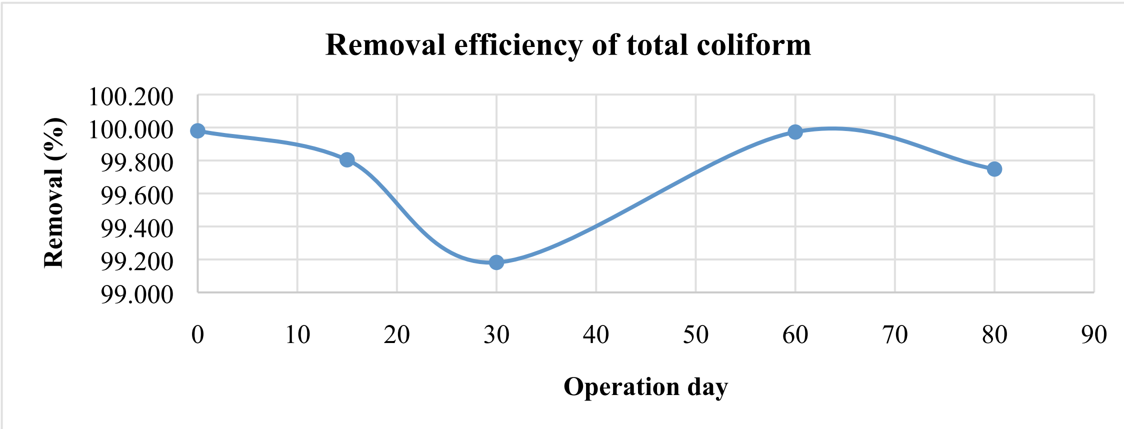
Graph 2. Concentrations of total coliforms in the influent and effluent of the biofilter



Graph 3. Concentrations of fecal coliforms in the influent and effluent of the biofilter

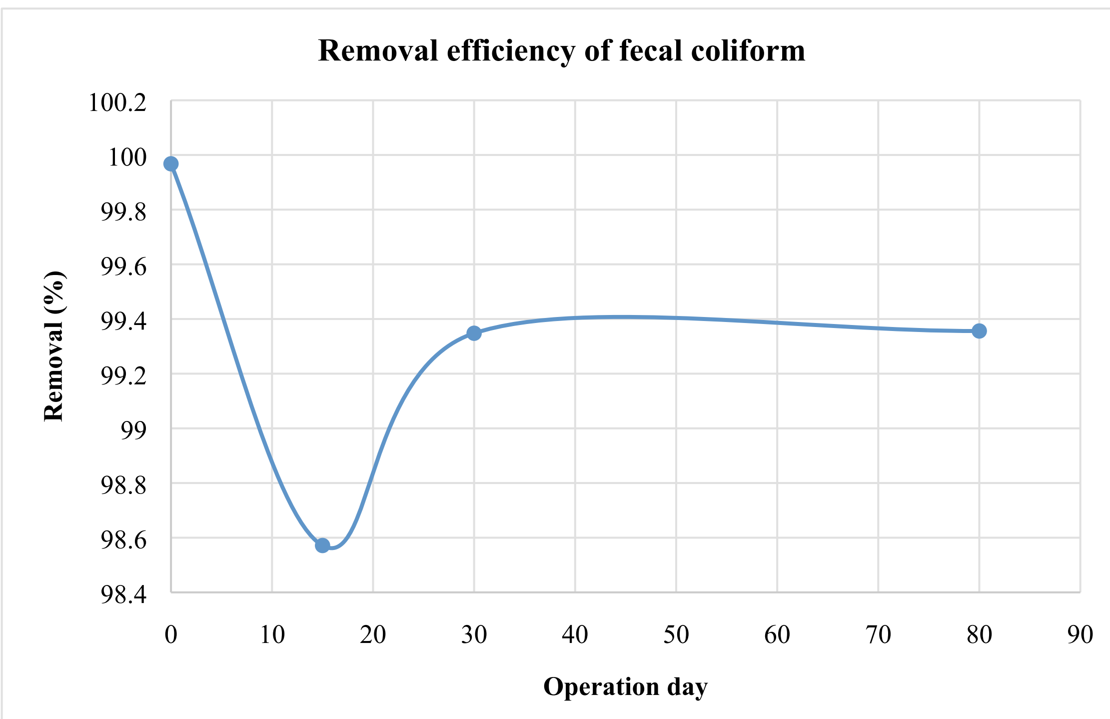
The concentrations of total coliforms in the influent were between 300 and 15,000 MPN/100 ml, and for fecal coliform were 3 to 1,000 NMP/100mL while the effluent concentrations ranged between 1 and 9 NMP/100mL for total coliforms and lower than 3 NMP/100ml for fecal coliform. Both parameters decreased since starting which indicates that the biological layer began to form.

The regulations indicate that the total and fecal coliforms should be absent from drinking water, so that the filter does not reach to comply during the time of filter operation (80 days). However, the reduction is significant thus reducing the risk of waterborne diseases.



Graph 4. Removal of total coliforms in the biofilter

The removal efficiency of total coliforms since the first day in the biofilter was higher than 99%, resulting in an average removal of 99.73% during the 80 days of operation. Being these higher than those reported in the final report of the project "Evaluation of a sand biofilter as system of single family disinfection in rural communities," conducted by the Appropriate Technology area at IMTA in 2011, where average removals of 97.85%, 98.47% and 96.26% were obtained after 60 days at laboratory level.



Graph 5. Removal of fecal coliforms in the biofilter

Since the start, the efficiency of removal of fecal coliforms in the biofilter was higher than 99%, resulting in an average 99.3% removal during the 80 days of operation. For this graph was discarded on day 60, because the concentration of both influent and the effluent was less than 3 NPM/100mL and the technique used does not allow the calculation of concentrations lower than this, making it impossible to calculate the percentage of removal.

The average removal rate is higher than that reported in other field studies, such as the one carried out in Kenya, Mozambique, Cambodia, Vietnam, Honduras, Nicaragua by the Samaritan's Purse Organization of Canada in 2002, where a 93% removal was obtained.

As shown in table 3, the efficiencies found in coliform removal are higher than reported in previous studies, although concentrations in the effluent was higher in this study, indicating that the filter functions properly even with high concentrations of microorganisms in the effluent.

Table 3. Comparison of removal efficiencies and effluent concentrations between this study and previous studies.

Other studies				Present study	
Author	Parameter	Effluent	Average removal efficiency (%)	Effluent	Average removal efficiency (%)
Aiken (2008)	Total coliforms	1,181 MPN/100 ml	88.7	300 y 15,000 MPN/100 ml	99.73
Horne (2012)	Total coliforms	104 – 21.6 MPN/100 ml	99 - 86		
Mudie (2013)	Fecal coliforms	647 MPN/100 ml	96.95	3 y 1,000 NMP/100mL	99.3

Conclusions

The biofilter can be coupled to a rainwater collection system for disinfection because it showed removal efficiencies of total and fecal coliforms over 99%. The increase in pH at the outlet of the biofilter could be due to the use of a filter material with calcareous remains.

Recommendations

It is necessary to carry out tests covering more than three months to find out if the pH continues increasing over time. If so, analysis to the filter material should be made to check if this is what causes the increase and find a solution to decrease the pH to values that mark the current regulations, such as using silica sand free of calcareous impurities guaranteed by supplier.

It is recommended test new packaging materials such as zeolite, which has been studied wastewater filtration, showing removal efficiencies between 80 and 99% for fecal coliform, between 70 and 99% for total coliforms and most assays of over 80% for *Salmonella shigella* (Acevedo et al., 2012).

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Urban Anaerobic Wastewater Treatment: Contamination of the Atmosphere, Consequences and Possible Solutions

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Abstract

This paper examines the regrettable tendency in wastewater management, whereby the anaerobic process releases toxic gases into the atmosphere. Wastewater treatment using lagoons or ponds, provides an inexpensive and effective treatment of urban wastewater, especially sewage. The effect of these gases on the atmosphere, human health, livestock and the ecosystem is examined. Wastewater lagoons are generally located away from human population, but rapid urban growth, especially among the poor in countries such as Kenya, has led to the establishment of human settlements within the vicinity of treatment facilities. Methods of capturing these gases are discussed. The possible use of methane as a clean household cooking gas is explored. The argument made here is that the poor population close to the treatment works relies on biomass fuels (which produce toxic indoor emissions) and inefficient stoves for cooking. Mortality due to indoor pollution is a serious issue. In order to successfully rectify these problems the paper recommends the creation of multidisciplinary linkages between various relevant actors. In light of the fact that it is women who suffer most from issues of household energy and indoor pollution the paper elaborates the importance of having women as major players in this technology.

Keywords: wastewater treatment, greenhouse gases, tropospheric ozone, biogas scrubbing, multidisciplinary, investment groups

Introduction

Sanitation is a major concern in urban areas. The urban population density is high requiring the establishment of large facilities for the disposal of organic waste, of which wastewater is a major component. Wastewater stabilization ponds (WSP) or lagoons offer a technology, that in the words of Kayombo, et al (2004) is simple, low cost, low maintenance, low energy consumption, robust, and sustainable. It is a technology that works best in warmer climates; hence it is ideal in the tropics. Warm weather provides the heat required to support effective anaerobic processes.

The municipality of a large city can operate several WSPs. The Nairobi City County, for example, operates four WSPs. Large private institutions and industries in the city also operate their own wastewater treatment facilities.

Generation of Greenhouse Gases (GHG)

Briefly, upon entering the treatment plant wastewater moves through a series of carefully calculated phases. The first step is the physical stage, which involves the application of mechanical procedures to remove large objects and organic solids. The second stage comprises of a series of waste stabilization ponds. Each series is made up of three types of ponds, namely anaerobic, facultative and maturation ponds. Production of methane and other gases (collectively called biogas) occurs in the anaerobic ponds. The high organic loading with no dissolved oxygen creates the anaerobic conditions. Ferry (1992, p.473) states that, "methane is the product of the energy-yielding pathways of the largest and most phylogenetically diverse group in the *Archaea*" namely methanogens. (Sometimes methanogens are referred to as bacteria in the literature, but they belong to the domain *Archaea*). Table1 provides the composition of biogas as listed by Graaf and Fendler, (2010).

Table 1 Composition of Biogas

Methane CH_4	50-75%
Carbon dioxide CO_2	25-45%
Hydrogen sulfide H_2	0-1%
Hydrogen H_2	0-1%
Carbon monoxide CO	0-2%
Nitrogen N_2	0-2%
Ammonia NH_3	0-1%
Oxygen O_2	0-2%
Water H_2O	2-7%

Biogas from large urban wastewater facilities usually contains other gases and substances such as nitrous oxide and siloxanes. The wastewater entering such a facility contains sewage but also other effluents. Some industries that are required to pre-treat factory wastewater before it is released into the sewer fail to do so, thereby releasing various substances into the municipal facility (SMEC 2013).

