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CONSTRUCTED WETLANDS: POTENTIAL FOR THEIR USE IN TREATMENT OF GREY WATER IN KENYA''

Vorgelegt von

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Declaration

I hereby declare that the master thesis under the title “CONSTRUCTED WETLANDS: POTENTIAL FOR THEIR USE IN TREATMENT OF GREY WATER IN KENYA” is my own work and it has not been submitted anywhere for any award. Where other sources of information have been used, they have been acknowledged.

Cynthia Gitiri Kamau ……………………… Kiel, March, 2009

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ABSTRACT

Constructed wetlands are cost-effective, nature oriented alternatives for wastewater treatment that have gained acceptance worldwide. For Kenyan small communities in particular, constructed wetlands offer opportunities for wastewater reuse and resource recovery as well as improvements in local environmental health conditions. These communities generally lack conventional centralized waste water treatment systems. This thesis aims to identify peri- urban and rural areas suitable for the establishment of CW for their use in treatment of grey water in Kenya. Further, it identifies the most suitable constructed wetland type and suggests suitable emergent wetland plants for use in Kenya.

Literature research and digital mapping are the proceedings of this thesis. The literature explores case studies and journals investigating constructed wetlands, emergent wetland plants and grey water reuse. Digital mapping on the other hand uses GIS data to delineate areas suitable for constructed wetland establishment in Kenya.

This study reveals that large areas in Kenya are suitable for constructed wetland establishment are mostly located around the fertile agricultural areas where most of Kenya's population lives. Taking into account the tropical climate of Kenya which is characterized by high temperatures and conducive weather all year round, sub surface flow systems have been identified as the constructed wetlands of choice. Six emergents of the species *Typha*, *Phragmites* and *Poaceae* have been identified as showing high biomass productivity and versatility in utilization options, thus a high potential for waste water treatment

At present due to lack of awareness and funding constructed wetlands are not widely used in Kenya especially in small communities. There is a need for further investigation of suitable wetland plants and also raising awareness and financial support for constructed wetland establishment.

List of abbreviations

°N	**North latitude**
°S	South latitude
BOD	Biochemical Oxygen Demand
BOD_5	Biological Oxygen Demand, Five-Day
COD	Chemical Oxygen Demand
Conc.	Concentration
CW	Constructed Wetland(s)
COD	Chemical Oxygen Demand
Conc.	Concentration
CW	Constructed Wetland(s)
DO	Dissolved Oxygen
Dry wt	Dry Weight
ECOSAN	Ecological Sanitation
E. *coli*	*Escherichia coli*
ET	Evapotranspiration
FWS CW	free water surface constructed wetland
t/(ha*yr)	Tones per hectares per year
GIS	Geographical Information Systems
Ha	Hectare
HFS	Horizontal Flow Systems
HFPF	HFPF
HLR	Hydraulic Loading Rate

HRT	Hydraulic Residence Time
LMIC	Low and middle-income countries
mg/l	Milligrams per Liter
MPIP	Max Planck Institute Process
ppt	Parts per trillion or part per thousand
PET	Polyethylene terephthalate
RBTS	Reed Bed Treatment System
RZM	Root Zone Method
SF	Surface Flow
SSF	Sub Surface Flow
Sp.	Species
Spp.	Subspecies
KN	Kjeldahl Nitrogen
T. angustifolia	*Typha angustifolia*
T. *latifolia*	*Typha latifolia*
TKN	Total Kjeldahl Nitrogen
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids
VSB	Vegetated submerged bed
VF	Vertical Flow
VFS	Vertical flow systems
VF CW	Vertical Flow Constructed Wetlands

List of figures

Contents

1. INTRODUCTION

Water is the earth's eye, looking into which the beholder measures the depth of his own nature. Henry David Thoreau.

Due to the current energy crisis, globally we have become increasingly aware of the fact that the resources we rely on are not boundless. Something much greater than the energy crisis that faces us: the depletion and pollution of the planet's limited supply of freshwater. Unlike the energy crisis, the water crisis is life-threatening since unlike oil, freshwater has no viable substitute**.** The centrality of water in our lives – social, economic, political and spiritual cannot be overestimated (Töpfer, 2003).

According to UNEP's **(**United Nations Environment Programme) *Global Environment Outlook Reports*, global freshwater consumption rose six-fold between 1900 and 1995 – more than twice the rate of population growth. Only < 1 percent of the world's fresh water (~0.007 percent of all water on earth) is accessible for direct human uses and water resources are being used faster than they are being replenished. Infrastructure development, land conversion, intensive land use and the massive deposition of pollutants in water threaten all ecosystem functions that produce our freshwater resources (Verhoeven et al., 2006). Because of the slow development of ecosystems most of these quick and dramatic changes are irreversible (Anker, 2002).

Indeed, humans often do not appreciate their water resources until "the well runs dry". A proactive approach to these problems is at the core of sustainable development, and will provide society and governments with a basis for harmonious co-existence with the environment and its natural resources. Water resource management (including treatment and reuse of grey water) is intended to optimize available resources and their management and use (Töpfer, 2003).

In Kenya, for example, only around 70 percent of the urban and 48 percent of the rural population have access to safe drinking water. Only 50 percent of all households are connected to a sewerage system. Increasing water pollution, unchecked water withdrawal, wastage and degraded water catchment areas are endangering water availability, in turn aggravating health risks for the population (GTZ, 2008**).** Its further asserted that the water crisis is also due to the wave of droughts, poor management of the water supply, under-investment, unfair allocation of water, and a huge population explosion (thirty-fold increase since 1900).(Water Partners International 2008 ;World bank 2004).

In 1995 Kenya was classified in the category of water stressed countries and in 2025 it's predicted to be among the 8.3percent countries classified as water scarce (Gardner et al., 1997). Wastewater treatment in Kenya is becoming increasingly important due to rapid population growth, and urbanization. Difficulties in securing finances to solve this problem have brought the need to search for cheaper and appropriate solutions suitable for Kenyan conditions to which wetland technology may provide a solution (Nyakang'o and Bruggen, 1999). By now there is rising evidence that the use of constructed wetlands (CW) is of particular importance for the purification of waste water and the protection of water quality in catchments, rivers and lakes (Denny, 1997; Verhoeven et al. 2006).

CW have been defined as ''engineered systems that have been designed and constructed to utilize the natural processes involving wetland vegetation, soils and their associated microbial assemblages to assist in treating wastewater''. They are designed to optimize many of the same processes that occur in natural wetlands, but do so within a controlled environment (Vymazal, 1998). They are therefore more effective in waste treatment.

At the Max Planck Institute in Germany in the late 1950s, invaluable pioneer research work was conducted by Dr. Käthe Seidl, who investigated workings of the submerged gravel bed which proved remarkably effective in breaking down highly polluted water. The gravel bed became the first element in many designs for Constructed Wetlands. CW have gained acceptance worldwide (Tanner, 1996), due to their economically and environmentally sound attributes as a waste water management option and as design, construction and operational experience has accumulated. Today CW are common in Europe, Australia and America (Denny, 1997). However, CW are a relatively new concept in tropical Africa, and of the few that exist none are community owned or managed.

Kenya in 2006, had six working CW that recycle wastewater and return it clean to surface systems, create healthy aquatic ecosystems in the harshest of environments, yield significant amounts of biomass for mulch, fodder and compost, and provide thriving year-round wildlife and fish habitats. However it must be noted that CW cannot replace the long term developed natural wetlands. CW offer a way forward for economical and environmentally sound wastewater management in Africa. CW are better suited to the tropics than to the temperate latitudes where they were evolved first. They can, and should be, replicated all over tropical Africa in a wide variety of applications (Raymer, 2006).

According to Raymer (2006), Kenya needs to improve water security, sanitation and hygiene especially for the Peri-urban and rural poor who often live in harsh environmental conditions. Flourishing market gardens are watered directly from these rivers, and from sewer mains that are sometimes deliberately fractured for the organic nutrients within. Groundwater as well, while still assumed to be clean, is actually alarmingly polluted. Test results conducted by Raymer on water from a *rural* Kenyan spring during the year 2000 indicated a count of 35 *E. coli* per 100 ml (WHO potability criteria is zero), and the worst, 1800/100ml. This last fails to meet health standards even for drip irrigation. Some urban and Peri-urban boreholes are now yielding water with *E. coli* counts similar to those in raw sewage from busy public toilets it may look rather better, but drinking it untreated will see one in the doctor's waiting room. This illegal and irresponsible disposal of wastewater is causing a high countrywide incidence of water-borne diseases as we contaminate dwindling fresh water resources with our filthy discharges; poorer Kenyans, generally the most affected, cannot always afford the cost of medical treatment (Raymer, 2006).

Peri-urban areas form belts of non-urban land fringing metropolitan centers. They are often neither fully urban nor rural but form a mosaic of often incompatible and unplanned uses including agriculture. Due to unplanned heavy settlements, water and sanitation services are often inadequate or lacking in entirety. Rural areas are settled places outside cities (Rechner, 2008).

Provision of adequate safe water and sanitation is vital to improving life. Approximately 60percent of Kenya's hospital attendance is due to preventable diseases and about 50percent of these illnesses are related to sanitation, hygiene and water. Lack of water has also threatened livelihoods and caused conflicts in some communities (USAID, 2006). In rural areas the time-intensive pursuit of water collection often prevents women from taking up income generating activities, or in the case of girls, prevents them from attending school (Water Partners International, 2008).

It is clear that the treatment of waste water in particular greywater would go a long way in solving the water crisis for the rural and Peri-urban populations. The issue of greywater management including wastewater from bath, laundry and kitchen but excluding toilet wastewater is steadily gaining importance, especially in low and middle-income countries (LMIC) where inadequate wastewater management has a detrimental impact on public health and the environment. Appropriate reuse of greywater not only reduces agricultural use of drinking water and water costs, but also increases food security and improves public health (Morel and Diener, 2006). Access to safe water and sanitation in Kenya will also help achieve the millennium development goals (UN, 2000) to halve the number of people without access to safe drinking water today by the year 2015.

Greywater management systems vary significantly in terms of complexity, performance and costs. They range from simple systems for single-house applications (e.g. local infiltration or garden irrigation) to rather complex treatment trains for neighborhoods (e.g. series of vertical and horizontal-flow constructed wetlands). In regions with water scarcity and poor water supply services, emphasis is placed on agricultural reuse of treated greywater, whereas in regions with abundant water, greywater reuse is of minor importance and locally infiltrated or discharged into nearby water streams(Morel and Diener, 2006). Thus, use of greywater should be possible in Kenya where nearly two thirds of the population relies on agriculture for their livelihood.

The end-of-pipe sanitary systems that areused today are based on the modern misconception that human excreta and urine are simply wastes with no useful purpose and must be disposed off. Ecological sanitation (ECOSAN) is a new paradigm in sanitation that recognizes human excreta and water from households not as waste but as resources that can be recovered, treated where necessary and safely used again (GTZ, 2005).

CW have been envisaged as cost effective waste water treatment technologies suitable for developing countries and an effective tool for raising the quality of life for local communities (Denny, 1997). Unfortunately the spread of CW in developing countries (Kenya included) have been depressingly slow, yet most of the developing countries lie within the tropics and sub-tropics where it might be expected that the warmer temperatures and conducive climate would favor rapid biological activity and greater efficiency (Denny, 1991).

At present, CW are not widely used in Kenya except in a few instances. This is usually on large scale mainly in municipalities, industries, hotels or farms. This thesis therefore seeks to identify areas (Peri-urban and rural) in Kenya that would be suitable for the establishment of CW and their use in treatment of grey water.

All of the existing CW in Kenya were started with private sector initiatives and investments. The largest CW in Kenya so far, with a 1200 person equivalent, occupies just over half a hectare (Raymer, 2006). In Kenya, the efficiency of CW in purification of domestic wastewater (Nyakango & Van Bruggen, 2001; Nzengya & Witshitemi, 2001), industrial wastewater from pulp and paper effluents (Abira *et al*, 2003), sugar milling effluents (Bojcevska and Tonderski, 2006) has been investigated. Their use for wastewater treatment is a relatively new approach to waste disposal, which hasn’t been well exploited, even though as a community-based concept, CW have almost limitless potential in Kenya. Further they have rarely been used on household or neighborhood level. Oketch (2006) identifies poor understanding of CW potential as one of the challenges and constraints to be overcome for adoption of CW for waste management in Kenya. At this point, the presented study tries to fill the gap.

In detail, the aims of the analysis are:

1. To identify areas (Peri-urban and rural) in Kenya that would be suitable for the establishment of CW for their use in treatment of grey water.
2. To identify wetland plants that would be suitable for use in Kenya.
3. To identify options of grey water reuse in Kenya.
4. To identify issues for further investigations by researchers and policy makers in Kenya.