Greenhouse Gases

An examination of Table1 reveals that a number of these gases are powerful greenhouse gases. In Kenya, as in many other developing countries, municipal anaerobic ponds are not covered and therefore release gases directly into the atmosphere. In particular methane, carbon dioxide and nitrous oxide have a very strong greenhouse effect. Greenhouse effect is measured in terms of a substance's Global Warming Potential (GWP), which in turn is determined by a timeframe of 100 years. Methane is comparable to 25 tons of carbon dioxide over a period of 100 years, and similarly, nitrous oxide is equivalent to 310 tons of carbon dioxide over a period of 100 years. (IPCC Fourth Assessment Report, 2007; and Corcoran, et al. 2010).

It is important also to understand the significant difference of the impact of CO_2 originated from biomass and CO_2 from fossil fuel combustion. Gupta and Singh (2012) point out that CO_2 from anaerobic fermentation is biogenic because its origin is in the atmosphere during photosynthesis within the short carbon cycle. In other words the same amount of carbon dioxide that was removed by plants returns to the atmosphere during wastewater treatment.

Tropospheric Ozone

The release of methane (CH_4) into the atmosphere raises the level of tropospheric ozone (also known as ground level ozone) in the atmosphere. CH_4 is a precursor of tropospheric ozone. CH_4 is responsible for about a quarter of the rise in global tropospheric ozone. A part from CH_4 a number of other compounds contribute to the formation of tropospheric ozone. Some of these are nitrogen oxides (NO_X), carbon monoxide, and volatile organic compounds. Ground level ozone is produced when these substances react in the presence of sunlight, specifically ultra violet radiation, through complex photochemical processes. (Dagiliūtė and Uždanavičiūtė, 2010)

Tropospheric ozone has an adverse impact on human health, agriculture and livestock. Elevation of ground level ozone is evidenced through increased incidence in asthma, heart disease, emphysema, headaches, irritation of the eyes, upper respiratory system, and can result in fatal pulmonary edema and bronchitis. Ground level ozone produces yellow and black spots on green leafs, lowers a plants resistance to viruses, bacteria, and insects, again reducing agricultural productivity. Many cash crops such as wheat, rice or maize are also damaged by tropospheric ozone. These effects are not only evident where the ozone is produced but because of wind currents, areas far from the ozone source can also be affected. (Johansson and Hedenus, 2009; Mustafa and Mohammed, 2012; and UNEP, 2012)

In light of these negative environmental consequences it behooves us to take every practical step to reduce the release of methane into the atmosphere. Methane needs to be recovered, especially in light of the fact that it is a valuable fuel.

Foul Odor

A characteristic quality of neighborhoods close to anaerobic lagoons is the strong sewage odor from the release of hydrogen sulfide (H_2S). This is especially strong if the lagoons are not well maintained or when the load of organic material exceeds the planned quantity. H_2S is poisonous and corrosive. It also damages machinery and other equipment. Its release into the atmosphere must be avoided at all costs.

Tragic Neglect of the Atmospheric Commons

Municipalities find open WSP systems attractive because of the low cost of construction, operation and maintenance (Mara 2004). Hardin (1968) in his classic article “The Tragedy of the Commons” argues

> Here it is not a question of taking something out of the commons, but of putting something in … noxious and dangerous fumes into the air… The rational man finds that his share of the cost of the wastes he discharges into the commons is less than the cost of purifying his wastes before releasing them. Since this is true for everyone, we are locked into a system of ‘fouling our own nest’. (p. 1243).

Just how inexpensive then are these WSPs in light of the fact that several noxious gases are released into the atmosphere? There is a cost to the economy in terms of public health, damage to agriculture and the ecosystem, as well as destruction of the natural composition of the atmosphere itself.

Anaerobic Pond Covers

There is, therefore, a definite need to protect the atmosphere from gases released during the anaerobic fermentation process. A characteristic of the open WSP, especially in developing countries, is the foul odor of sewage. DeGarie et al (2000) explain that anaerobic lagoons can be covered to eliminate not only odor, but also to control greenhouse emissions into the atmosphere, while at the same time capturing biogas as a source of energy. This is an important point in that it is not possible to control what substances may be contained in municipal wastewater.

Geomembrane covers are frequently used in industrialized countries for the reasons mentioned above. They are used to cover not only anaerobic ponds for sewerage wastewaters but for other biomass wastes, such as, from livestock farms or as liners for landfills. Briefly, geomembranes are low permeability synthetic liners or covers used to control fluid or gas migration from a structure into the environment. Common geomembranes are made from polyvinyl chloride (PVC), high-density polyethylene (HDPE), flexible polypropylene (fPP), and many others. They must withstand environmental conditions, such as rain, wind and chemical corrosion. They are designed to last for hundreds of years (DeGarie, 2000; Mara, 2004). In developing countries geomembrane covers are rarely used in municipal wastewater treatment. Indeed a DANIDA/UNEP manual for the construction of WSPs and constructed wetlands entitled *Waste Stabilization Ponds and Constructed Wetlands Design Manual*, does not mention the use anaerobic pond covers (Kayombo, et al (2004).

Scrubbing of Biogas

Anaerobic pond covers not only prevent gases and odors from escaping into the atmosphere but also serve as storage for biogas. Several methods of scrubbing the biogas have been designed. A few examples are mentioned here. Both the cost and the efficiency of the selected methods are important factors. The final product, biomethane, consists of approximately 95 to 99 per cent methane, with the 1 to 5 per cent being carbon dioxide. This small quantity of carbon dioxide does not affect the quality of the methane. Biomethane can have a higher concentration of carbon dioxide if it is to be used as a household fuel. (Vienna University of Technology, 2012)

Polyethylene glycol is used frequently to simultaneously remove carbon dioxide, hydrogen sulfide, ammonia, water moisture, and other compounds from biogas. Siloxane, which causes severe damage to engines and equipment, can be removed by adsorption on activated charcoal or adsorption in a strong acid such as sulfuric acid.(Ryckebosch, Drouillon,& Vervaeren; 2011).

Utilization of Biomethane

Once the biogas has been scrubbed, then the WSP facility has to decide on the most profitable method of utilizing the biomethane. The common method is to use some gas directly as fuel for the facility and/or generate electricity. Some of the electricity is utilized at the facility while the rest is sold to the power company. This is a common practice in industrialized countries.

The Case of Nairobi's Dandora Estate Sewage Treatment Plant (DESTP)

The Nairobi City County is taken here as an example of a possible intervention method. The City boasts having the second largest wastewater/sewage treatment lagoon system in Africa, namely the Dandora Estate Sewage Treatment Works (DESTW), located in the Dandora/Ruai area of the City. The plant treats approximately 80% of the wastewater generated from the city of Nairobi. This volume is roughly 800,000 M^3 per day. A tour of the plant reveals an extensive layout. DESTW occupies 200 hectares and with an additional 500ha set aside for expansion. None of the anaerobic ponds are covered. (Nairobi City Water & Sewerage Company. 2012)

However, an Australian consulting company, Snowy Mountain Engineering Company (SMEC) was commissioned to prepare a feasibility study and preliminary design for an energy generation facility at the DESTP. SMEC (2013) estimates that the mean production of biogas is between 7,000 M^3/d to 9,000M^3/d. This study includes the recommendation of the installation of anaerobic pond covers. The biomethane which will be produced after scrubbing the biogas will be utilized to generate electricity to meet the fuel requirements of the facility, with the excess electricity being sold to the Kenya Power Company through the Feed-in-Tariff (FiT) program. Thus the plant will generate an income besides protecting the atmosphere from GHGs.

SMEC is based in the city of Melbourne, Australia. Melbourne operates one of the most successful wastewater treatment plants in the world, the Western Treatment Plant. The Melbourne Water Company collects the methane produced to generate electricity at a profit. This operation has been cost effective for more than twenty years. DeGarie et al (2000) document the planning, installation and commissioning of floating self-draining geomembrane covers over the anaerobic ponds. The success of this project is reflected in the numerous citations DeGarie's report has received over the years. It is not surprising then that SMEC would recommend a technology that has been remarkably successful in Australia.

An important question, however, is whether this technology transfer is really appropriate for Kenya. Melbourne is a 'first world' economy while Nairobi is a third world economy. The population living close to the DESTP in the Dandora/Ruai area is poor. The predominant source of cooking fuel is charcoal. Indoor pollution is a problem. The production of charcoal is also one of the major causes of deforestation in Kenya. These problems do not exist in Melbourne. Thus when addressing the final utilization of the biomethane it is important to take into account the probability of linking the process to the reduction of indoor pollution and conservation of forests in Kenya.

Indoor pollution is a major public health problem in developing countries. The World Health Organization estimates that indoor pollution leads to 3.5 million premature deaths a year – majority of them are women and children under the age of five years (WHO (2012). It is evident then that there is an urgent need to find clean forms of energy. The recommendation here then is that the biomethane produced at WSPs be utilized as a source of cooking fuel.

This move will require a paradigm shift in technology transfer; from a straightforward technology adoption of generating electricity and selling it to the power company, as is the case in Australia, to the more complex method of dealing with community issues. In his seminal essay *The Structure of Scientific Revolutions*, Kuhn (1970) maintains that making a paradigm shift is difficult in that relinquishing allegiance to a paradigm that appears to have worked well in a certain scenario to a different paradigm can meet with great resistance.

Discussion and Recommendations

Possible Techniques to Reduce Emissions from WSP Appropriate to Africa

Research is required to find lasting solutions. What is the most appropriate technology when it comes to managing gas emissions from WSPs in Sub-Saharan Africa? The challenges discussed above are diverse and, therefore, require to be addressed through a cohesive multidisciplinary approach, rather than having various professionals addressing different issues without much reference to each other (as is often the case). Here the nexus approach is recommended. Focused determination towards a common goal is likely to bear more success than scattered efforts.

It is important to measure the quantities of greenhouse gases within the vicinity of WSPs. This would only provide partial data because wind currents tend to move gases in a random manner, but the concentration would be highest at the source of emissions. Likewise, it is important to measure the level of tropospheric ozone in the area of anaerobic fermentation. The effect of these gases and ground level ozone on people, livestock, agriculture and the ecosystem should be quantitatively determined, with comparison to a similar socioeconomic populations located away from open WSPs.

A study of geomembrane covers that would be appropriate for various types of WSP in Kenya is required. This includes the most appropriate methodology for scrubbing biogas collected in such covers, the utilization of methane and the disposal of other products from the scrubbing process.

The disciplines constituting the research teams should include meteorology, wastewater engineering, urban resource planning, public health, urban agriculture and forestry, environmental agencies such as the National Environment Management Authority, Athi Water Services Board, as well as business and financial organizations. This is not an exhaustive list and its composition would be flexible.

Engaging Women in Sustainable Biomethane Enterprises

Generation of electricity from large quantities of biogas is common. In developing countries electricity is too expensive to use as a source of cooking energy. However it is important to find alternatives to toxic household fuels, such as charcoal. Furthermore recalling that it is women who suffer most from indoor pollution, it is recommended that women be engaged in the packaging and distribution of biomethane that may be captured from WSPs in various municipalities. Moreover this is in keeping with the principles of gender mainstreaming (ECOSOC 1997).

In 2004 the United Nations Development Program (UNDP) maintained that women needed to be engaged directly in energy technologies that pertain to indoor pollution (namely fuels and cookstove technologies). The report further infers that failure to do so has been behind the slow adoption of clean fuel/cookstove technologies in developing countries. The same report noted that nearly 2 million premature deaths occurred annually due to indoor pollution (UNEP 2004). There is not much evidence that the report was ever adopted. Today, ten years later, the premature mortality rate from indoor pollution has risen to over 3.5 million deaths per annum.

Women in Kenya have a thriving entrepreneurial character, as evidenced in the creation of numerous investment groups, popularly known as *chamas*. Such a *chama* can be engaged in the packaging and sale of biomethane as part of a project to substitute charcoal as a cooking fuel. Research is needed in providing such groups with the necessary technical skills, which should also include the examination of profitable methods of disposing of the products from the biogas scrubbing process. *Chamas* that are members of the Kenya Association of Investment Groups (KAIG 2014) are more likely to succeed in business, because of the professional guidance the Association provides.

A study of the existing health condition of the population that depends on charcoal as the primary household fuel needs to be examined. A longitudinal study should then follow to check the health of the population as the use of biomethane replaces charcoal and other biomass fuels.

Conclusion

This discussion illustrates a possible comprehensive method of reducing sewage odor, greenhouse gases, and tropospheric ozone produced by open anaerobic wastewater treatment lagoons. The capture of biogas using geomembrane covers, and the subsequent scrubbing of the gas will provide urban areas with a clean source of cooking fuel.

Since the introduction of the devolved government in Kenya the various counties are in the process of planning infrastructure projects. Among them are possible wastewater treatment plants. It is important that the use of geomembrane covers and the utilization of biomethane be included in such plans.

Using Kenya as an example, the discussion has also indicated that the most appropriate technology is one that addresses the socio-economic status of African countries using the nexus approach, rather than adopting isolated technologies from Western countries that may not adequately address the Sub-Saharan African situation. These recommendations will likely require a radical paradigm shift before acceptance and implementation.

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Appropriate Water Technologies Search System

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Abstract

Appropriate water technologies currently offer an alternative solution for water supply and sanitation problems in deprived rural areas. Some communities are unable to connect to traditional drinking and sanitation systems because they are isolated, widely dispersed and lacking in resources. In parallel, a growing number of people and organizations are aware of the environmental damage being caused by urban lifestyles, and are searching for new ways of living and production methods that are less damaging to the environment.

Keywords: Water, appropriate technology, search system

Introduction

The Appropriate Water Technologies Search System has been created as a tool for decision making, to develop and disseminate the use of appropriate water technologies. This initiative has been promoted in Mexico by the Gonzalo Rio Arronte Foundation and the Mexican Institute of Water Technology (IMTA). For over a decade these organizations have worked together on the transfer of low-cost technologies for the harvesting, supply, storage, efficient use, recycling, purification and wastewater treatment in deprived rural areas.

This search system provides clear, rapid and straightforward information about organizations that are developing, transferring, selling, disseminating and researching in appropriate water technologies around the world. The system also enables access to specific information about appropriate water technologies currently in use in several countries. The information stored on the system has been obtained directly and exclusively checked from the websites of each organization. In order to present the wide range of information available in an organized way, a classification for appropriate water technologies was developed. So far, 260 organizations and 480 technologies have been registered and classified in the search system.

This paper aims to present and promote the Appropriate Water Technologies Search System as a way to contribute to the solution for water supply and sanitation problems in deprived rural areas.

Background

"The development of health, education, agriculture and food production, energy, industry and other social and economic activities all depend on the effective management, protection and provision of water and the delivery of safe water supply and sanitation services. Communities also need protection from the dangers that water---related hazards can present" (UN Water, 2014).

There is a global consensus on the importance of water on human health and well being. Goverments around the world consider water as a prioty in their agendas, but are still inefficient in resolving the problems related to water in rural and marginated communities. These communities are unable to connect to traditional drinking and sanitation systems, that use capital intensive technologies. Isolation, dispersion and lacking in resources are some of the obstacles. Appropriate water technologies currently offer an alternative solution for water supply and sanitation problems in deprived rural areas.

We refer to Appropriate water technologies to those that can meet communities needs in terms of water and contribute to preserve the water cycle. Although there isn't a final agreement about what appropriate technologies are, most of the literature agree that this kind of technologies require small amounts of capital, emphasize the use of local materials, are relatively labor intensive, have a small scale and are affordable. (Tharakan, 2010)

Two Mexicans organizations working together to transfer and disseminate the use appropriate water technologies

For over a decade the Gonzalo Rio Arronte Foundation[1] and the Mexican Institute for Water Technology[2] have worked together on the transfer of low-cost technologies for the harvesting, supply, storage, efficient use, recycling, purification, alternative sanitation treatment and disposal of water in deprived rural communities.

These organizations have worked bringing water and sanitation where the global public policy related to water does not reach. By 2014, 12,099 technologies have been transferred at household level and reached 42,496 beneficiaries. Additionally 209 technologies have been transferred at community level that benefited over 900,000 people all around the Mexican Republic (IMTA, 2014).

Although the technologies have been proven over the years, still this organization, mainly the Mexican Institute for Water technology, work in research and development to improve them and find alternatives. Currently they transfer rainwater harvesting systems, covered lined ponds, ecological toilets, bicycle pumps, artificial wetlands, water disinfection devices, ecological washing facilities, among other.

As a result of all the years working together in the field, arose the necessity to have and share a search system that could ease the provision of information on the work that has been done around the world in the field of appropriate water technologies.

The Appropriate Water Technologies Search System (AWTSS)

The AWTSS is presented on a web platform and it's been designed to provide clear, rapid and straightforward information about organizations that are developing, transferring, selling, disseminating and researching appropriate technologies around the world. The system

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[1] The Gonzalo Rio Arronte Foundation is one of the biggest foundations in Latin America its mandate is to give donations to public and private organizations involved in projects with social benefit in the fields of Health, Adictions and Water. http://www.fgra.org.mx/quienes-somos

[2] The Mexican Institute for Water Technology is an autonomous public organization whose mission is to produce, instill, and disseminate knowledge and technology for the sustainable management of water in Mexico. https://www.imta.gob.mx

also enables access to specific information about appropriate water technologies currently in use in various countries.

The information stored on the system is obtained directly and exclusively checked on the websites of each organization.

The system for consulting appropriate water technologies around the world has been created as a tool for decision making, developing and disseminating appropriate water technologies. Its many potential users include:

- Project managers and program coordinators working on solving water-related problems
- Technicians working on research and development of appropriate technologies
- Public policy makers working on access to water in rural and deprived areas
- Organizations financing water-related projects.
- Communities or individuals interested in applying a particular type of technology

Criteria used to organize the information stored on the system

Search criteria by organization.

Table 1 below, presents the search criteria by organization. Searches can be done by regions or by specific country. In order to display the available information about the organizations a filter has been included that classifies the organizations according to its type. Additionally it´s possible to choose the kind of activities related to appropriate water technologies the organizations carry out.

Table 1. Search criteria by organization:

• Name of the organization • Region and country • Type of Organization: – Civil Society Organization[3] – Company – Network – Government Agency – Foundation – Agency for Technical Cooperation – Research Centre – University	• Organization's activities related to appropriate water technologies – Transfer – Sale – Dissemination – Training – Research – Funding

Search criteria by technology

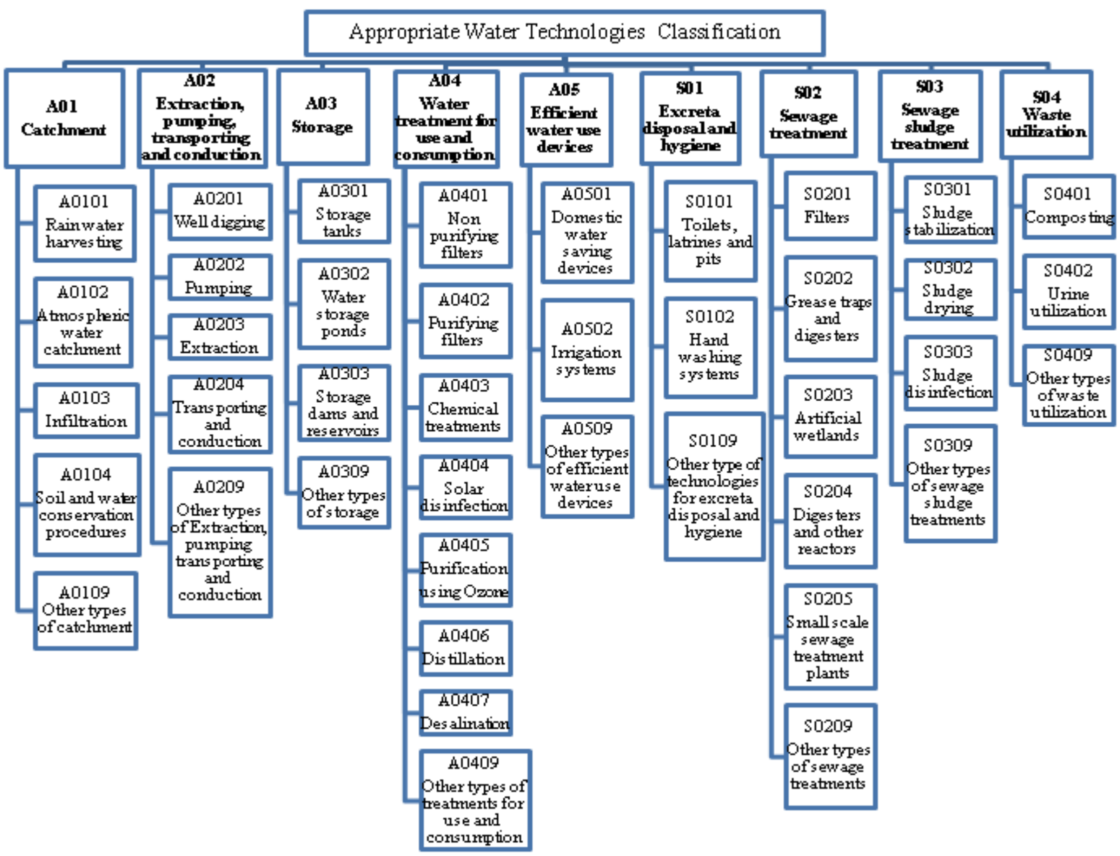
One of the central issues that arose in the development of this project, was the generation of a classification of the appropriate water technologies available around the world. The vast quantity of information available about technologies, demanded to have a tool to give order and map clearly the universe of appropriate water technologies. With the support of experts in the

[3] Civil Society Organizations (CSOs) refer to a wide array of organizations: community groups, non-governmental organizations (NGOs), labor unions, indigenous groups, charitable organizations, faith-based organizations, professional associations, and foundations". World Bank (2007)

field, the first version of the Appropriate Water Technologies Classification was generated. Some widely accepted methods of classification were consulted, and some were chosen as references, the International Standard Industrial Classification of all economic activities (ISIC)[4], and the Harmonized Commodity Description and Coding System [5]. This review was useful to assign a code to each classification category.