The method of this study involved:

i) Literature review on CW in East Africa with specific emphasis on Kenyan examples.

ii) Identification of representative Peri-urban and rural areas in Kenya for the setting up of demonstration projects. These demonstration projects can then be extrapolated for replication to country level.

The thesis begins with a presentation of theoretical principles and concepts of wetlands and waste water management by use of CW. Based on lessons learnt from the case studies, the research further suggests the best options for the Kenyan situation and also suggests countrywide utilization possibilities.

Geographical characteristics ;(Library of Congress, 2007; WRI)

Kenya lies across the equator on the Eastern seaboard of Africa, It boarders the Indian Ocean coastline, stretching from the Somali boarder in the north for 380 miles(680 km) to Tanzania in the south.

i. Climate

Kenya's climate varies from tropical along the coast to arid in the interior, especially in the north and northeast. Intermittent droughts affect most of the country. Less than 15 percent of the country receives somewhat reliable rainfall of 760 millimeters or more per year, mainly the southwestern highlands near Lake Victoria and the coastal area, which is tempered by monsoon winds. Most of the country experiences two wet and two dry seasons. The driest month is August, with 24 millimeters average rainfall, and the wettest is April, the period of "long rains," with 266 millimeters. The hottest month is February, with temperatures of 13°C to 28°C, and the coolest is July, with temperatures of 11°C to 23°C. The highlands feature a bracing temperate climate. Nairobi, at an elevation of 1,820 meters, has a very pleasant climate throughout the year.

ii. Topography

Kenya rises from a low coastal plain on the Indian Ocean in a series of plateaus to more than 3,000 meters in the center of the country. An inland region of semi-arid, bush-covered plains constitutes most of the country's land area. In the northwest, high-lying scrublands straddle Lake Turkana (Lake Rudolf) and the Kulal Mountains. In the southwest lie the fertile grasslands and forests of the Kenya Highlands, one of the most successful agricultural production regions in Africa. North of Nairobi, the Kenya Highlands is bisected by the Great Rift Valley, an irregular depression that cuts through western Kenya from north to south in two branches. The Rift Valley is the location of the country's highest mountains, including, in the eastern section, the snow-capped Mt. Kenya (5,199 meters), the country's highest point and Africa's second highest. In the south, mountain plains descend westward to the shores of Lake Victoria

iii) **Vegetation**

Kenya has five major vegetation types: Savanna and grassland ecosystems and bushland and woodland ecosystems cover 39 and 36 percent of Kenya, respectively. Agroecosystems extend over another 19 percent and closed forests make up about 1.7 percent of Kenya's land area. Urban ecosystems cover only about 0.2 percent of the country.

iv) **Social structure**

Kenya has a very diverse population that includes most major language groups of Africa. The different tribes are grouped according to their linguistic origin. Around 65percent of the total belong to Bantu tribes, dwelling in the Central Highlands, the southeast and the coastal regions. The Nilotic 30percent settle in the southwest and the central Rift Valley region, whereas the 3percent Cushites inhabit the northern areas. The population spectrum also comprises some minorities, such as Hindus, Arabs and Europeans.

The age structure based on the 1999 national census is as follows:

0-14 years: 42.1percent (male 7,826,804/female 7,720,456)

15-64 years: 55.2percent (male 10,219,575/female 10,174,922)

65 years and over: 2.6percent (male 446,355/female 525,609) (2007 est)

2. LITERATURE REVIEW

2.1 CONSTRUCTED WETLANDS AS A TOOL FOR WASTE WATER MANAGEMENT: AN OVERVIEW

Wetlands are natural resources of global significance. They are transitional areas between land and water and are distinguished by wet soils, plants that are adapted to wet soils, and a water table depth that maintains these characteristics. Wetlands are among the most important ecosystems on the earth because of their ability to cleanse polluted waters, prevent floods and storm surges, protect shorelines, bring about sediment control and nutrient recycling and recharge groundwater aquifers (Mitsch and Gosselink, 2000, Hammer and Bastian, 1989).

However, despite of the high biodiversity and the high importance of the goods and services of wetland ecosystems, local and regional wetlands are under increased threat by human activities (Verhoeven et al., 2006). Disposal of domestic and industrial wastes and increased nutrient supply have been recognized as major factors for wetland degradation in the world (Verhoeven et al 2006, Gopal, 1999), leading to adverse impacts on wetland biodiversity and wetland ecosystems. Brix (1993), states that natural wetlands should not be used deliberately as wastewater treatment systems, but should be preserved for environmental conservation.

The functional role of wetlands in improving water quality has been a compelling argument for the preservation of natural wetlands and the construction of wetland systems for wastewater treatment (Bastian, 1993). In addition, constructed wetlands(CW) offer several additional advantages compared to natural wetlands, including site selection, flexibility in sizing, and most importantly, control over the hydraulic pathways and retention time (Brix ,1993). They aim to systematically control and optimize the ability of a wetland system to remove or transform wastewater pollutants, and in many cases to for the development of wildlife and social objectives. Denny (1997), further argues that CW provide a sound foundation for nature conservation and improvement of water quality.

CONSTRUCTED WETLANDS

Constructed wetlands (CW) have been defined as ‘‘ engineered systems designed and constructed to utilize the natural processes involving wetland vegetation, soils and their associated microbial assemblages to assist in treating wastewater.’’ Synonymous terms to constructed include man-made, engineered, treatment and artificial wetlands (Hammer and Bastian, 1989).

CW have been used for waste water treatment for nearly 40 years and thus improving water quality and sanitation in nearly all regions of the world. The first experiments on the possibility of waste water treatment by wetland plants were done by Dr Seidel in 1952 at the max plank institute in Plön- Germany. CW have since then been used either for the treatment of point-source pollutions which are mainly municipal and domestic, but also of non-point source pollutions such as agricultural run off ,land fill leachate or, particularly in the USA ,acid mine drainage.(Reed, 1995). CW are not recommended for treatment of raw waste water.

The pollutants in these systems are removed through a combination of physical, chemical, and biological processes including sedimentation, precipitation, adsorption to soil particles assimilation by the plant tissue, and microbial transformations (Brix, 1993). CW have gained acceptance worldwide (Tanner, 1996), due to their economically and environmentally sound attributes as a waste water management option and as design, construction and operational experience has accumulated.

CW could be classified according to the various parameters but the two most important criteria are water flow regime (surface and sub-surface) and the type of macrophytic growth. Different types of constructed wetlands may be combined with each other (so called hybrid or combined systems) in order to exploit the specific advantages of the different systems. The quality of the final effluent from the systems improves with the complexity of the facility *(*Vymazal and Kröpfelová 2008*)*. Emergent macrophytes based systems can be constructed with surface flow, subsurface horizontal flow and vertical flow (fig 2.1).

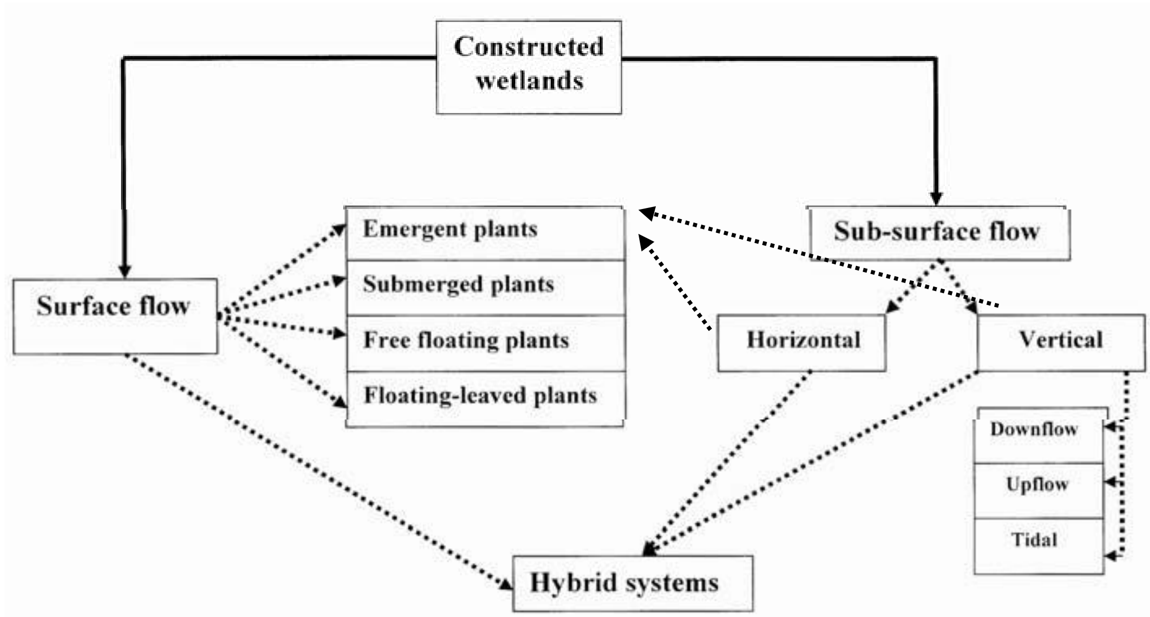

Fig.2 .1 Classification of constructed wetlands for wastewater treatment (taken from: Vymazal and Kröpfelová 2008; modified)

i) Surface flow systems

A typical surface flow (SF) or free water surface constructed wetland (FWS CW) with emergent macrophytes (usually covering more than 50 percent), is a shallow sealed basin or sequence of basins, containing 20-30 cm of rooting soil, with a water depth of 20-40 cm. As the name suggests, the waste water flows above the ground exposed to the atmosphere. Inflow water containing particulate and dissolved pollutants slows and spreads through a large area of shallow water and emergent vegetation (Kadlec and Knight, 1996).

FWS CW typically have aerated zones, especially near the water surface because of atmospheric diffusion, and anoxic and anaerobic zones in and near the sediments. In heavily loaded FWS wetlands, the anoxic zone can move quite close to the water surface.

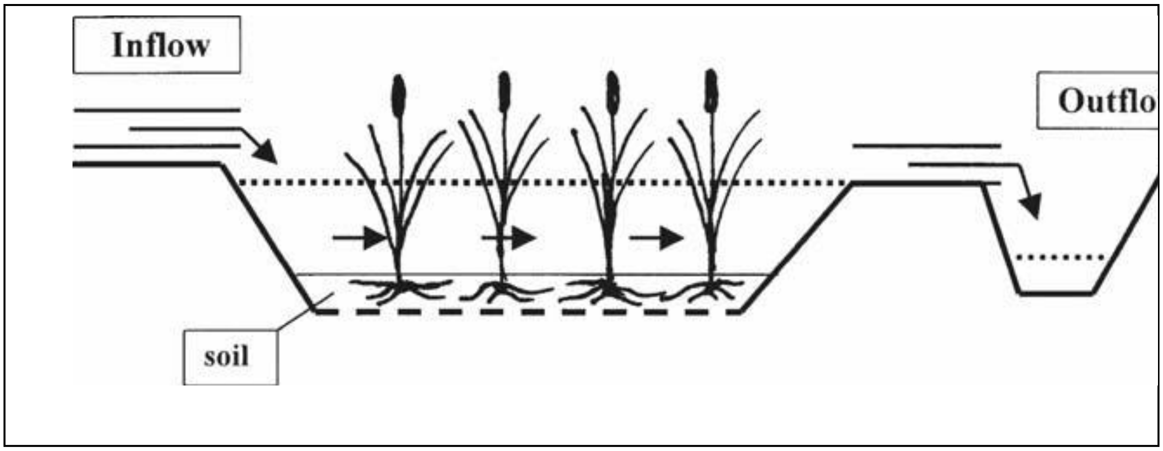

Fig. 2.2 Schematic representation of the free water surface constructed wetland with emergent macrophytes. From Vymazal (2001)

Long retention times and an extensive surface area in contact with the flowing water provide for effective removal of particulate and organic matter. The sediment, plant biomass and plant litter surfaces are also where most of the microbial activity affecting water quality occurs, including oxidation of organic matter and transformation of nutrients. Biomass decay provides a carbon source for denitrification, but the same decay competes with nitrification for oxygen supply. Low winter temperatures enhance oxygen solubility in water, but slow microbial activity (Kadlec and Knight, 1996).

ii) Sub-surface systems

These systems have the water level designed to remain below the top of the substrate. They have the added component of emergent plants with extensive root systems within the media. Soil media systems designated as the Root-Zone-Method (RZM) were developed in Plön, Germany (EPA, 1988).

CW with sub-surface flow may be classified according to the direction of flow; horizontal and vertical (Fig.2.1*)* on one hand, and into soil, sand and gravel based wetlands on the other hand. The substratum provides the support and attachment surface for microorganisms able to anaerobically (and/or anoxically if nitrate is present) reduce the organic pollutants into CO_2, CH3, H_2S, etc. The substratum also acts as a simple filter for the retention of influent suspended solids and generated microbial solids, which are then themselves degraded and stabilized over an extended period within the bed, such that outflow suspended solids levels are generally limited.