The result is a tree-structured, ordered and progressive Classification of Appropriate Water Technologies. Under this system, the top categories of technologies, are identified by letters. Those categories that begin with the letter A correspond to water supply, and with the letter S to waste management. They are then divided by adding digits: the more digits, the more detailed the categories are. For example, A01 code refers to the Group of technologies that are used to collect water. Adding two-digit code A0101 refers to rainwater harvesting (Figure 1). Additional digits are added and there are more detailed categories, but do to space limitations they are not presented in this paper. Figure 1 presents the tree with the first two levels of classification with their respective codes.

Figure 1. Appropriate Water technologies classification Tree



[4] International reference classification of productive activities. Its main purpose is to provide a set of activity categories that can be utilized for the collection and reporting of statistics according to such activities. (United Nations, 2008)

[5] Multipurpose international product nomenclature developed by the World Customs Organization. It comprises about 5,000 commodity groups; each identified by a six digit code, arranged in a legal and logical structure and is supported by well-defined rules to achieve uniform classification. (WCO, 2014)

All these criteria, to search both by organization and technology, are complemented with some characteristics that the technologies must have in order to be included in the database. Those related to appropriate technologies. Such as:

- Small scale
- Low cost
- Selfconstruction
- Simple Assembly
- Local materials
- Use renewable energy
- Non-technological dependence
- Replicable
- Environmentally friendly
- Low cost of operation and maintenance
- Easy use and maintenance
- Proven and in use
- With technical specifications

It is difficult to find technologies that fulfill all this requirements, but prior to entering the information into the database, a validation is performed to ensure that the majority of them are considered.

The web platform

The system works in an Web platform and is necessary have internet connection to gain access. The internet domain is www.codexaqua.com . When entering this page is necessary to subscribe providing some basic information, then a user name and password will be send to the user´s email address. Once received the information the user can access the database and carry out multiple searches of appropriate water technologies.

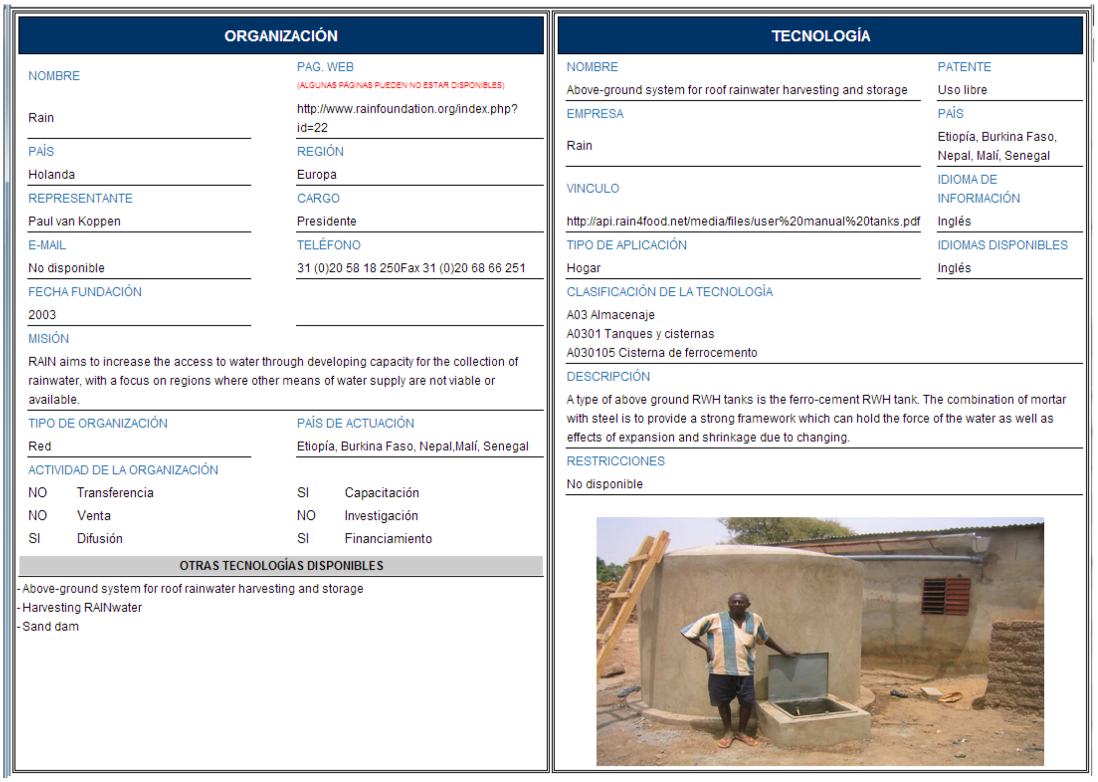
The search system structure consists on a window split into the two search criteria above mentioned : Organization and technology. See Figure 2.

Figure 2. Screen capture of the Appropriate water technologies screen search

In the process of adding technologies to the system technologies with potential use in emergency situations were identified, hence a shortcut to access this information directly was created.

The system allows multiple search criteria. When selecting one or more criteria, a list of the search results will be shown at the bottom of the window. If the principal search criteria was by organization, in the list the name of the organization will appear, its type of activity, and its country. Otherwise if the search was made by technology the list including the name of the technology, the organization responsible for it, and the origin country of the organization will be shown. In both cases is possible to access more detailed information. After choosing one organization or technology a pop up window will be displayed (Figure 3) with the most relevant information about the Organization and the technologies that this organization promotes. There is a link to the web page of the organization and a direct link to the information about the technology for further information.

Figure 3. Example of a search result window



In this window showing both the organizations and technologies more specific data, there's a list of other technologies available for the same organization. Here you can select any other technology related to that organization and the data will be displayed. Note that the language of the system is Spanish but the information about each organization and technologies is presented in the original language. Soon the system will be available also in English and French.

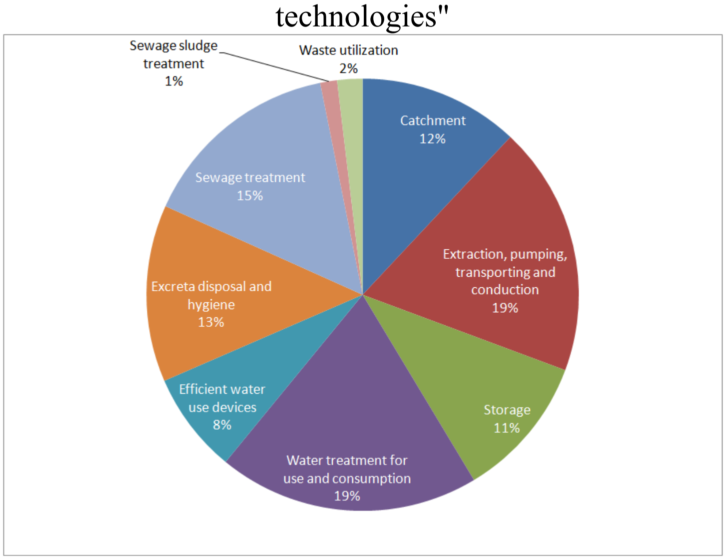
Some results

Up to date the system holds information on 260 organizations and 480 technologies. Half of the organizations contained in the database are companies that sell one or more appropriate water technologies, followed by the CSOs and the foundations, and to a smaller extent, universities, research centers and technical cooperation agencies. This reveals that some firms are considering appropriate water technologies an attractive niche market to do business. So a field that years ago was an agenda largely pursued by the not-for-profit Appropriate Technology movement (Kaplinsky, 2009) now shares space with firms that want to participate in large aid programs and in a new market for environmentally friendly technologies.

According to their country of origin, the highest representation of organizations in the database is located in Latin America (near 60%). This mainly due to the importance that has been given in some countries of the region to improve the access to drinking water and sanitation rural communities, especially in México, Peru and Uruguay. Worth mentioning is the case of Africa where, although up to date, only eight local organizations are in the system, there are many organizations from Europe and North America with humanitarian projects related to water in that continent. In fact, near 40 organizations from Europe and North America have developed projects in several countries in Africa

There is a good representation of almost all the more general categories of classification in the AWTSS. Extraction, pumping, transportation and conduction; and water treatment for use and consumption are the two categories with the largest number of technologies on the database. Although there is no way to know how representative is the sample contained in the system, some trends in the sector can be seen. There is still a significant weight on the way people traditionally relate to water, the major efforts are made to extract the water from ground and underground water bodies and making it suitable for drinking and use.

Graphic 2
Percentage of technology according to the first level of the "classification of appropriate water technologies"



Conclusions

The AWTSS can be used as a powerful tool to search and compare experiences in implementing appropriate water technologies around the world. Although there is much information to be included in the system, the data collected until now is showing tendencies in the growing field of appropriate water technologies.

It is known that appropriate technologies depend to a big extended on the context where applied, but the system can be useful to find similarities between countries and needs that other way would not establish technical cooperation.

The appropriate water technology field is gaining maturity over the years, but there is still much research and development work to be done in order to consider it the best solution to solve the problems related to water in deprived rural areas and perhaps even to consider it as an alternative solution in urban areas. The AWTSS is offered to contribute to this challenge.

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AREAS OF ENVIRONMENTAL EDUCATION, WATER CULTURE AND SELF-SUSTAINING FOREST IN WATER AND ENERGY

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Abstract

The areas of environmental education or locally called 'Green Houses' are a way of contributing to environmental care from different angles. The main objective of these areas is to increase environmental education through effective communication, training and enthusiastic social participation of the citizen. In order to support this objective a green house model for rural areas was developed. This green house in addition to fulfill the rules and basic parameters of bioconstruction, has the main feature on the use of recycled, biodegradable and natural materials as well as the use of local materials. It also contributes to the training of people in water management in each of the phases within the family like the use of solar panels for electric energy consumption, catchment and store of rainwater, composting practices, treatment and reuse of gray water and sewage and installation of ecological toilets among other technologies. In the last few years, four green houses in the watershed of Patzcuaro Lake, Michoacan and 10 green houses in the watershed of Apatlaco River, Morelos, have been transferred and have been used to impart tours, talks and workshops on water management, solid waste management and alternative technologies among others to fulfill the main objective.

Key words: Appropriate Technology, water management, water culture, sustainability.

INTRODUCTION

For several years the Mexican Institute of Water Technology (IMTA), through Appropriate Technology Subcoordination has worked in research, development, adaptation and transfer of appropriate technologies in themes of water both at the household level and at community level.

With the support of foundations such as the Gonzalo Rio Arronte Foundation, the IMTA has worked on several projects at national level in order to attack the main problems in water aspects.

In the watershed of Patzcuaro lake in the state of Michoacan and in the watershed of Apatlaco river in the state of Morelos -both watersheds located in Mexico- were implemented the develop of strategic plans, in order to know, prioritize and plan a range of solutions that help to the environmental recovery of these watersheds.

Among the strategic objectives of the strategic plans, the main objective of this study was to increase environmental education through effective communication, training and the enthusiastic social participation of the citizens (Garcia, 2011).

To do this, staff of Appropriate Technology Subcoordination of IMTA, coordinated installation activities of an area of environmental education, water and forest culture, water and energy self-sustaining locally called "Green House" in each of the 10 municipalities that integrated the watershed of Apatlaco river and in each of the 4 municipalities that integrated the watershed of Patzcuaro lake, to function as models of educational spaces on culture of the environment, culture of water and energy and the conducting workshops for care and management of environmental resources (Cordova, 2007) (Figure 1).

(a)

(b) (c)

Figure 1. (a) Green house front; (b and c) Green house backyard and appropriate technologies.

INSTALLING GREEN HOUSES MODELS

For the design and construction of green house model qualified personal searched the minimum elements and materials that allow comfort and space to carry out workshops, lectures or any activity related to preserving the environment.

The model design has a wide area, for the implementation of workshops and the installation of two to six tables to accommodate 36 people and one instructor or teacher, two bathrooms, one for men and one for women and a kitchenette where you can prepare breakfast or any kind of food for the people who attend the workshops or tours. A drawing of the distribution of educational spaces is presented in Figure 2.

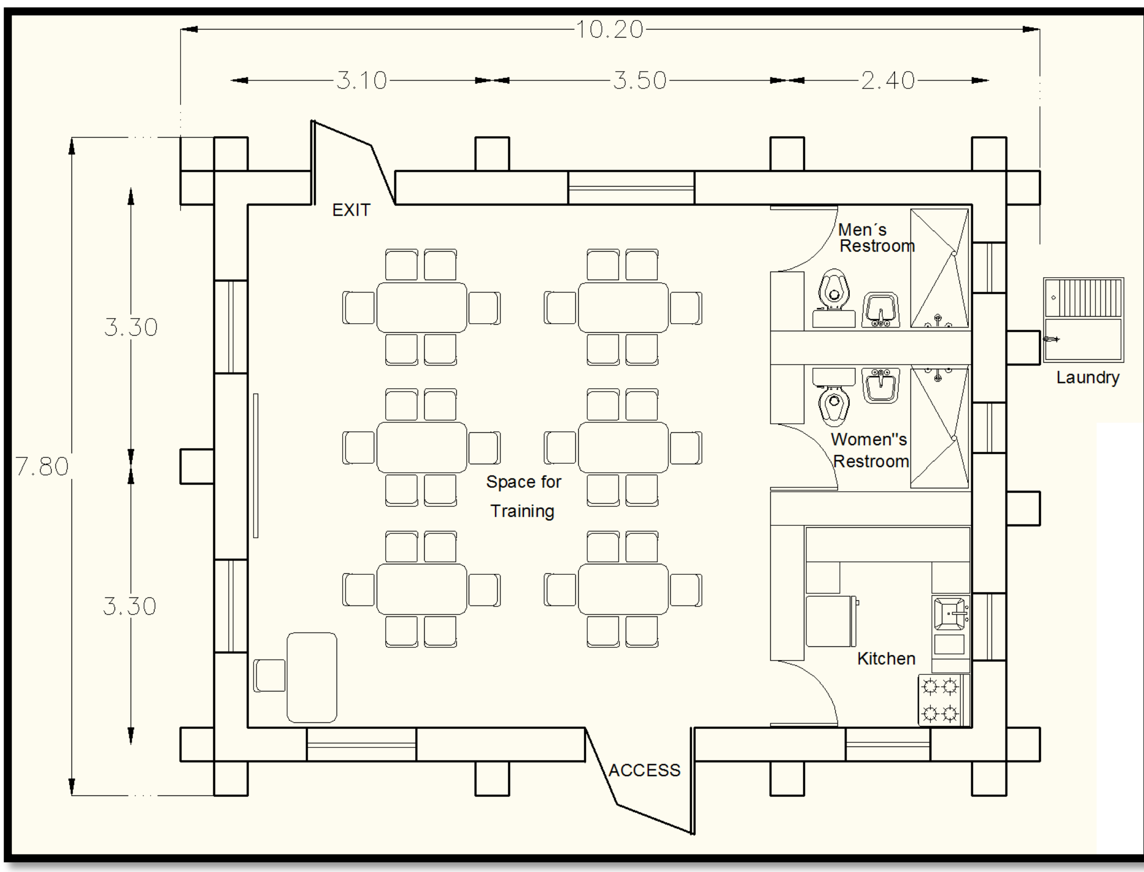

Figure 2. Area of environmental education model. Dimensions in meters (Cordova, 2007).

In the construction of green house, implementations of recycled, biodegradable and natural materials as well as the use of materials and resources in the local area were searched, to ensure that the elements of green models were easy to install in order that the families can participate in the construction of the house and the model becomes quickly replicable.

Basically all green houses are built with adobe, wood, reeds (bamboo) and tile. The fact that the house is built with adobe is because it is a material that provides excellent thermal performance, good sound insulation and radiation insulation, it also provides excellent moisture balance, and it is economic and ecological. The green house has some items installed that allow it be self-sustaining such as (Cordova, 2007):

* **Photovoltaic System:** The system consists of monocrystalline silicon cells, with tempered glass anti-reflective cover, charge controller with voltage meter and batteries to store the energy required for the night or on cloudy days.


Figure 3. Solar panels


Figure 4. Solar water heater

* **Solar Water Heater:** It is a thermal photo system that uses solar energy to heat water by making it circulates it through a line of great length which it is inside the panel that has a tempered glass cover, its function is to dissipate the bright sun waves and take advantage of heat waves. Once the water is hot it is stored in a tank to keep the heat in a temperature range of 45-70 degrees Celsius (Garcia, 2011).

* **Solar Pump System:** It consists of a pump designed to operate directly with captured sunlight into a polycrystalline silicon panel. When the pump is started sucks out water from the cistern to the water tank in the house.

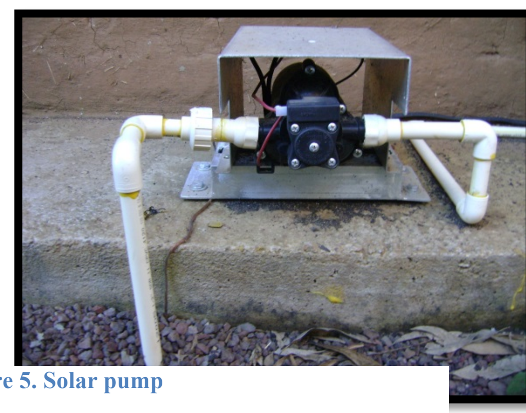
Figure 5. Solar pump

In addition to the aforementioned eco-technologies seven different technologies that were developed within the Appropriate Technology Sub-coordination, which are used for water supply, disinfection, treatment and reuse of water at the household level were installed. Listed below are brief descriptions of them:


Figure 6. Solar box

1. Solar disinfection box, with five faces of mirrors of 3 mm thickness. This appropriate technology is a device for exposing the water to sunlight for 24 hours to disinfect, achieving disinfect 6 liters of water per day. Solar disinfection improves water quality at the moment that pathogens that cause multiple gastrointestinal diseases are inactivated (Rivera, 2010).

2. Rainwater catchment system. This appropriate technology is used to collect rainwater of the roofs and transport it through galvanized steel gutters and Polyvinyl chloride (PVC) pipes to the storage cistern of 50 m^3.

Figure 7. Rainwater catchment system

3. Storage cistern of 50 m^3. This appropriate technology allows to store up to 50 m3 of water with sufficient quality to meet the basic needs of water in rural houses. It consists of a cylindrical structure placed the material in cappuccino style, reinforced with wire mesh and steel rods.

4. Wetland sewage treatment: it is a structure of three cameras, the first chamber is filled with bottle PET rings, the second chamber contains beds of graduated materials filters which acts as natural filters and hydrophytes plants, in the third chamber the treated water is deposited and this chamber is used as a lift station (Ortega, et al, 2007).

Figure 8. Wetland

Figure 9. Bici-pump

5. Bici-pump. It is an appropriate technology wich consists in a device for pumping small flows by the mechanical action of pedaling a bicycle. The movement of the rear wheel rotates the pump impeller that is connected to a suction line and is by means of this action as the treated water is extracted from the wetland and is conducted through a hose to the download tank fund.

6. Download Tank Fund (TDF). It is an appropriate technology which consists of a self-operated device to irrigate by gravity the home garden with treated wastewater. The tank is made of plastic with a capacity of 200 liters.

Figure 10. Download tank fund

Figure 11. Home garden

7. Home garden. It is an appropriate technology with a cultivable area of 12m x 6m, destined for food production for self-consumption at household level, which is irrigated by the TDF. In home gardens, the families can grow good quality products as part of their diet in sufficient amounts food for sustenance of a family of up to 6 members (Vazquez, Cordoba, 2014).

RESULTS

Currently 10 models of green houses in the watershed of Apatlaco River and four models of green houses in the watershed of Patzcuaro Lake have been installed. One model was installed in each of the municipalities that integrate and participate in environmental conservation of the watersheds. Each of the municipalities is in charge of a space model of environmental education and organizes activities related to environmental protection and water culture

These activities such as conferences and workshops are conducted with students from elementary school, middle school and groups of people of different communities nearby, in order for them to know and interact with appropriate technologies and raise public awareness of the participants on the subject of water management, solid waste management, energy and others.

Another purpose that it is pursued is that each person who attends to the environmental education spaces may adopt either of appropriate technologies installed in the green house in order to have a better management of natural resources within their home and increase their quality life.

CONCLUSIONS

Clearly every day the irresponsible actions and lack of awareness among people about the environment exacerbate the problem of pollution of watersheds. The areas of environmental education, water and forest culture, water and energy self-sustaining, installed in each of the municipalities in the watersheds are incorporated to the municipal property and become a stronghold of the public servants of the three levels of government and of civil society organizations to implement training and awareness of citizens on issues of care and environmental protection (Garcia, 2011).

In addition, these areas allow people to have the opportunity to meet a self-sustaining building that includes appropriate technologies of storage and disinfection of rainwater for human consumption, generation of electricity from sunlight, treatment of domestic wastewater for subsequent use in the irrigation of a home garden.