The provision of a suitably permeable substrate in relation to the hydraulic loading to obviate surface ponding tends to be the most expensive component of the subsurface flow systems, and the factor responsible for the most treatment problems when permeability is not adequately catered for (Crites, 1994). Sub-surface systems are also referred to as planted filters, reed beds, root zone method, gravel bed hydroponics filters, vegetated submerged beds or artificial wetlands (Morel and Diener, 2006).

iii) Horizontal flow Systems (HFS)

It is called horizontal flow because the wastewater is fed in at the inlet and flows slowly through the porous medium under the surface of the bed in a more or less horizontal path until it reaches the outlet zone where it is collected before leaving via level control arrangement at the outlet (fig 2.3). During this passage the wastewater will come into contact with a network of aerobic, anoxic and anaerobic zones. The aerobic zones occur around roots and rhizomes that leak oxygen into the substrate (Brix, 1987; Cooper et al., 1996). CW with horizontal subsurface flow require much larger vegetated bed area in order to effectively eliminate phosphorous and nitrogen (Schierup et al., 1990).

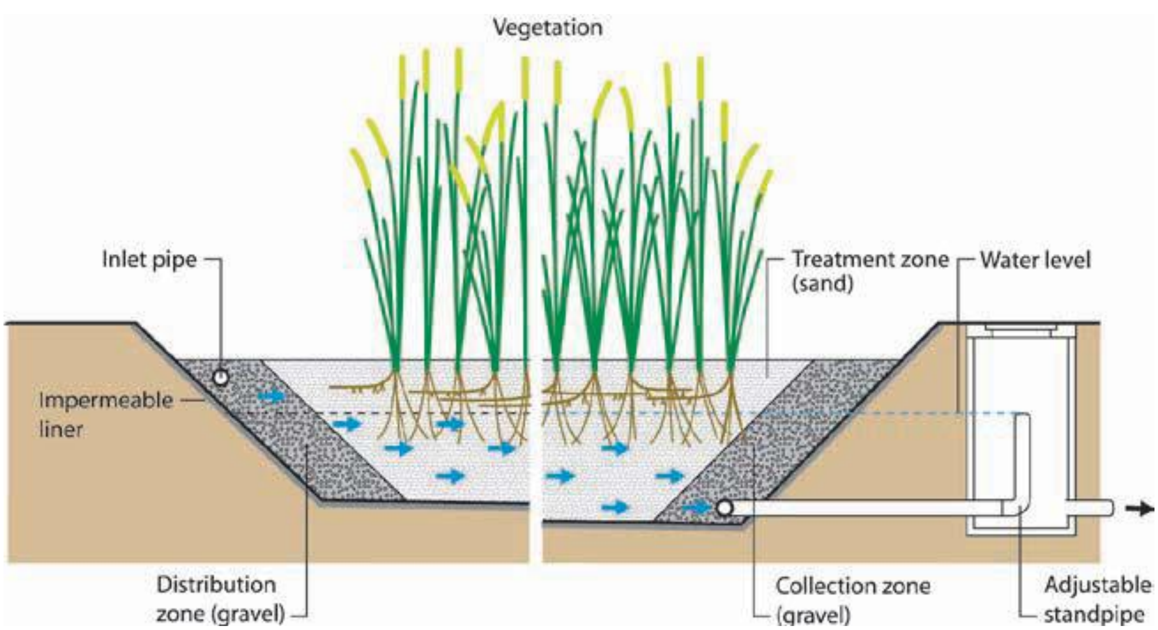

Fig 2.3 Schematic cross-section of a horizontal-flow constructed wetland (HF CW). From Morel and Diener (2006)

HFS are very efficient in removing organic matter and suspended solids. BOD removal rates range between 65 percent and 90 percent, with average BOD effluent concentrations below 30-70 mg/l. Typical effluent TSS levels are below 10–40 mg/l and correspond to 70–95percent removal rates. Pathogen removal amounting to 99 percent or more (2–3 log) total coliforms has been reported by Crites and Tchobanoglous (1998).

Tropical and subtropical climates hold the greatest potential for the use of HFS. Cold climates tend to show problems with both icing and thawing. Water stress of plants in a HFS is an important issue to be considered especially in households systems during periods without inflow (e.g. during holidays).

iv) Vertical flow systems (VFS)

VFS are shallow excavations or above-ground constructions with an impermeable liner, either synthetic or clay. They are characterized by intermittent (discontinuous) loading and resting periods where the waste water percolates vertically through the substrate. Intermittent and batch loading enhances oxygen transfer and thus nitrification. The main purpose of plant presence in VFS is to help maintain the hydraulic conductivity of the bed. VFS have a typical depth of 0.8–1.2 m (Sasse, 1998). For small systems (i.e. single households) receiving septic tank effluents, Cooper (1999) proposes the use of two vertical –flow beds in series.

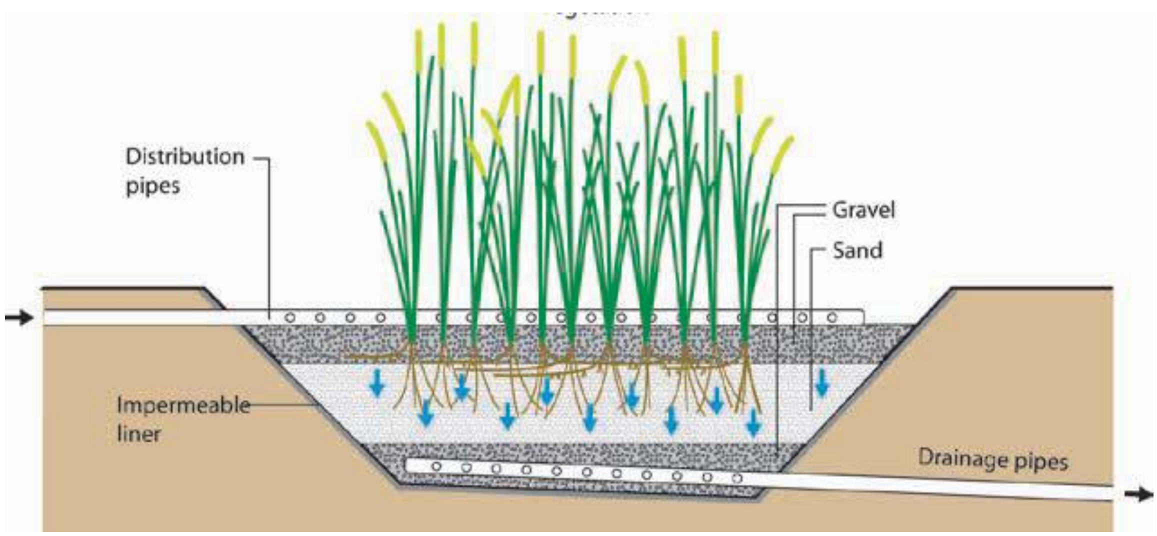

Fig. 2.4 Schematic cross-section of a Vertical-flow constructed wetland (VF CW). From Morel and Diener (2006)

Removal efficiencies in terms of BOD, COD, ammonia-N and pathogens of VFS are generally higher than comparable HFS. However removal of suspended solids is somewhat lower than in HFS (Cooper et al., 1999). Average removal efficiencies are typically within a range of 75-95percent and 65-85 percent in terms of BOD and TSS respectively. Pathogen removal in terms of total coliforms are typically within a range of 2-3 log and can be as high as 5 log as seen in Nepal (Shrestha, 1999). However, removal of total nitrogen is comparable with FWS and HF systems due to inability to provide denitrification. This could be resolved by recycling of the effluent into the pretreatment unit, e.g. septic or Imhoff tank (Arias and Brix, 2006).Removal of phosphorus is also comparable with other types of CW.

One of the major threats of good performance of VFS is clogging of the filtration substrate (Winter and Goetz, 2003; Chazarenc and Merlin, 2005). Therefore, it is important to properly select the filtration material, hydraulic loading rate and distribute the water evenly across the bed surface in order to avoid overloading of certain parts of the surface.

Given their reliance on a well functioning pressure distribution, they are more adapted to locations where natural gradients can be used, thus enabling the filter by gravity. Since flat areas require the use of pumps, they are thus dependent on a reliable power supply and frequent maintenance (Moore and Diener, 2006). VFS could be further categorized into down-flow and up-flow depending on whether the wastewater is fed onto the surface or to the bottom of the wetland.

VFS are primarily used to treat domestic or municipal sewage. The system has also been successfully applied to municipal, industrial (explosives, food processing, airport de-icing water, acid mine drainage) as well as agricultural (aquaculture, swine feedlot) wastewaters (Behrends et al., 2001).

v) Downflow

The earliest form of downflow VFS is that of Seidel in Germany in the 1970s, sometimes called the Max Planck Institute Process (MPIP) or the Krefeld Process (Seidel, 1978).

Similar systems in the Netherlands were called “infiltration fields” (Greiner and de Jong, 1984). Interest in the particular process has been revived in the last decade because of the need to produce beds which nitrify and overcome the problem HF beds. Typical arrangement of downflow VFS is shown below in (Fig. 2.5).

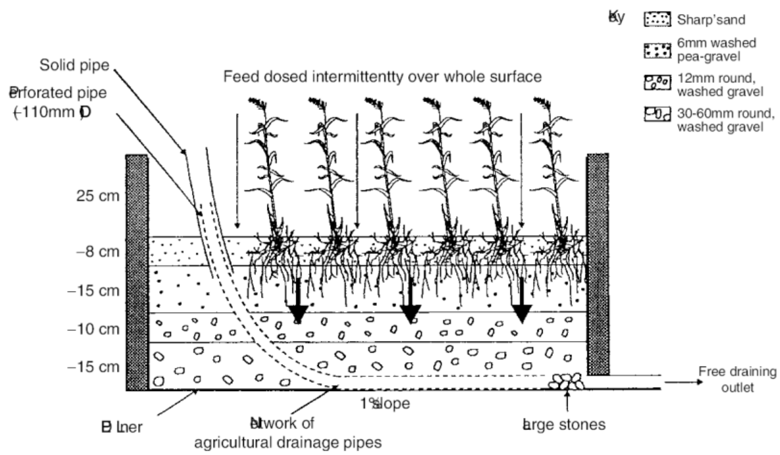

Fig 2.5 Typical arrangement of a downflow vertical-flow constructed wetland (from Cooper et al., 1996).

Vertical flow constructed wetlands (VF CW) comprise a flat bed of graded gravel topped with sand planted with macrophytes. The size fraction of gravel is larger in the bottom layer (e.g. 30-60 mm) and smaller in the top layer (e.g., 6 mm). VFCW are fed intermittently with a large batch thus flooding the surface. Wastewater then gradually percolates down through the bed and is collected by a drainage network at the base. The bed drains completely free and it allows air to refill the bed. This kind of dosing leads to good oxygen transfer and hence the ability to nitrify (Cooper et al., 1996).

vi) Upflow

In vertical-upflow CW the wastewater is fed on the bottom of the filter bed. The water percolates upward and then it is collected either near the surface or on the surface of the wetland bed.

These systems have commonly been used in Brazil (Salati, 1987; Manfrinato et al., 1993; Salati et al., 1999) since the 1980s. The beds are filled with crushed rock on the bottom, the next layer is coarse gravel and the top layer is soil planted with Rice (*Oryza sativa*).

This treatment system is called in Brazil "filtering soil" (Fig 2.6). However, outside Brazil, the layer of soil is usually not used and beds are filled with gravel and usually planted with common species such as *Phragmites australis*.