The installation of this model allows the spread among the population about the use of these technologies at home and thus change behaviors and daily habits to the benefit of the surrounding environment and thereby contribute to the success of the objectives in the strategic plans.

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Performance Of A Two-Stage Phytosystem In Landscape Water Purification: Biological Nutrients Removal Efficiencies

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Abstract

Water pollution coupled with water scarcity has been a serious environmental concern in Africa. Eutrophication of existing water bodies has over time reduced the available drinking water supplies. A two-stage, solar-powered phyto-system situated in Shanghai Jiao Tong University, China, proved useful in purifying the institution's landscape water. Whereas *Tank 1* was operated under anaerobic conditions, aerobic conditions were maintained in *Tank 2* containing fully grown *Pontedaria Cordata.* Experiments conducted from August to October 2013 revealed a significant biological nutrient removal (BNR). In addition, significant turbidity and chlorophyll removal efficiencies were noted. The system was subjected to six (6) different hydraulic loading rates (HLR). Whereas Total Phosphorus (TP) was analyzed using the Molybdenum-blue UV-spectrometric method, total nitrogen (TN) was analyzed using the Multi N/C 3100 Analyzer. Whereas maximum removal efficiencies were noted under a HLR of 0.7 m^3/hr, minimal removal efficiencies were noted under a HLR of 3.5 m^3/hr. Maximum TN and TP removal efficiencies for the system were 55.65% and 73.33% respectively. The corresponding minimum removal efficiencies were 4.92% and 15.38% respectively. The extensive use of the phytosystem for purification of storm-water runoff can be a cheap and sustainable technology for Africa.

Keywords: Constructed Wetlands, Hydraulic Loading Rate, Hydraulic Retention Time, *Ponted aria Cordata*, Phytosystem.

1. Introduction

The small scale and large scale application of constructed wetlands (CW) in wastewater treatment is gaining much popularity in both the developing and developed world. This is partly due to their energy-efficiency, cost effectiveness and low maintenance cost over conventional wastewater treatment technologies (Kadlec and Knight, 1996). Storm runoff from agricultural lands is one of the common sources of excessive nitrogen and phosphorus in the receiving waters. The effects of high nitrogen and phosphorus concentrations are oxygen depletion and eutrophication in receiving waters.

Several studies have concluded that constructed wetlands could remove 25-85% of the available nitrogen in water (DeBusk, 1999). However, the removal of phosphorus from constructed wetlands depends mainly upon the interactions between water, plants, microbiota, sediment and the media (Sakadevan & Bavor, 1999). Studies reveal that the biological oxidation of phosphorus within reed beds initially converted most phosphorus (P) species to a soluble orthophosphate form. This process was later followed by the P adsorption onto the bed's media, precipitation/fixation reactions, bacterial action and biomass uptake (DeBust et. al 1995). It has been found that a small percentage (<5%) of the total phosphorus (TP) is removed by plants (Vymazal, 2004). This implies that phosphorus adsorption onto the substrate media is mainly responsible for significant phosphorus removal.

Several emergent macrophytes have been used in real time conditions as well as in pilot scalemesocosms. *Typha latifolia, Scirpus validus, Cyperus alternifolius* and *Pontedaria cordata* are some of the widely used emergent macrophytes (Reed & Brown, 1992). *Pontedaria cordata* also referred to as Pickerel weed is characterized by tall upright stems, bright green, spoon shaped lanceolate leaves and deep blue/purple flowers. The flowering process is usually from May to October. The optimal temperatures that support their growth range from 18-35^{0}C (Audlbach-Smith and deKozlowski, 1996). Several studies have employed the use of this macrophyte to examine the overall biological nutrient removal in constructed wetlands (White et al, 2010, Taylor et al 2006). Other studies conclude that its uptake of nitrates from the waste water is high (Yan et al 2009, Ou et al 2006). However, the inability of single-stage constructed wetlands to achieve high total nitrogen removal is attributed to their inability to simultaneously provide both aerobic and anaerobic conditions (Vymazal, 2007). The performance of a two-stage solar-powered phytosystem in landscape water purification was studied.The main objectives of the study were; 1) To evaluate the overall efficiency of a two-stage phyto-system in TP, TN, turbidity and chlorophyll removal from landscape water under varying HLR (2) To examine the relationship between varying HLR and parameters' removal characteristics.

Materials and Methods

System Description

The system is located in Shanghai Jiao Tong University (31°5' N, 121°25' E) in Minhang District, Shanghai, China. The system composed of two reactors (each having a depth and diameter of 2.2 m and 1.9 m respectively) connected in series provides both anaerobic and aerobic conditions for nutrients degradation and removal. The anaerobic and aerobic reactors are denoted as *Tank 1* and *Tank 2* respectively. In addition to providing favorable conditions for aerobic degradation, *Tank 2* provides a ground for self-growing *Pontedaria cordata* covering an approximate area of 2.504m^2.The aerobic conditions in Tank 1 are achieved by a solar-powered air pump (SECOH IP 45, 40 l/min, 11.8kPa, 220-240V, 50Hz, and 30-40W). Unlike conventional constructed wetland systems where plants are supported by substrate-filled columns, *Pontedaria cordata* in this system is supported by substrate free columns. However, a substrate-filled column positioned at the inner column of *Tank 2* provides a room for substrate replacement. A schematic representation of the system is shown by **Figure 1**. At the intake point of the system is a submerged pump (UNILIFT KP 250, 50Hz, 480W, 2.2 A) that supplies landscape water into the tanks. Water control valve and water flow-meter were used to regulate and monitor the water flow into the system. 35kg of shale and 17 kg of biological ceramsite were introduced into the substrate column prior to the study.

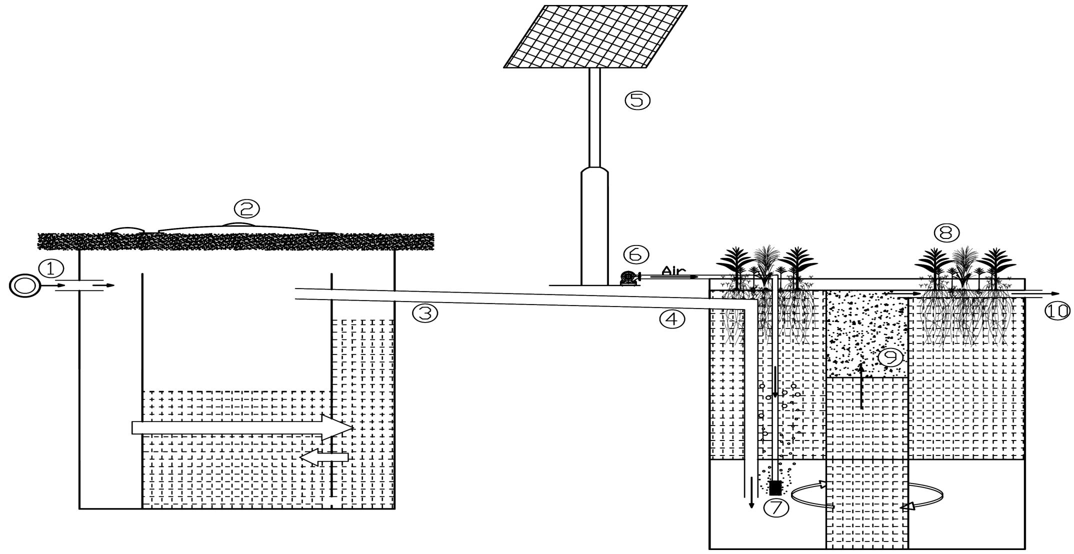

Figure 1. (1).Inlet (2)Tank 1 (3) Connecting pipe (4)Tank 2 (5) Solar-Energy System (6) Air Pump 7) Air nozzle (8) *Pontedaria Cordata (*9)Substrate column 10). Outlet

Samples Collection

Water samples from the *Inlet, Tank 1, Tank 2* and *Outlet* sections of the system were collected twice (8am and 5pm) daily during the experimental period under respective HLR and analyzed. **Figure 2** summarizes the average temperatures during the study.

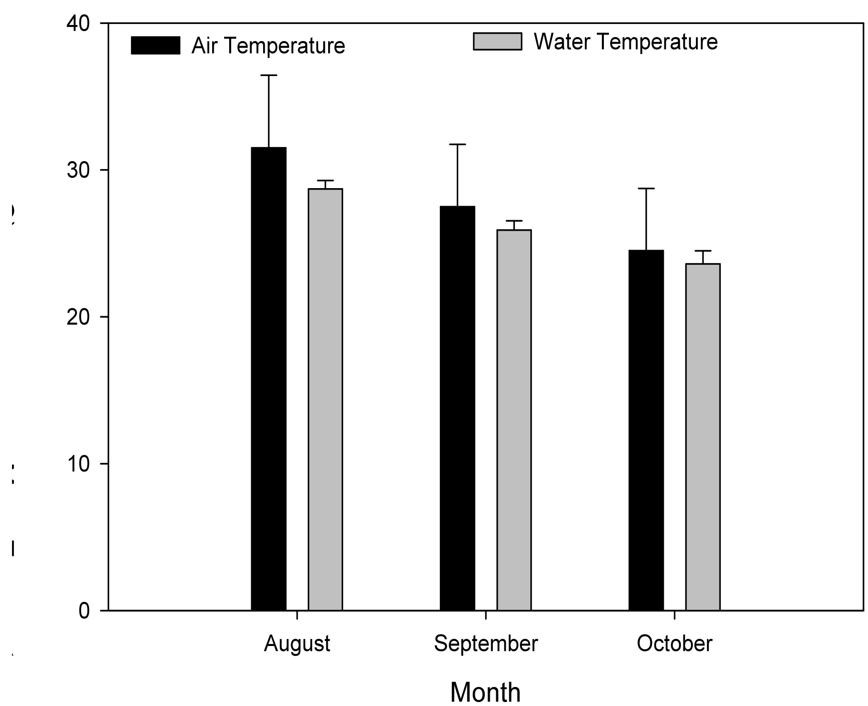

Figure 2. Mean air and water temperatures.

System's Hydraulic Conditions

The respective HLR and their corresponding HRT are summarized in **Table 1**.

Table 1.The system's hydraulic conditions

FLOW	DURATION (Days)	Average Hydraulic Conditions			
		V (1) (m3)	*V (2) (m3)*	*HLR* (m3/hr)	*HRT(Hours)*
1	10	6.238	5.671	0.7	17
2	10	6.238	5.671	1.6	7.5
3	10	6.238	5.671	2.2	5.4
4	10	6.238	5.671	2.9	4.1
5	10	6.238	5.671	3.1	3.8
6	10	6.238	5.671	3.5	3.4

Sample Analyses

The 2100Q Portable Turbidimeter, PHYTO-PAM plankton Analyzer (Water-PAM, Walz, Germany), Multi N/C 3100 analyzer (analytikjena, Germany) were used to monitor the DO, turbidity, chlorophyll-α and TN respectively. All standard solutions were prepared using 18.2MΩW ultra-pure water. Total Phosphorus (TP) was determined using the molybdenum-blue method (APHA-AWWA-WEF, 1998)

Results and discussion

Overall System's Performance

Table 2 summarizes the TP, TN, turbidity and chlorophyll-α concentration values at the inlet, Tank 1, Tank 2 and the outlet sections of the system. The overall removal rates obtained by comparing the influent and effluent concentrations are also shown.

Table 7. Concentrations and removal rates under varying Hydraulic Loading Rates

Parameter	**Concentration**				**HLR (m3/hr)**	**Removal Rate (%)**
	Influent	**Tank 1**	**Tank 2**	**Effluent**		
TP	0.3	0.38	0.12	0.08	**0.7**	73.33
(mg/l)	0.24	0.34	0.16	0.14	**1.6**	41.67
	0.46	0.58	0.36	0.3	**2.2**	34.78
	0.18	0.18	0.16	0.14	**2.9**	22.22
	0.22	0.2	0.18	0.18	**3.1**	18.18
	0.26	0.3	0.24	0.22	**3.5**	15.38
TN	1.45	1.21	0.82	0.64	**0.7**	55.65
(mg/l)	1.34	1.17	0.88	0.81	**1.6**	39.58
	1.81	1.59	1.37	1.24	**2.2**	31.53
	1.49	1.29	1.12	1.10	**2.9**	25.71
	1.87	1.81	1.47	1.65	**3.1**	11.77
	1.38	1.51	0.51	1.31	**3.5**	4.92
Turbidity	44.34	12.16	3.65	3.35	**0.7**	92.44
(NTU)	47.05	26.05	8.61	8.14	**1.6**	82.7
	45.94	20.6	8.95	8.34	**2.2**	81.8
	37.15	20.3	9.78	9.09	**2.9**	75.5

	44.93	32.34	15.6	14.5	**3.1**	67.7
	46.69	34.71	20.39	18.9	**3.5**	59.43
Chl-α	20.95	4.24	2.57	2.48	**0.7**	88.14
(μg/l)	22.45	4.49	2.78	2.68	**1.6**	88.07
	20.27	5.14	2.69	2.65	**2.2**	86.89
	21.68	5.41	3.06	2.93	**2.9**	86.49
	27.16	5.55	4.00	3.87	**3.1**	85.74
	31.07	8.23	5.19	4.96	**3.5**	84.04

Nitrogen Removal

Whereas optimal TN removal (55.65%) was observed under a HLR of 0.7 m^3/hour, least removal (4.92%) was observed under a HLR of 3.5 m^3/hour. Increase in flow led to a decrease in hydraulic retention time (HRT) hence a decrease in microbial degradation time. Denitrification and plant uptake were the two major processes responsible for nitrogen removal in the system. The results were consistent with results obtained from past studies (Akratos and Tsihrintzis 2007, Taylor et al 2005)

Total Phosphorus Removal

Whereas optimal TP removal rate (73.33%) was observed under a HLR of 0.7 m^3/hour, least removal rate (15.38%) was observed under a HLR of 3.5 m^3/hour. Increase in flow led to a decrease in the contact time between the water and the substrate media (Jiang et al 2014). Consequently, decreasing removal rates were observed. Sedimentation and adsorption onto the substrate media were the major TP removal mechanisms in Tank 1 and Tank 2 respectively. The TP concentration increase observed in Tank 1 was as a result of the sediment TP release (Chuai et al 2011)

Chlorophyll-α Removal

Chlorophyll-α removal was noted in the system as shown in **Table 2**.. Whereas the highest removal efficiency was 88.14%, the corresponding least value was 84.040 %. Light attenuation was responsible for the reduced values in Tank 1, Tank 2 and effluent sections. Similar results were obtained in previous studies (Vymazal, 1995; Campbell & Ogden 1999).

Turbidity Removal

Turbidity removal rates of 59.43% and 92.44% were noted under HLR of 3.5 and 0.7 m^3/hour respectively. Increase in HRT was matched by an increase in removal rates (**Table 2**). The results were consistent with those from a previous study (Bidhendi et al 2006). Sedimentation of particulate matter and filtration by the roots of *Pontedaria cordata* played a significant role in turbidity removal (Vymazal 2011, Jin et al 2013).

Relationship between HLR and Removal Efficiencies

Linear regression analysis to investigate the relationship between varying HLR and Parameters removal efficiencies revealed strong correlation co-efficients **(R^2>0.8)** implying that increase in HLR caused a decrease in the removal rates. **Figure** also confirms these observations.The results were consistent with those obtained in previous studies (Akratos & Tsihrintzis 2007, Taylor et al 2005, Jiang et al. 2014).

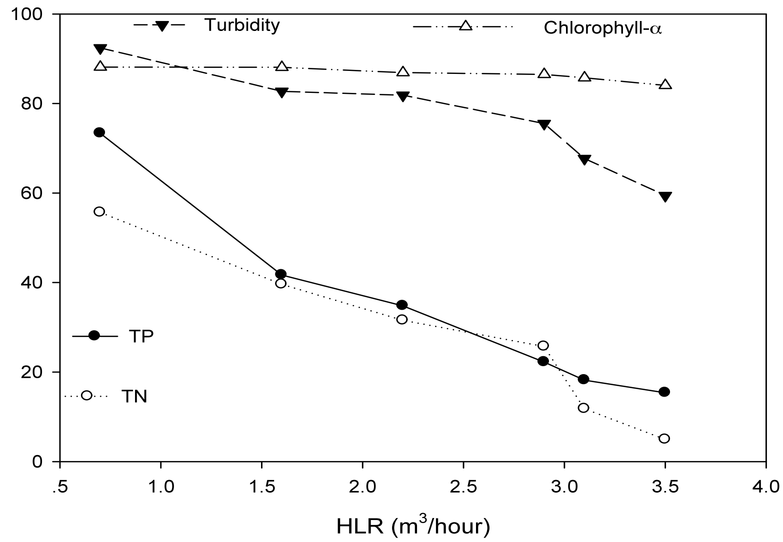

Figure .The relationship between varying HLR and parameter removal behavior

Conclusion

The study investigated biological nutrient removal of a two-stage solar powered phyto-system from August to October 2013. The system operating under both anaerobic and aerobic conditions, containing fully grown *Pontedaria Cordata* was investigated under various HLR. The parameters of consideration were TP, TN, turbidity, chlorophyll-α and DO. It was observed that an increase in HLR led to a decrease in the removal efficiencies. Maximum removal rates for TN, TP, turbidity and chlorophyll-α were observed under a HLR of 0.7 m^3/hour. The corresponding removal rates were 55.65%, 73.33%, 92.43%, 88.14% respectively. Minimum removal rates were noted under the highest HLR. The corresponding removal efficiencies were 4.92%, 15.38%, 59.43% and 84.04% respectively. Longer HRT has been associated with reduced wash out of microbial organisms, efficient settling time for particulate matter and increased contact time for phosphorus adsorption onto the substrate media. The fact that most African countries are warm all year round renders the application of the two-stage phyto-system a cheap and sustainable technology. The results obtained from our study in China can also be replicated in Africa.

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Assessment of Water Sources in the Nyangores sub-catchment of the Mara River Basin of Kenya

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ABSTRACT

In this study, water resources of the upstream Nyangores sub-catchment were mapped as a basis for developing sustainable planning and management options. Apart from quantitative measurements of major springs, the relative water quality was assessed on the basis of electrical conductivity measurements of protected and unprotected water sources of the region. Over 90% of the upstream springs and wells are noted to be active sources supporting the rural communities. In the downstream arid and semi-arid area - less than 60 km away – very few springs and wells presently exist. About 25% of the downstream springs are completely dry and another 25% are seasonal in nature. In overall, the spring flow rates during the measurement campaign in the May-June-July season of 2014 lay between 0.1 – 0.2 liters/second. The results also indicate that electrical conductivity tends to increase in downstream regions, indicating deteriorating water quality generally. This can be attributed to accumulation of pollutants and increase in sediment load, as the river winds its way downstream. Generally, electrical conductivity values ranging from 87 to 196 micro-Siemens/centimeters were obtained. The preliminary results have been discussed by the local water users who find the results in tandem with their local knowledge of the area. Additional measurement campaigns in the next months will help to improve the data basis, by including more water sources and also assessing the spring discharges in different seasons in order to better understand seasonal trends.

Key words: Water Allocation; Total Dissolved Solids; Water Resource Modeling; Nyangores sub-catchment

INTRODUCTION

Many developing countries are today facing formidable freshwater planning and management challenges (Wang et al., 2003:11). In Kenya, allocation of limited water resources due to degradation of environmental quality and lack of appropriate policies for sustainable water resource management are key issues of increasing concern. In the Nyangores sub-catchment in the upstream of the Mara River Basin of Kenya, already there exist some conflict associated with water use and allocation (Kilonzo 2014:1). The main reason here can be attributed to high water demand and uneven seasonal distribution of water availability, which can lead to water scarcity in the dry season (Olang et al., 2010:1744). It can be expected that water conflicts will increase in future, mainly due to population increase and economic development (Lotze-Campen & Welp 2007:306). For the assessment of water resource planning and management options, e.g. for the development of water allocation plans, the mapping of water sources and sinks is inevitable.

In the Nyangores sub-catchment, it has been noted that water allocation follows certain conditions and dictates which are often political, historical, institutional, legal and social in nature. However, factors such as population increases may in time affect this allocation protocol as well as exacerbate changes in environmental conditions. This division of water may also be slow to adapt to changes that affect water regimes due to increasing demand and climatic variations (Harou et al., 2009:628 and Banghash et al., 2012:61). Water scarcity in the basin often leads to conflicts when different users compete without proper allocation structures. Such regions with water scarcity should reform their water allocation institutions and methodologies so as to achieve sustainable development goals (Wang et al., 2008:800). The allocation of water resources in river basins is one of the critical issues. An integrated analysis at the watershed-scale would be valuable, where individual water related sectors, such as agriculture, municipal, and industrial water supply are brought together in a framework (Bangash et al., 2012:61).

Expected future changes in the water balance also threatens water availability as water demands are expected to increase, whereas water resources are expected to decrease because of climate warming and or decreasing precipitation (Bates et al., 2008:210). The percentage of water total dissolved solids (TDS) in the catchment is also expected to rise due to increased human induced activities near and in-stream (Minaya, 2010:7). Various studies have noted that anthropogenic activities have led to a continued degradation and faster loss of vegetation, especially in the upper catchments, such as Nyangores and consequently the reduction in the quantity and probably quality of the Nyangores River and its tributaries (Mati et al., 2008:171). As a result, there is a tremendous need for thorough evaluation of the current ecological, biophysical and hydrological status of the river ecosystem and development of proper protocols for its management. In this study, water resources of the upstream Nyangores sub-catchment were mapped as a basis for developing sustainable planning and management options, which can be used to support policy in the Nyangores Sub-catchment of the Mara River Basin.