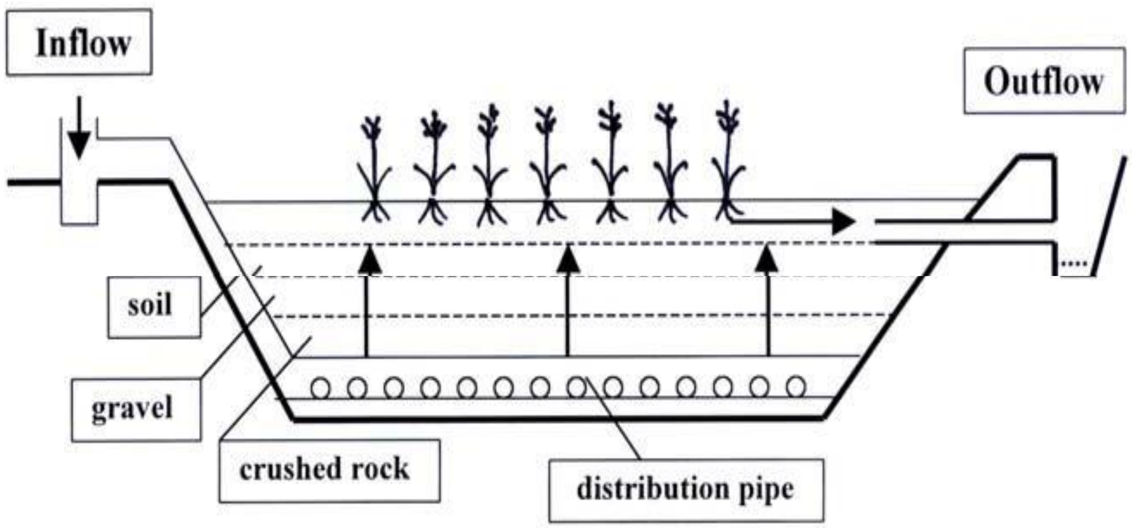

Fig 2.6 Schematic representation of a constructed wetland with vertical up-flow. From Vymazal (2001)

vii) Tidal flow

Tidal flow systems are a new form of VFS (Zhao et al., 2004; Cooper and Cooper, 2005). Cooper (2005) pointed out that tidal flow systems were developed to try to overcome some of the problems that were seen in the early forms of VFS related to clogging of the surface. Upflow systems have been used for about 20 years but they suffer from the problem that distribution is below the surface and hence hidden from the observers.

In tidal flow systems at the start of the treatment cycle the wastewater is fed to the bottom of the bed into the aeration pipes. It then percolates upwards until the surface is flooded. When the surface is completely flooded the pump is then shut off, the wastewater is then held in the bed in contact with the microorganisms growing on the media. A set time later the wastewater is drained downwards and after the water has drained from the bed the treatment cycle is complete and air diffuses into the voids in the bed (Cooper, 2005).

viii) Biosolids Wetlands

The concept of VF wetlands to remove organic matter extends back to the original system of Seidel (Seidel, 1965), but is also used in a modern context for VF wetlands in France, which are typically designed to accumulate biosolids associated with raw sewage (Boutin *et al.*, 2002; Chazarenc and Merlin, 2004; Molle *et al.*, 2004). In France, more than 1000 VFS treat unsettled (raw) sewage (Boutin and Liénard, 2003; Molle et al., 2005; Paing and Voisin, 2005; Paing et al., 2006; Esser et al., 2007). The special feature of this system is that it accepts raw sewage directly onto the first stage allowing for easier sludge management in comparison to dealing with primary sludge from an Imhoff tank (Molle et al., 2005).

Wetland beds designed specifically for biosolids dewatering have been most extensively developed in Denmark, where over 110 systems have been constructed since 1988 (Nielsen, 2006). The largest current system is in Kolding, Denmark (123,000 PE). Use of wetlands for stabilization of organic biosolids is expanding throughout Europe (DeMaeseneer, 1997; Barjenbruch *et al.*, 2002; Obarska-Pempkowiak and Sobocinski, 2002; Lesavre and Iwema, 2002).

ix) Hybrid systems

Various types of CW may be combined in order to achieve higher treatment effect, especially for nitrogen. In these systems, the advantages of the HSF and VF systems can be combined to complement each other. Therefore, there has been a growing interest in hybrid systems (also sometimes called combined systems). Hybrid systems used to comprise most frequently VFS and HFS arranged in a staged manner (fig 2.7); however, all types of CW could be combined. In hybrid systems, the advantages of various systems can be combined to complement each other. It is possible to produce an effluent low in BOD, which is fully-nitrified and partly denitrified and hence has much lower total-N concentrations (Cooper, 1999, 2001).

The design consists of two stages of several parallel VF beds ("filtration beds") followed by 2 or 3 HF beds ("elimination beds") in series. The results indicate very good removal for organics (BOD_5 and COD) and TSS while removal of nitrogen is enhanced with no nitrate increase at the outflow (Cooper, 2001; VMM., 2006).

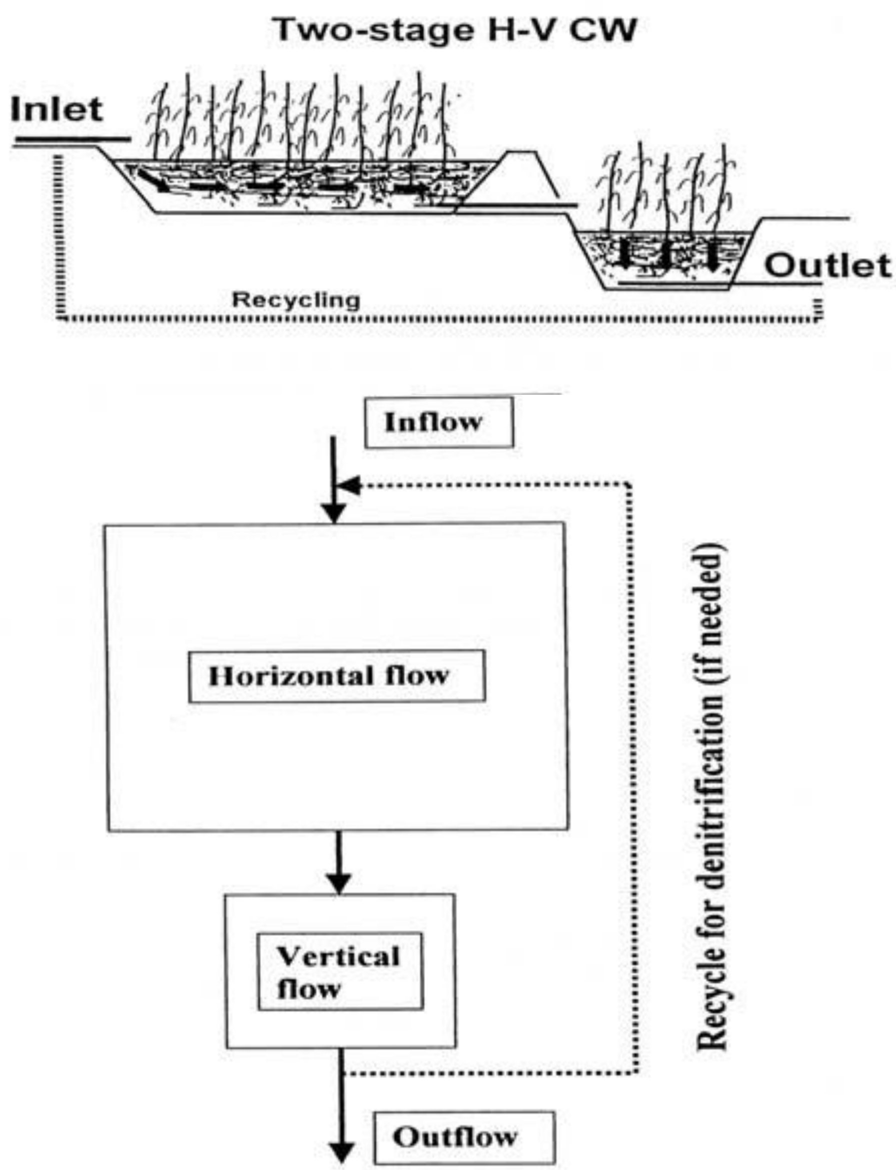

Fig2.7. Schematic arrangement of the HF-VF hybrid system according to Brix and Johansen. From Vymazal (2001)

WETLAND VEGETATION

The role of wetland vegetation as an essential component of CW is well established (Lim et al., 2001). Emergent plants contribute both directly and indirectly to the treatment processes. In spite of the fact that the most important removal processes in CW are based on microbial processes, the macrophytes posses several functions in relation to the water treatment. They influence treatment process in CW by their physical presence and metabolism (Brix 1994, 1997; Vymazal et al., 1998).

In general, the most significant functions of wetland plants (emergents) in relation to water purification are the physical effects brought by the presence of the plants. The plants provide a huge surface area for attachment and growth of microbes. The physical components of the plants stabilise the surface of the beds, slow down the water flow thus assist in sediment (Brix, 1994).

However, not all wetland species are suitable for wastewater treatment since plants for CW must be able to tolerate a combination of continuous flooding and exposure to wastewater or storm water containing relatively high amounts of pollutants. The larger aquatic plants growing in wetlands are usually called macrophytes (Vymazal, 2006). Three most important criteria form the basis for the plant choice: (Herrs, 2006)

- Availability in climate zone
- Pollutant removal capacity (treatment efficiency) and tolerance ranges
- Plant productivity and biomass utilization options

2.2.1 Constructed wetland species for Kenya

CW worldwide are mainly planted with emergent macrophytes (non –woody plants that grow with their roots in the substrate and their stems and leaves emerging from the water surface). Emergent wetland species can grow in a water level ranging to a water depth of 1.5m or more depending on the species and its inundation tolerance (cronk and Fenssey, 2001). Common species used in CW include bulrushes (*Scirpus sp*.), catt ails (*Typha sp*.), common reed (*Phragmites australis*), different Cyperaceae (*Carex sp.,Cyperus sp*.) and a number of broad-leaved species. In the following, these species are described according to:

- Distribution, traits and ecology
- Evaluation of existing case studies
- Productivity and biomass utilisation options

i) Typha domingensis (southern cattail)

Common name	Southern cattail
Scientific name (genus / species)	*Typha domingensis*, syn.: *Typha angustata*
Family	*Typhaceae*

Distribution, traits and ecology

Usually distributed in warm temperate and tropical areas worldwide. *Typha domingensis* is a perennial and rhizomatous plant, showing persistent year-round growth in warm and subtropical climates. The species has a very fast, rapid establishment (similar to *Typha latifolia*) and spread rapidly by vegetative reproduction, but also readily by generative reproduction (similar to *Typha latifolia).* Root penetration is shallow (up to 0.3m), close to the ground surface (Gopal, 1982).

The natural habitats are fresh water to brackish and nutrient-enriched marshes, pond margins, shallow water sites and coastal marshes (PFAF, 2004; Stevens, 2000). *Typha domingensis* is a highly invasive and dominant species, an aggressive colonizer which commonly forms dense monoculture stands (PFAF, 2004). According to Kadlec and Knight (1996), it can be inundated irregularly to permanently; up to 0.75 m. It tolerates temporarily inundations up to 1 m, but is sensitive to droughts of a few weeks (Gopal, 1982).

Evaluation of existing case studies

Typha domingensis has been used in diverse CW. In the study conducted by Cerezo (2001) in Mojacar, Almeria Southeast Spain (semi-arid/Mediterranean climate), *Typha domingensis* was planted together with *Phragmites australis*, in a multistage horizontal subsurface low wetland (influent: pre-treated wastewater from an anaerobic stabilization pond) and tested under different HRTs, hydraulic loadings and area sizes. High removal efficiencies of TSS: 90 - 96 percent; COD: 78 - 87 percent; BOD: ≈ 90 percent were observed.

The potential of *Typha domingenesis* for treatment of industrial wastewater was investigated in bucket mesocosms at Pan African Paper Mills (E.A) Limited in western

Kenya. *Typha* was found suitable for removal of organic matter and suspended solids in pulp and paper mill wastewater in a CW (Abira et al. 2003)

Productivity and utilisation options

T. domingensis is a highly productive species with a high potential as a renewable biomass source (similar to the other types of *Typha sp.*). According to Greenway (2001) in a CW for polishing of secondary treated municipal effluent in Queensland, Australia under subtropical conditions, its productivity was 22.64 t/ (ha*yr).

It has a high potential as a biomass source for renewable energy e.g. source of fuel (direct combustion).The stems and leaves can serve as raw material for thatching, paper making, weaving, basket making, addition for composting purposes and insulation material.

ii) Vetiveria zizanioides (vetiver grass)

Common name	Vetiver grass
Scientific name (genus / species)	*Vetiveria zizanioides*
Family	*Poaceae (Gramineae)*

Distribution, traits and ecology

Native to India, Sri Lanka, Burma and Southeast Asia (e.g. South China and Thailand) and subtropical Northern Australia (Queensland), (FAO, 2006; Truong, 2001). It’s a perennial and persistent and fast growing plant showing year-round growth in tropical climates (Kantawanichkul, 1999). A non-invasive species which grows up to 1.5 -2 m (Vetiver Network, 2005). *Vetiveria zizanioides* shows mainly vegetative, but also marginal generative reproduction (Chaipat, 2005). It has extensive, strong and dense root system that penetrates vertically deep into the soil (up to 3 m under ideal conditions), (Chaipat, 2005; Vetiver Network). Vetiver grass can grow in a wide range of areas and under various soil conditions (Chaipat, 2005). Prefers full sun, but also tolerates semi-shade conditions (Vetiver Network, 2005).