MATERIALS AND METHODS

The Study Area

The Nyangores sub-catchment covers a total of 696 km^2. The altitude within the sub-catchment ranges between 2951m around the sources in the Mau Escarpment to 1706m downstream in Kaboson and the amount of precipitation varies according to these altitudes. The Mau Escarpment receives most rainfall with a mean annual rainfall between 1,000 and 1,750 mm. The rainfall seasons are bi-modal with the long rains starting in mid March to June with a Peak in April, while the short rains occur between September and December. The Nyangores sub-catchment is largely hilly in topography with 50% of the total area above the altitude of 2202m. The Nyangores River has two tributaries; Chepkositonik and Ainop'ngetunyek. Along the longest tributary, the River runs approximately 94Km before joining Amala River at Kaboson to form the main Mara River. The basin is endowed with plenty of water sources with an average flow of 8.6 cubic meters per second at the gauging station in Bomet (1LA03).

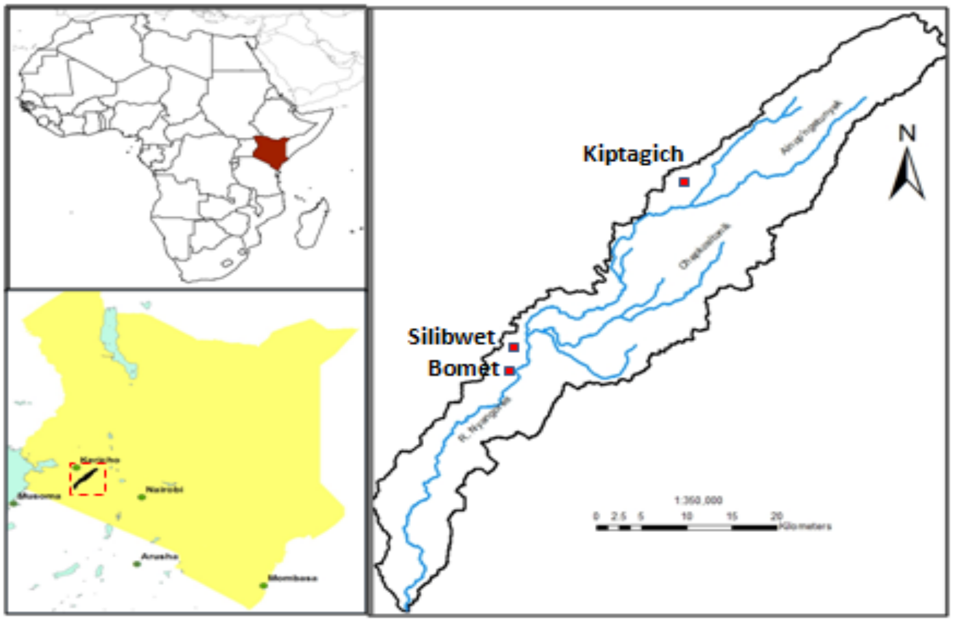

Figure 1.0; Location of Nyangores Sub-Catchment

The sub-catchment forms the headwaters of the Mara river basin which is the lifeline of the Mara-Serengeti ecosystem, a UNESCO world heritage site due to the unprecedented annual wildebeest migration. Water conflicts are increasingly present in the area. This is especially common among downstream users. The Mara ecosystem is an important resource in the sustainability of the tourism industry and support of local livelihoods. With the increase of human population at an annual rate of 7% within the basin and the 55% increase in agricultural land in the last 14 years, the Catchment has been under constant pressure (Mati et al., 2008:172)

Data Collection

The types of data collected in the study included rural water use data, types of water sources, the status of the water source and the environmental conditions around the water source. Others included water conductivity measurements and the amount of time required to fetch one Liter of water. The water conductivity was measured using the *Conductivity Meter*. And finally, using a GPS handset, *Garmin etrex 20*, spatial location of the water source and watering points along the river were marked.

Purposive sampling was done to get the water sources for sampling. Nyangores WRUA personnel assisted in determining major springs, streams and wells for sampling within the catchment. A total of 26 water sources and watering points were sampled along the lower half of the entire length of the catchment. An electrical conductivity meter was used to measure the electrical conductivity of the freshwater systems. This was done to monitor the amount of nutrients, salts or impurities in the water. It was not possible to reach the only borehole in the catchment for sampling. The electrical conductivity (EC) measurements were done by immersing half the electrode cord into the water and noting the corresponding readings on the screen of the conductivity meter.

The EC meter measures conductivity in Micro-Siemens per meter and the temperature in degree Celsius. A GPS handset, *Garmin Etrex 20,* was used to mark spatial locations of water sources. River points and stream points from the edge of the forest at *Kenon* village and Trans Mara west forest block of the Mau forest were also measured. Bridge points, watering points and points of convergence of streams and rivers were also measured during the survey. At each point, a description of the environmental situation was noted. For instance, stone and sand quarrying is a prominent feature at most points along the river. These activities accelerate erosion of river banks and siltation of the river.

RESULTS

The DEM mapped over spring locations and spring attributes indicate a decreasing water discharge with reducing elevation. For example, the springs at Kibangas and Kinyogi – 1884m and 1846m – respectively, registered a slower rate of discharge (an average 0.125 liters/s) as compared to the springs at Chesungat and Chemeres – 2013m and 2237m – with an average discharge of (0.185 liters/s).

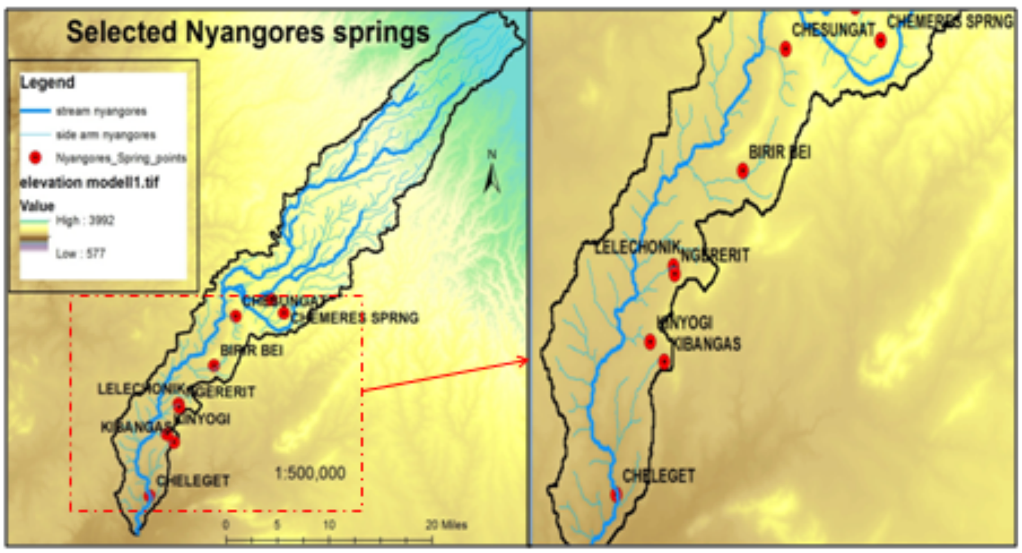

Figure 1.1: Map and DEM of selected springs of the sub-catchment.

Spring	Elevation (m)	Discharge (L/s)
Chemeres	2237	0.19
Chesungat	2013	0.18
Birirbei	1952	0.16
Lelchonik	1899	0.17
Ngererit	1904	0.15
Kibangas	1884	0.16
Kinyogi	1849	0.09

Table 1.0: Spring Water Discharge vs Elevation

Over 90% of the upstream springs and wells are noted to be active sources supporting the rural communities. In the downstream arid and semi-arid area - less than 60 km away – very few springs and wells presently exist. About 25% of the downstream springs are completely dry and another 25% are seasonal in nature.

In overall, the spring flow rates during the measurement campaign in the May-June-July season of 2014 lay between 0.1 – 0.2 liters/second. This analysis focuses on results from a sample of 7 springs, evenly spread out and representative of the study sight i.e. upstream, midstream and downstream. This is aptly captured in Table 1.1 with the summarized table of results.

Spring Name	**Coordinates**	**Elevation (m)**	**EC** (µS/cm)	**Temp (^oC)**	**TDS (0.64xEC)** ppm
Chemeres	S00.75956 E035.44909	2237	106	19.0	67.84
Chesungat	S00.76384 E035.38123	2013	86.7	19.6	55.488
Birirbei	S00.82576 E035.35073	1952	117.4	22.0	75.136
Lelchonik	S00.87412 E035.30138	1899	196.2	26.1	125.568
Ngererit-Cheptuonik	S00.87817 E035.30217	1904	157.0	23.2	100.48
Kibangas	S00.92257 E035.29482	1884	134.2	21.9	85.888
Kinyogi	S00.91257 E035.28480	1849	126.1	22.0	80.64

Table 1.1: Summarized Results on spring sources.

Electrical conductivity tends to increase in downstream regions, indicating deteriorating water quality generally. This can be attributed to accumulation of pollutants and increase in sediment load, as the river winds its way downstream. Generally, electrical conductivity values ranging from 87 to 196 micro-Siemens/centimeters were obtained. The preliminary results have been discussed by the local water users who find the results in tandem with their local knowledge of the area. The temperature is variable and varies with altitude.

DISCUSSION

The conductivity of a solution is highly temperature dependent (Baron & Ashton, 2007:1) therefore it was important to calibrate the instrument at the same temperature as the water being measured. Unlike metals, the conductivity of common electrolytes typically increases with increasing temperature. This was actually true of the measurements taken. For instance at the highest conductivity of 196.2 micro-Siemens per meter, the corresponding temperature of the water was 26.1 degrees Celsius. On the other hand, at the lowest conductivity reading of 86.7 micro-Siemens per meter, the average temperature was 19 degrees Celsius.

CONCLUSIONS

The study identified significant differences in conductivity among the various water sources as you move downstream. This can be attributed to increased level of water disturbance, change in land use type as well as increased erosion and pollution. Similar studies attributed high conductivity values downstream to near and in-stream activities (Kibichii et al., 2007:113 and Kasangaki et al., 2008:684). This is exemplified by the several quarrying sites and animal watering points that increase as you go downstream.

Several protected springs are dry or drying up downstream. This can be attributed to over-abstraction due to increased water demand, degradation and deforestation activities in the catchment as well as poor workmanship during spring protection exercise. This study is ongoing and will further involve the use of water modeling tool, WEAP to incorporate the various water quality and quantity variables to be collected. The tool shall then be used to build scenarios for water use and management for the entire sub-catchment. This is intended to help with decision making on water use and allocation in the area.

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