According to Truong (2001), vetiver grass can survive under very high salt concentrations of up to about 31 ppt and pH tolerance of 3.0-10.5. However, in an investigation conducted by Klomjek (2005), *Vetiveria zizanioides* could not survive the following conditions: salt concentrations of about 10 ppt and prolonged flood conditions (eight weeks). (Vetiver Network, 2005). The species shows a high tolerance to flooded conditions as well as longer drought periods, can survive complete submergence in water for up to three months (Vetiver Network, 2005).

Evaluation of existing case studies

Numerous investigations and researches in North Australia, South China and Thailand have proved the effectiveness of *Vetiveria zizanioides* in constructed wetland systems for the treatment of domestic (municipal), industrial and agricultural wastewaters, but also landfill leachate (Truong, 2001). This plant was very successfully used in Australia for the treatment of domestic primary effluents from septic tanks (Truong, 2001).

According to Liao (2000), *Vetiveria zizanioides* was able to tolerant to high-loaded organic wastewaters at COD concentrations of 2,800 mg/L. (Liao, 2000, in: Truong, 2001). In a study conducted by Kantawanichkul (1999) in subtropical Thailand, *Vetiveria zizanioides* was planted in a vertical flow CW treating diluted settled pig farm wastewater: a mean COD influent conc. of 601 mg/L was tolerated with a removal performance of 78.7 percent (HLR: 18.5 mm/d).

In another study in subtropical South China, *Vetiveria zizanioides* was planted in an experimental culture system without a soil medium treating relatively high strength pig farm wastewaters (Liao, 2003). The results of this study are

- Mean COD influent conc.: 825 mg/L, removal rate: 64 percent,
- Mean BOD influent conc.: 510 mg/L, removal rate: 68 percent.

(HRT: 4 d)

The available investigations show that vetiver grass has proved to be a well suitable plant species for wastewater treatment, especially when planted in vertical flow systems.

Generally, vetiver grass proved to be tolerant to eutrophic conditions and was able to grow at high strength NH3-N concentrations of about 390 mg/L (Liao, 2000, in: Truong, 2001). In the study conducted by Klomjek (2005) in Thailand, *Vetiveria zizanioides* showed a good NH3-N treatment performance for medium strength municipal wastewater. The mean reduction was 76.5 percent (mean influent conc.: 19.5 mg/L). The species has significantly higher water use rates compared to other common wetland species, e.g. *Typha sp., Phragmites sp*. or *Scirpus sp.* (Truong, 2001) and is highly tolerant to elevated concentrations of certain heavy metals (e.g. Cd, Cu, Cr, Pb, Ni or Zn), (Truong, 2001).

Productivity and utilisation options

According to Liao (2003) *Vetiveria zizanioides* is a highly productive species usually harvested two or three times a year to export nutrients or for biomass utilization purposes (Truong, 2003). The typical biomass yield ranges in natural habitats between 15 and 30 t/ha and under fertile and moist (irrigated) conditions up to 100 t/ha. (Vetiver Network, 2005).

Vetiver grass shows highly versatile utilization options (Chaipat, 2005; Vetiver Network, 2005) as it is often used for soil stabilization and erosion control due to the extensive and deep root system. The leaves and stems can be used as raw material for handicrafts (e.g. weaving of hats, mats, baskets, etc.), as construction and building material (e.g. thatching) or energy source, ethanol production and “green” fuel.A proportional mix of vetiver grass and water hyacinth(*Eichhornia crassipes*) biomass serves as a high-quality source of "green" fuel:

- Industrial products (e.g. raw material for paper making)

- Agricultural purposes (mulching, making of vetiver compost)

- Animal food (e.g. for dairy cows, cattle, sheep or rabbits)

- Miscellaneous other utilization options (medicinal applications mushroom culture, etc.).

iii) Pennisetum clandestinum (Kikuyu grass)

Common name	Kikuyu grass
Scientific name (genus / species)	*Pennisetum clandestinum*
Family	*Poaceae (Gramineae*

Distribution, traits and ecology

From Zaire and Kenya the grass has been introduced widely in tropical areas, especially in Costa Rica, Colombia, Hawaii, Australia and southern Africa. It's a perennial, rhizomatous and stoloniferous (Cook, 2005) grass with a growth height of up to 1.2 m (USDA-IPIF, 2005)

The growth rate is strongly dependent on nutrient supply. It rapidly spreads by vegetative reproduction, but also readily shows generative reproduction. It is an invasive species usually forming monospecific stands (FAO, 2006).

The species has an extensively creeping, relatively deep rhizome system. 90 percent of the total root weight is usually found in the upper layer up to 0.6 m (FAO, 2006). However, other studies in South Africa showed that the root and rhizome development in subsurface flow beds is less prolific which may limit the root zone oxygenation capacity (Wood, 1989). Natural habitats are coastal areas, wetlands, grasslands and forest margins (ISSG, 2005). It thrives in full sun to light shade but is not shade tolerant (FAO, 2006). The species tolerates saline conditions and low pH values of up to 4.5 (Cook, 2005). It shows a good tolerance to inundations and has a relatively high drought tolerance due to the deep root and rhizome system (FAO, 2006).

Evaluation of existing case studies

The performance of this species in CW was primarily investigated in South Africa (Batchelor, 1990; Wood, 1989). In one pilot study in South Africa, the treatment bed planted with *Pennisetum clandestinum* achieved a very high COD removal efficiency of 95 percent. The influent was settled sewage from a septic tank with a mean COD conc. of 332 mg/L; using soil substrate and waste ash (Wood, 1989).

The behaviour of *Pennisetum clandestinum* is similar to other, more commonly used species (e.g. *Scirpus lacustris* or *Phragmites australis*).

Productivity and utilisation options

Potentially it is a high productive species, strongly depending on nutrient supply (especially nitrogen fertilizers). Data about growth rates or biomass yields for *Pennisetum clandestinum* growing in CW under tropical or subtropical conditions were not available.

In Northern New South Wales, Australia, a maximum biomass yield of 30 t/(ha*yr) dry wt was obtained by use of nitrogen fertilizers (Cook, 2005). In domestic or municipal wastewaters that are usually characterized by evaluated concentrations of nitrogen and phosphorus compounds, an enhanced growth rate can be expected.

Generally, *Pennisetum clandestinum* is a highly digestible, palatable and valuable pasture grass which can be used as grazing for domestic animals (e.g. cows, sheep). It is a high quality forage plant due to the high crude protein (normally > 12 percent of dry wt) and low fibre content of the leaves. It's a valuable pasture grass for dairy (milk) production and cattle finishing in tropical and subtropical areas. It can also be used as hay or silage, (Cook, 2005; FAO, 2006)

Studies in South Africa showed that *Pennisetum clandestinum* responds well to frequent harvesting (Batchelor, 1990).

iv) Phragmites mauritianus (Lowveld reed)

Common name	Lowveld reed
Scientific name (genus / species)	*Phragmites mauritianus*
Family	*Poaceae (Gramineae)*

Distribution, traits and ecology

The species can be found in tropical and southern Africa (e.g. Congo, Ethiopia, Kenya, Sudan, and Tanzania). It is a perennial, rhizomatous and persistent plant with a growth height of 4 m to 7 m.

The reproduction is mainly vegetative, but also has a low generative reproduction (similar to *Phragmites australis*). The root and rhizome growth and development is presumably similar to that of *Phragmites australis.* It usually grows in saline (brackish) swamps (“reed swamps”), more at saline sites compared to *Phragmites australis (*Kabii, 1997). Tolerates full sun (similar to *Phragmites australis*), however there is no sufficient data available for pH optimum and tolerance range. The specie has a high salinity tolerance eg. to brackish and saline waters.

Phragmites mauritianus is a highly invasive species which often forms monospecific stands (similar to *Phragmites australis*. No sufficient data is available on its tolerance to inundations, droughts and water levels but it is presumed to be similar to *Phragmites australis.*

Evaluation of existing case studies

In the study conducted by Okurut (1999) in Kampala, Uganda (tropical climate, ≈ 1 °N), the removal performance of *Phragmites mauritianus,* planted together with *Cyperus papyrus* in a SFCW, was investigated.

The Removal rates in very low-loaded influent concentration were as follows:

COD: 43.0 percent (mean influent conc.: 155.2 mg/L)

BOD: 51.2 percent (mean influent conc.: 48.4 mg/L)

Compared to Cyp*erus papyrus*, the effluent conc. of the *Phragmites mauritianus* system are slightly, but not significantly poorer.

Another comparative study investigated the performances of *Phragmites mauritianus* and *Typha latifolia* in a subsurface flow CW for polishing of pre-treated domestic wastewater under tropical conditions in Tanzania (Kaseva, 2004).

Removal efficiencies were as follows: COD: 56.3 percent (mean influent conc.:106.4 mg/L)

The performance was similar to that observed with *Typha latifolia* (60.7 percent). Its' oxygenation capacity and effect on microbial transformations (nitrification and denitrification activity) can be assumed to be similar to *Phragmites australis*

Productivity and utilisation options

A highly productive species (similar to *Phragmites australis*), however no data is found on growth rates and yields.

The biomass utilization options are similar to those of *Phragmites australis*, e.g.:

- The stems areused as building material for houses,
- Fibres of the stems can be used for construction purposes and handicrafts,
- Raw material for paper making,
- Renewable biomass source for fuel and energy.

v) Typha latifolia (broad-leaved cattail)

Common name	Broad-leaved cattail, common cattail
Scientific name (genus / species)	*Typha latifolia*
Family	*Typhaceae*

Distribution, traits and ecology

Its nearly cosmopolitan and found all over the world from Europe and West Asia , North America, central America and North Africa, new Zealand ,Australia and Japan), (PFAP, 2004,Rook, 2004)

A perennial and rhizomatous, persistent (Thunhorst, 1993) plant with a growth height of between 2.5 - 3 m (PFAF, 2004). It shows very fast and rapid establishment (Thunhorst, 1993) produce dense vegetation stands within three months after planting (EPA, 1988) and shows markedly aboveground senescence in autumn (Chambers, 1994).

It’s a highly invasive species which rapidly spreads by vegetative reproduction, but also readily by generative reproduction (ISSG, 2005). Has an extensive horizontal rhizome system and shallow depth penetration. The root biomass is largely confined to the upper 0.3 m of the soil layer (Gersberg, 1986).

The species naturally inhabits freshwater wetlands, lake and pond margins and wet ditches,shallow water sites but prefers soils rich in organic matter (Rook, 2004). It tolerates full sun (Thunhorst, 1993; Ellenberg, 1991) and has a pH tolerance range of 4 – 10 (Reed 1995).

It’s a freshwater species with a low salinity tolerance (< 0.5 ppt). It can be inundated irregularly to permanently up to 0.3 m (Thunhorst, 1993) but tolerates only short drought periods (Floridata, 2006). Temporary inundations up to 1 m can be tolerated (Reed, 1995).

Typha latifolia is a typical plant species for surface flow as well as subsurface wetlands in the USA (Brown, 1994; Reed, 1995) and for gravel bed treatment systems in Canada (Lakshman, 1994). Typically used in the horizontal flow stage of the Krefeld Process or Haider/Rausch Process, not recommended in vertical flow wetlands due to the shallow root system.

Evaluation of existing case studies

The plant is tolerant to high organic loadings (Brändle, 1996) and shows a good performance in cold/boreal climates. It’s mean BOD removal efficiency in a vertical flow wetland in Estonia (cold/boreal climate, ≈ 58 °N) was 82 percent for a domestic wastewater with an influent conc. of 27 - 460 mg/L BOD (Mander, 1997).

The BOD and TSS removal efficiencies of a pilot multistage CW system near Murmansk in the Russian Arctic (sub-arctic climate, ≈ 68 °N) planted with *Typha latifolia*, C*arex aquatilis* and *Phragmites australis* were more than 81 percent (Vasilevskaya, 2004).

The BOD treatment performance of several multistage systems with a BOD influent conc of about 200 mg/L, in Norway (cold/boreal climate, ≈ 60 °N) planted with *Typha latifolia* amounted up to > 80 percent (Jenssen, 1993; Maehlum 1995, 1999).

Typha latifolia has a high tolerance to certain heavy metals, especially lead, zinc, copper (Wissing, 2002).

Productivity and utilisation options

A highly productive species with a high potential as a renewable biomass source. Has an annual aboveground productivity of ≈ 30 t/(ha*yr) dry wt (in temperate climates) according to Reed (1995).The range of annual aboveground productivity according to Lakshman (1987) is 3.8 - 52.7 t/(ha*yr) dry wt. Annual biomass production (growth rates) ranges between 5.7 - 93.4 t/(ha*yr) dry wt depending on nutrient supply, site and climate (Vymazal, 1995; in: IWA, 2000)

Typha latifolia shows highly versatile utilization options:

- Fuel source (direct combustion), e.g. as heating fuel, due to the high energy content (calorific value) of the biomass, comparable to conventional fuel sources

- Can be used for agricultural purposes, e.g. as additional material for composting

- Can be used as feed for cattle due to the high crude protein and DOM content when growing in nutrient-enriched wastewaters (Lakshman, 1987, 1994).

Harvested leaves and stems have versatile utilization options:

- building material, e.g. thatching and roof materials,

- Weaving material, e.g. mats, hats, chairs, etc.,

- Raw material for paper making (source of fibre),

- Many other utilization options, e.g. insulation material, rayon production or packing material (Rook, 2004; Wissing, 2002)

vi) Pennisetum purpureum (Napier grass)

Common name	Napiergrass, elephantgrass, mfufu
Scientific name (genus / species)	*Pennisetum purpureum*
Family	*Poaceae (Gramineae)*

Distribution, traits and ecology

Native to subtropical Africa (Zimbabwe) and now introduced into most tropical and subtropical countries

It's perennial and rhizomatous and grows in dense clumps (NewCROP, 2005). Normally grows to a height of up to 4 m; however, 6 - 7 m is possible (USDAIPIF, 2005). The species shows very fast, rapid regrowth rates after harvesting and strongly responds to nutrient supply (FAO, 2006). It reproduces mainly vegetatively, while generative reproduction is usually low due to the poor seed production. Has deep, extensive and vigorously growing root and rhizome system (FAO, 2006) and forms dense, pure stands that can out-compete other vegetation (USDA-IPIF, 2005).

The plant naturally inhabits moist grasslands and forest margins and grows better in full sun, but tolerates semi-shade conditions (FAO, 2006). Its pH tolerance is 4.5 - 8.2 (NewCROP, 2005). No sufficient data is available on salinity tolerance. The species does not tolerate prolonged inundation but tolerates drought periods quite well when established due to the deep root and rhizome system (FAO, 2006). *Pennisetum clandestinum* cannot be used in SFCW since it is not tolerant to prolonged inundations. The best performance was achieved in Taiwan in a gravel bed system (Yang, 2001, in: Kivaisi, 2001) for treatment of primary sewage.

Evaluation of existing case studies

In a pilot scale study conducted by Tayade (2005) near Bombay, India (subtropical climate, ≈ 19 °N), *Pennisetum clandestinum* was planted, together with *Typha latifolia*, in a horizontal subsurface flow system for treatment of primary treated municipal wastewater, high removal efficiencies were observed as follows:

BOD: 85 percent (mean influent conc.: 152 mg/L)

TSS: 83 percent (mean influent conc.: 144 mg/L)

The influent concentration corresponds to low strength domestic raw wastewater.

Productivity and utilisation options

A highly productive species; one of the highest yielding tropical forage grasses (NewCROP, 2005). Biomass and forage yields depend on fertility, moisture, temperature and management (harvesting); common and typical yields according to Cook (2005) are between 10 - 30 t/(ha*yr) dry wt.

Other recorded yields reported of annual productivities that are much higher (up to 85 t/ha dry wt per year) than the range mentioned above. However, such high biomass yields can only be obtained under ideal conditions: use of nitrogen fertilizers, harvesting three or four times a year and optimum climatic conditions (much rainfall and warm temperatures), (FAO, 2006; NewCROP, 2005).

The species is one of the most valuable forage and silage crops in the tropics with high dry matter yields:

- Can be made into nutritious silage of high quality and is highly palatable to animals,

- Young stands can be made into hay of good quality,

- Widely used for the production of dehydrated grass pellets in Taiwan. (Cook, 2005; FAO, 2006)

-Can also be used for paper making (NewCROP, 2005).

-Has a very high potential as a renewable energy crop (NewCROP, 2005).

2.3 GIS APPLICATION FOR KENYA

The rapid increase of the population in Kenya has led to a lot of pressure on the natural resources including water. There is a lack of information in supporting a monitoring process. This has set the need for an integrated and efficient information system particularly to assist in environmental protection.

2.3.1 DATA ANALYSIS

2.3.2 ASSEMBLING APPROPRIATE DATA

The purpose of environmental application for Kenya is to analyse the suitability of different areas of the country for the establishment of CW. Data sets on land use, land availability, water bodies, settlement and population density were identified as being most useful in developing and mapping areas suitable for the establishment of CW.

POPULATION DENSITY MAP

This is useful to assess the population distribution across the country. The map is readily available but more detail and accuracy is needed. It is based on the 1999 national census data when the total population was around 30 million. According to the economic survey of 2008, Kenya's population was projected at 37 million. Most of the population is concentrated in the agriculturally fertile areas with adequate rainfall

Land use

Current land use determines whether land will be available and affordable for establishing CW. The current and future use and values of adjoining land should also be considered as it will affect the suitability of a site for CW.

Urban areas

Land in urban areas is too expensive and would not be viable to establish a CW in these areas. Furthermore this study focuses on rural and peri urban areas only. However, the data available does not differentiate between large cities and smaller urban areas which tend to have very different population densities.

Areas of savannah and grassland

Savannah and grassland areas are usually arid and semi arid. Rain falls infrequently, usually only around April or October, and quite sporadically from year to year. Combined with hot temperatures and extreme evaporation the area is unsuitable for agriculture but the region best suited to nomadic pastoralism. The population in these areas lacks water supply and keeps moving from place to place in search of water. High rates of evaporation affect the function of a CW since most of the water would evaporate.

Protected areas and forests

National parks, game parks, mangroves and most forested areas fall under the government. These areas have no human settlement. Legal permits which are required before a CW can be established would not be granted for these areas. Forests are major catchment areas and river sources and are protected by law.

Agricultural types and areas

Since 80percent of Kenyans rely on agriculture it's a good indicator of human distribution and settlement. The good soils and climate also indicate that the areas would be suitable for wetland plants. Source of waste water (from households) for treatment in the CW should not be far from the site where the CW is located.

Bare areas

Areas devoid of vegetation are an indicator of bad soils, climate, poor rainfall and lack of human settlement. This means that they would be unsuited for CW development.

Water bodies and wetlands

Lake Victoria is the largest water body in Kenya. It's situated on the western part of the country and that explains the high population settlement in the adjacent area. The locals engage in fishing activities and farming for their livelihood. Water bodies and rivers supply water from human and agricultural needs and also influence settlement.

It is important to ensure that the area is not already a wetland: not all wetlands have standing water throughout the year. Wetlands should be conserved and are protected by international treaties and conventions.

PROCEDURE

- A gross density of above 260/km^2 and less than 2753/km^2 is selected from the population density map. A lower density indicates that the area in consideration is in the semi arid and arid areas where the livelihood is mainly nomadic pastoralism. A population density greater than 2753 indicates an urban area.

However suburbs around the cities have a lower gross density than that which is prevalent in the urban areas. This criteria ends up classifying the suburbs as rural areas.

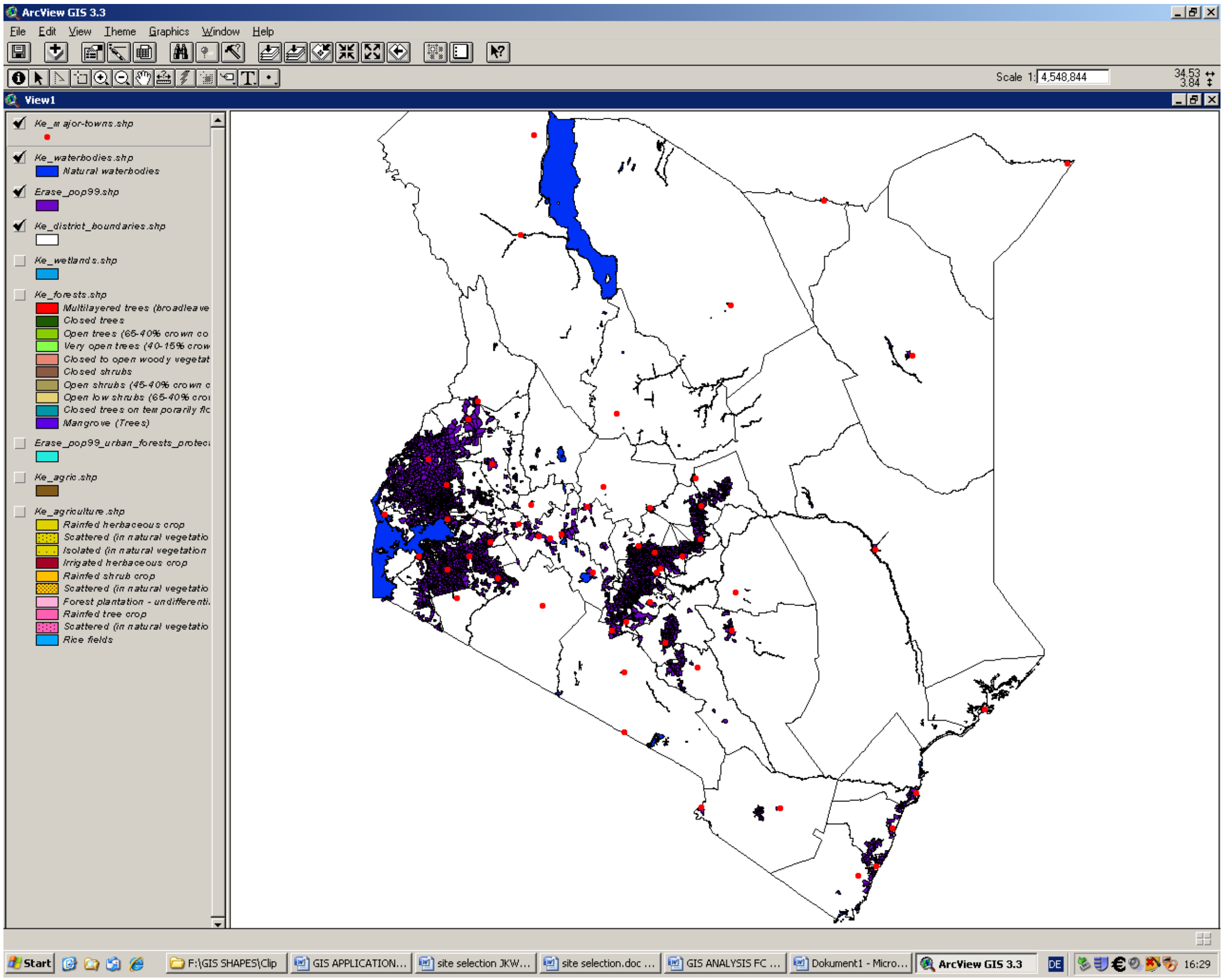

Fig 2.8. Human population distribution in relation to water bodies and urban areas in Kenya

- Areas in which no settlement is expected or allowed are erased from the map. These areas include wetlands, protected and bare areas, water bodies and wetlands.(fig 2.9 below)

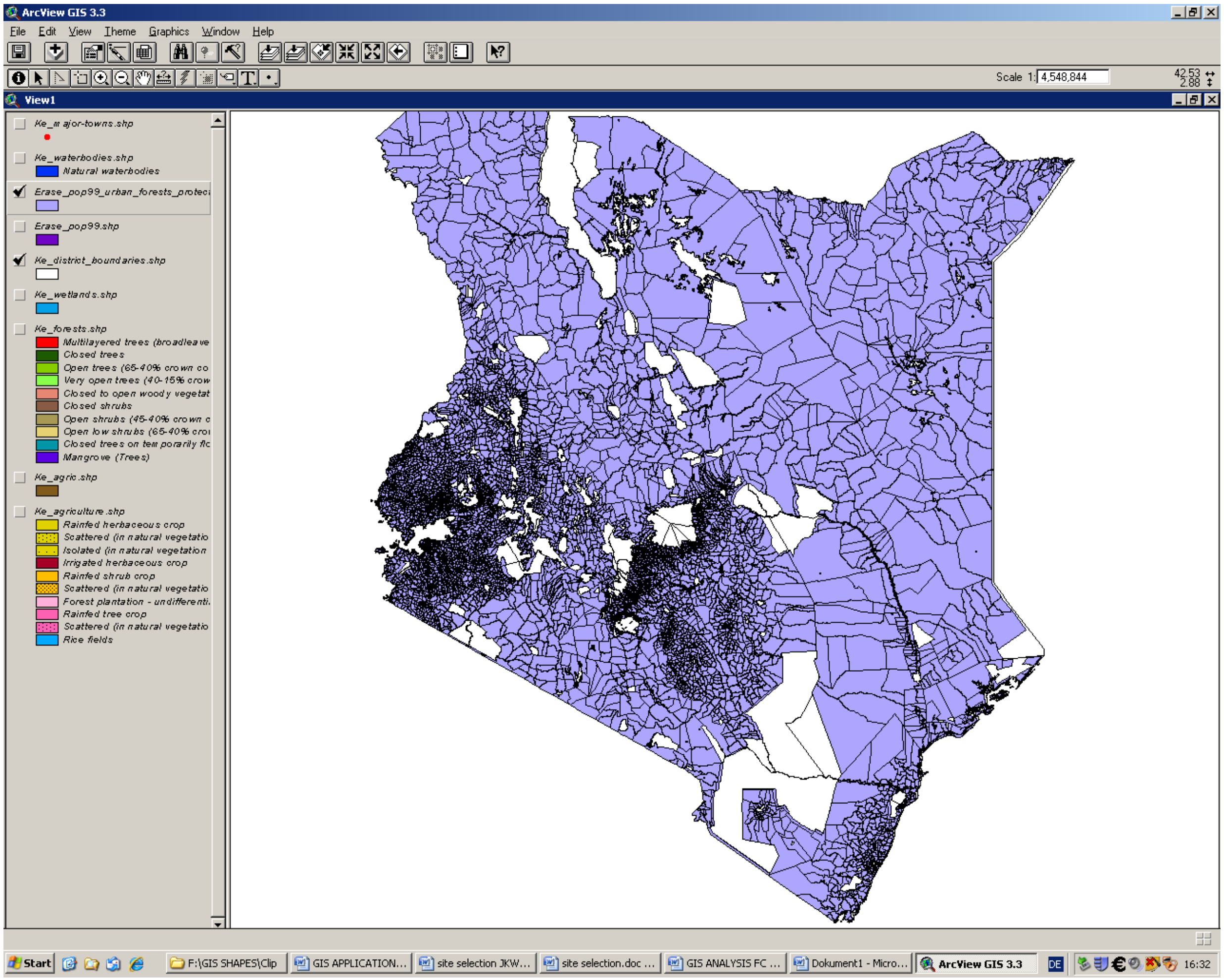

Fig 2.9 .Resulting map of erasing areas unsuitable for CW

- Inorder to discern relationships between agricultural areas ,gross density and suitability of an area for CW, the map in fig 2.9 is used as an overlay on the agriculture map and then clipped based on the agric map. The resulting map shows the sites suitable for CW in Kenya

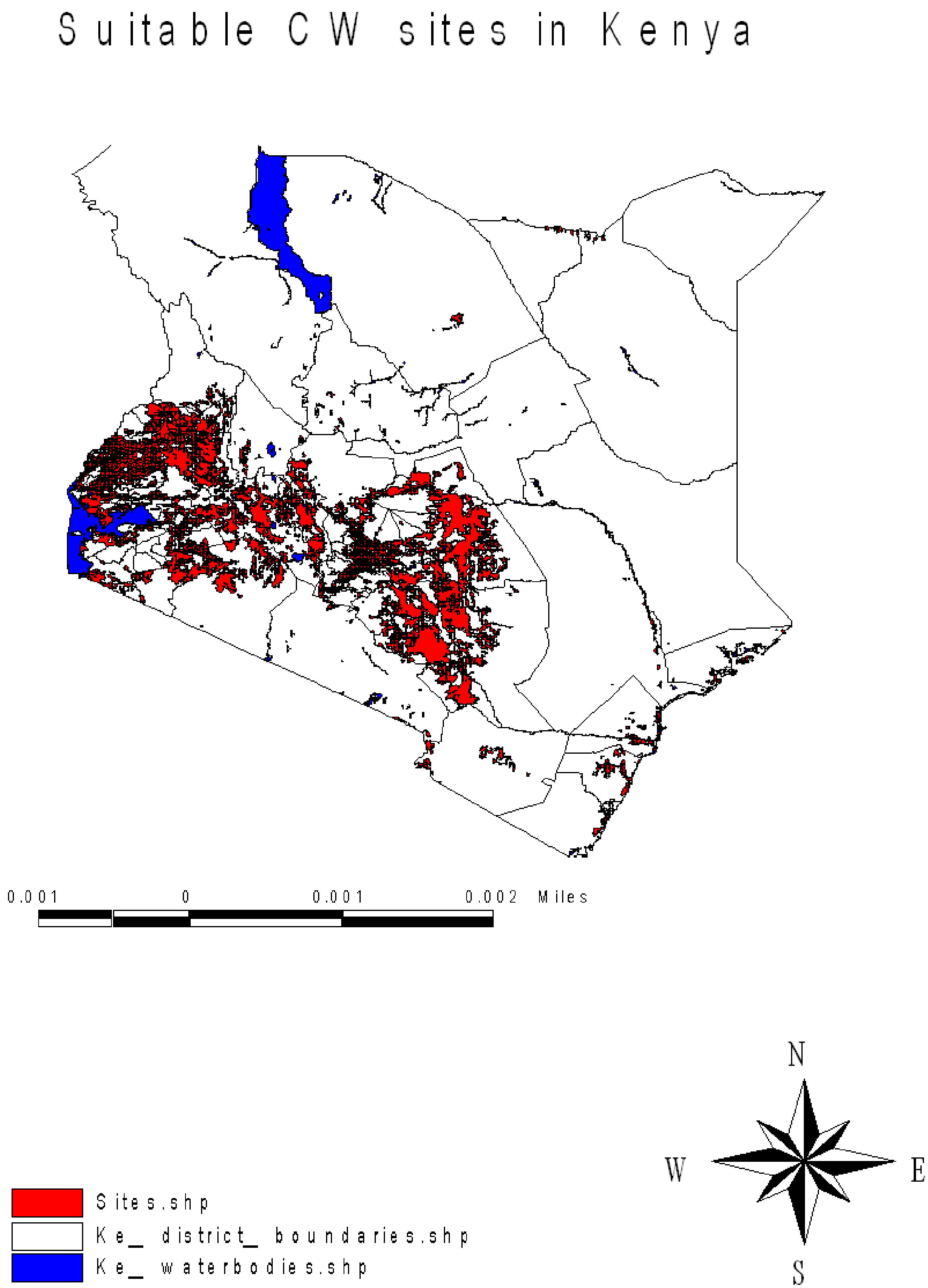

Fig 2.10 suitable ares for CW in Kenya

3. DISCUSSION

3.1 METHODOLOGY

This study involves two different approaches: literature study and digital mapping conducted at the University of Kiel within the period of Oct 2008 and March 2009. The first step is a literature study, while the second step is conducted by using GIS software.

Literature Study

This step involves investigation and evaluation of CW, wetland plants, grey water treatment and reuse, and the Ecosan concept. Ecological sanitation (ECOSAN) is a new paradigm in sanitation that recognizes human excreta and water from households not as waste but as resources that can be recovered, treated where necessary and safely used again.

The literature that is used in this study includes numerous case studies and practical applications throughout the world, full-scale as well as pilot-scale treatment systems, practical experiences and reports. The sources can be classified into two main categories: 1) Published literature, and 2) Conferences and workshops. The published literature discussing CW is mainly limited to papers published during the 90s in the journals of Water Science and Technology e.g. Kadlec and Knight (1996), Reed (1995), and Vymazal (1998c) and Ecological engineering e.g. Mitsch (1994). This is due to the fact that research efforts on CW and their use, increased both in the US and Europe in the late 80s.

International conferences have been convened to present the findings of CW research from almost every continent. Conferences and workshops, particularly all the biennial international conferences under the auspices of the International Association of Water Quality (IAWQ: Wetland systems for water pollution control) and INTECOL's International Wetlands Conferences, are the main sources for this study. The proceedings of these conferences are available in a variety of journals such as Water Science and Technology and Ecological Engineering, in books, e.g. Moshiri (1993) and Hammer

(1989), and also in the Internet. Important, symposiums that concentrated on the Ecosan concept have been held in Germany (2000 and 2003).

SANDEC, the Department of Water and Sanitation in Developing Countries at the Swiss Federal Institute of Aquatic Science and Technology (Eawag) has published reports on grey water management. Of note is one report that compiles international experiences in greywater management on household and neighborhood level in low and middle-income countries.

Digital Mapping

The digital mapping is conducted in the University of Kiel. There are several steps involved in this method. A Base map by the World Resources Institute (WRI) will be used. The scale to be used is 1:3000 000 (according to www.wri.org). The base map to be used is a topographic map. To delineate possible areas for CW development, the following information is needed:

i) Administrative boundaries

Enables the identification of protected areas i.e. historical sites, National parks game reserves and urban areas which should be avoided.

ii) Demography (population densities, income/livelihoods, etc.)

Identify rural areas with populations large enough to require CW and also differentiate between Peri and rural areas.

iii) Rainfall distribution

Water availability and distribution especially in rural areas is determined by the amount of rainfall. More than 80 percent of Kenya is arid and semi- arid and has a very low population. Rainfall in Kenya is closely linked to the livelihood of its citizens and the health of the nation's economy.

iv) Ecosystem types

This will help to identify unsuitable for the establishment of CW e.g. urban areas, forest, bare land, arid and savannah and grassland areas.

iv) Surface water distribution i.e. lakes ,rivers

This determines water supply especially in rural areas. Areas with piped water are preferable. Open surface water is the major source of drinking water for Kenyan households, almost all of them in rural areas. Others in the rural area rely on groundwater for their drinking.

This information will be obtained from various sources i.e. the Kenya National Atlas 2003, WRI, UNDP, USAID, Kenyan data papers, etc.

3.2 CONSTRUCTED WETLANDS FOR KENYA

CW have a potential to play an important role in wastewater management and improving the livelihood of the people. However their design, performance and potential for wastewater reuse is critical to the overall realization of this potential(Raymer, 2006). CW are not only effective and reliable, but also simple and inexpensive to construct, operate and maintain should be promoted. Their use can help alleviate the problem of discharging untreated or partially treated wastewater into aquatic systems and provide water can be re-used for various purposes e.g. agriculture. This makes them part of the sustainable development approach to waste management (Oketch, 2006).

Generally, comparative performance evaluation of CW is not possible, due to variations, such as inflow characteristics, monitoring conditions and methods, design consideration, such as hydraulic loading, detention time, wetland sizing; vegetation, climatic conditions, substrate and site conditions(Mungasavalli and Viraraghavan, 2006). However, investigations show that subsurface flow (SSF) systems are more effective in removal of wastewater pollutants whereas less area is required (Herrs, 2006).

In tropical areas such as Kenya SSF systems is the type of choice, in particular because:

- No direct contact between water column and the atmosphere
- It eliminates the problem of mosquito breeding and hence risk of mosquito-borne diseases such as malaria
- Further, SSF are more effective in removal of wastewater pollutants
- Higher removal of organic matter, SS, pathogen and other pollutants

Demonstration projects on CW by WIO-LAB in East Africa (Kenya, Tanzania and Seychelles) has come to the following conclusions (WIOLAB, 2008):

- The medium sized projects in Kenya and Tanzania are cost effective methods of waste water management. The treatment systems as demonstrated cost approximately 5US $ per person investment (excluding the related sewage infrastructure), as opposed to mechanised systems such as activated sludge which may require 10 times or more this value
- Maintenance and operation are relatively simple and cheap
- Tropical wetlands are considerably more effective than non-tropical systems. BOD_5 removal rates achieved in Tanzania are factor 10 higher than standard literature values. Consequently, wetland size maybe reduced without loss of efficiency.
- In SSF systems, the most expensive component of the CW is the substrate and contributes to 60-70percent of the total investment costs

HFS are frequently applied in situations where treated greywater is planed to be reused in irrigation or where water quality requirements for direct discharge into surface water have to be met(Morel and Diener, 2006). For the Kenyan situation the HFS would be a preferable option over the VFS because nitrification is not necessary in the treatment of grey water for reuse in agriculture. The nitrates present in the waste water will provide valuable nutrition for the plants. On the other hand the VFS will require a pump or siphon for a well functioning pressure distribution. Expertise design is also required for design, construction and monitoring which in turn increases costs (Morel and Diener, 2006)

Biosolids wetlands commonly referred to as the French System would also be an ideal option for Kenya. This system has advantage since it treats raw waste water and requires only 1m^2/person. The effluent obtained thereof would then be used for a grey water garden.

3.3 WETLAND PLANTS

Numerous wetland plants are potentially suitable for waste water treatment in CW. Evaluation for plant suitability for Kenyan CW was based on existing studies. These studies have mainly focused on areas where CW have existed for a long time especially in Europe, North America and Australia. However, systems have now been constructed and tested in sub-tropical and tropical areas, especially south Asian and Southeast Asian countries e.g. China, India, Indonesia, Nepal and Thailand, but also a few in tropical Africa.

Most of the developing countries (Kenya included) have warm tropical and subtropical climates and these regions are known to sustain a rich diversity of biota that may be used in wetlands. Information is however limited concerning tropical plant species suitable for sustainable CW development (Kivaisi, 2001).

Generally, suitable wetland species should be perennial with a life cycle of more than one year or two growing seasons to ensure the sustainability of the CW system. Their ability to produce by vegetative means also ensures easy propagation and persistence. Among the plants evaluated for this thesis seven plants were eventually selected and can be recommended for use in CW. Effort was made to include other species apart from the commonly used species namely *Cyperaceae, Poaceae* and *Typha sp.*

Among the plants found suitable for CW in Kenya included six emergent macrophytes. These plants included *Typha domingensis*, *vetiveria zizaniodes*, *Pennisetum clandestinum, Phragmites mauritianus*, *Typha latifolia*, *Pennisetum purpureum*. The list is however not exhaustive and does not include *Cyperus sp*. *Cyperus* is the most commonly used emergents with a lot of recorded success worldwide including Kenya. The species *Typha domingensis*, *Phragmites mauritianus and Typha latifolia* have already been successfully used in Kenyan CW.

All the selected wetland plant species have important characteristics that make them suitable for wetland treatment. These common characteristics include:

- **Fast growth rate and large standing biomass**

For waste water treatment wetlands, the particular species selected are of less importance than establishing a dense stand of vegetation. Any species that will grow well may be chosen. (EPA et al., 2000). A well established underground system is also important (Brisson and Chazarenc 2008). However plant productivities can only be effectively compared within a definite climate zone. Productivity of plants is found to be highest in the tropics and it's with this in mind that it is assumed that any given productivity in a certain climate zone would eventually be higher in Kenya which lies in the tropics.

- **Local availability**

Appropriate choice of species adapted to tropical environments is of great significance (Kivaisi, 2001). For CW treating waste water, native local species should be used because they are adapted to local climate, soils and surrounding plant and animal communities and are likely to do well (EPA, 2000). Using plants that grow locally increases the likelihood of plant tolerance to local climatic conditions, pests, diseases, survival, and acceptance by local officials.

- **Potential for remediation**

Though numerous wetland plant species have been used in CW, little research has compared different plant species or species mixtures in promoting treatment (Coleman et al., 2000, Gersberg et al 1984). High plant biomass and growth rate have been used as good indicators for potential remediation (EPA et al., 2000; Tanner, 1996). Treatment efficiency is nearly on a similar level for all plant species and the differences in treatment performance are most not significant (Kadlec and Knight, 1996).

Species efficiency in pollutant removal is difficult to compare experimentally but it is nevertheless important (Brisson and Chazarenc, 2008) and needs further investigation (Coleman et al 2008). Studies by Coleman (2000) demonstrated significant differences among plant species in treatment of waste water and suggested that polycultures may perform better than monocultures. The case of splash wetland in Kenya also reveals a thrilling prospect in use of polyculture systems in wastewater treatment (Nyakang'o and Van Bruggen, 1999). Net nutrient removal by direct plant uptake is generally a relatively small proportion of total removal (Tanner 2001) and its only of quantitative importance in SFCW (Brix, 1997) and is often considered minor in SFF systems (Mander et al,2003).

- **Biomass utilization**

Productivity and versatility in biomass utilization options of macrophytes species are crucial decision and design factor for the choice of suitable plant species as differences in term of wastewater treatment efficiency are mostly not significant. At present it's not a widespread practice to harvest and use the biomass of CW for secondary purposes. However, biomass utilization is a feasible option in tropical wetlands which have high productivity and continuous growing season (Denny, 1991).

In the tropics where growth rates are high, the frequency and hence the cost of harvesting has to be considered. Use of very fast growing plants e.g. the water hyacinth (*Eichhornia crassipes*) that requires frequent harvesting is not likely to be feasible. Economic utilization of excess biomass and frequent harvesting costs should be well assessed before choosing such a plant (Kivaisi, 2001).

- **Cost of plants**

Most of the collected data exhibit similar conclusions concerning the slight cost differences between different wetland plants. Therefore costs in this case should be of less concern than other criteria. Moreover, the plants chosen are locally available hence cost differences are slight and should be of less concern (Herrs, 2006).

4. TOWARDS SUSTAINABLE WASTE WATER MANAGEMENT IN KENYA

Current situation

The use of CW for wastewater treatment in Kenya is a relatively new approach to waste disposal, which hasn't been well exploited even though as a community-based concept, CW have almost limitless potential (Raymer, 2006).

However, the efficiency of CW in purification of domestic wastewater (Nyakango & Van Bruggen, 2001; Nzengya & Witshitemi, 2001), industrial wastewater from pulp and paper effluents (Abira *et al*, 2003), sugar milling effluents (Bojcevska and Tonderski, 2006) has been investigated. These systems were successful. Maturation of all the Kenyan CW has been observed to take less than a year compared to the 3-5 years required for European conditions, thanks to the good tropical conditions (Raymer, 2006).The 0.5 ha Splash Carnivore wetland designed for 1200 has shown satisfactory removal efficiencies of 98, 67–99, 94–98, 99.4–99.9, 87–90 and 88 percent for BOD, TSS, COD**,** fecal coliforms, TN, and TP respectively (Nyakang'o and van Bruggen, 1999).

At present a few fully operational CW exist in Kenya including:

- Suera flowers ltd CW which treats Run offs (containing several agrochemicals) are discharged from greenhouses (both storm and effluents)
- The splash Carnivore wetland which was installed in 1994 and handles up to 80 cubic meters daily from a busy restaurant and a recreational complex
- Nandi Hills tea factory CW which recycles agricultural waste and toilet effluent
- Kenya wildlife Service's headquarters CW in Nairobi, treats 55,000 litres of water to benefit wildlife in Nairobi national park
- Shimo La Tewa Prison, Mombasa - Kenya

- Mara Simba lodge, Masai Mara National reserve

Other fully operational CW obviously do exist, but little information is available about them. Green-water org, a company providing water and sanitation solutions claims to have installed a CW for a private house in Nyali, Mombasa. Among other installations the company has made are for industries, lodges, golf resorts, flower farms and residential estates (Green water, 2009).

GIS RESULTS

The GIS analysis shows that Kenya has a large potential for CW establishment. Around 3 percent of the country is suitable for CW establishment. These areas mostly lie on the fertile land that has most of the human settlement. About 75 percent of the population lives on only 10 percent of the land. Establishing CW at a community level in these suitable areas would go a long way in reducing the water crisis.

From the final map, it's not possible to prioritize areas in order of urgency of CW requirement. This is due to lack of valuable data for the analysis resulting to a map of low resolution. Knowledge and data is lacking on water sources for the locals, pollution levels, effective demand management system and social cultural acceptance to waste water reuse. The source of water for a household determines how much waste water is produced per household. The highest amount of waste water comes from households with piped water which inturn increases the likelihood of pollution and thus the demand for waste water management.

Kenya has a nature based economy and the presence of natural resources therefore determines population distribution. This in turn determines the areas suitable for CW establishment. The areas close to Nairobi in the central highlands support the highest population densities, with more than 600 people per square kilometer. Similar high densities occur in the western part of the country slightly inland from Lake Victoria. About 80 percent of the Kenyan population relies on agriculture and lives in the fertile and wet areas. About 75 percent of the population lives on only 10 percent of the land. Only 24 percent of Kenyans live in Kenya's rangeland Districts and are mainly nomadic pastoralists.

A high population in Kenya depends on Surface water Open surface water is the major source of drinking water for 29 percent of Kenyan households, almost all of them in rural areas. At the same time only about 71 percent of urban households and 19 percent of rural households have piped water. Agriculture is the main user of water and currently consumes about 80percent, while domestic and commercial use accounts for the rest (17 and 4percent respectively).

The Kenyan population continues to grow at the rate of 2.8percent putting more pressure on the limited natural resources including water. As water scarcity continues to bite, an increased population produces more waste water thus increasing pollution. There is an increased need for cheap efficient ways of water treatment that will also provide water for reuse especially in agriculture. Cw provide the appropriate solution for this rising need.

LESSONS LEARNT AND RECOMMENDATIONS

As a community based concept CW have a lot of potential in Kenya. According to WHO(2005), the main factors influencing willingness of the household to invest in improved sanitation services are comfort, convenience, prestige, reuse opportunities and of course costs. Therefore, various factors need careful consideration before CW establishment so as to ensure success and sustainability of the systems. These include cost, land availability, education, awareness, ownership and capital.

i) Cost

This includes development cost and maintenance. The overall costs of the system should not exceed the effective and/or perceived benefits by the user. The cost of a CW are site specific and vary considerably, depending on geology, degree of site slope, method of excavation, length of pipe runs, whether the work is done in-house or by a contractor and the local cost of materials particularly the substrate e.g. ballast or gravel(Raymer, 2006). A Kenyan company (Green water) estimates that the cost for a domestic reed bed system (for 4-6 people) would be about 250000Kshs (2475 €, at present rate). This represents the total cost for design and construction, but will vary depending on location, transport and exact design (Green water, 2009).

To lower some of the cost the system could be hand dug with pooled community labor. Siting should be on a relatively flat topography to minimize the construction costs. Utilizing local engineers helps in avoiding the high costs often related to international experts and consulting engineers. A pioneer group of local engineers can be trained who then train other local engineers. Typically, the media for HFS consists of sand, gravel or crushed rocks. The high cost of substrate can be reduced by using plastic (PET) bottle segments. The use of PET bottle segments as an alternative media has been demonstrated with removal efficiencies comparable, and in some cases superior, to that of conventional crushed rock (Dallas and Ho, 2005). In addition it is generally available free of charge or at a very low cost, the only expense being the labour required to cut the bottles into suitably sized segments.

ii) Land availability

Although land may be a limiting factor in dense urban areas, CW are potentially well suited to smaller communities where municipal land surrounding schools, hospitals, hotels and rural areas is not in short supply(Kivaisi, 2001). Some private land owners may also be willing to give their land for CW development. If land must be purchased, it will add up considerably to the capital costs.

iii) Education, awareness and local participation

Reuse based management systems will only be successful if based on an effective demand and socio-cultural acceptance (Morel and Diener, 2006). Potential beneficiaries of improved sanitation should be given an opportunity to decide whether to participate in a CW project, and they should be offered a range of feasible technologies with price tags so that they can express their preferences and their willingness to pay (Wright, 1997).

Most systems failures are caused by inappropriate operation and maintenance, sometimes resulting from lack of system understanding by the owners. Therefore, simple systems requiring minimal operations and maintenance should be prioritised and beneficiaries trained on appropriate system management. They should be involved in planning and implementation (Morel and Diener, 2006)**.**

iv) Ownership

The need for local ownership is even more important, since it not only affects sustainability and chances of success, but also opportunities in replication. All relevant stakeholders are involved throughout the process of identification of current need for waste water management, design, feasibility study and implementation.

When establishing CW, involving local engineers i.e. existing local experience which provides enormous advantage among others in terms of potential for replication and adaptability to local circumstances and culture.

v) Financing

When there is a demand for waste water reuse management systems users are usually willing to pay for those benefits. The demand driven approach of strategic sanitation provides a way to think through how the costs of sanitation can be shared. User willingness to pay is usually high in peri urban areas and should be tested before considering cross-subsidies from other user groups or external provision of funds. In principle, households should fully repay investment and operational maintenance costs to ensure the sustainability of the system. Free or highly subsidized projects are likely to fail in the long run when false expectations have been raised regarding the cost of the system (Winblad and Simpson-Hebert, 2004).

User payments should not necessarily be in cash but can be in form of services offered to the project. Household borrowing to finance user payments is acceptable and the most effective systems have been those that insist on front-end payments for construction and access to the service. In cases where it’s not possible to obtain individual credit, groups can be formed which later organize collective payments to pay off the credit (Wright, 1997).

Recommendations for a wider promotion and acceptability of CW in Kenya

CW systems may, for the user and public officials, seem more complex than convectional waste management systems, and they do place more responsibility for appropriate functioning on individual families and local communities. Peri-urban and rural planning, promotion and support will have fundamental differences in the success or failure of the systems (Winblad and Simpson-Hebert, 2004). Inoder to increase the chances of success various factors need to be taken into consideration.

- Education and heightened awareness promotion programmes concerning both natural and constructed wetlands should be implemented at all levels. The local leaders and developers need to be educated on this new approach of waste water management. This may require visits to other rural or peri-urban communities that have established CW so that the leaders and developers can see CW in operation for themselves.

  Promotion to the public might involve meeting with smaller political units to seek their feedback on the proposal and determine what further information campaigns will be required for the public in general. A public education campaign involving the media needs to be designed and implemented before construction begins. Demonstration units should be built in strategic locations so that locals can see what is coming.

- There should be an advocacy of methods of waste disposal that are not only cheap and highly effective like CW but also which promote resource conservation and environmental protection. With the support of politicians, religious and local leaders, the media can be used as an effective tool to attitude change where people now value the environment even much more.

Subsidies for pollution control equipment and funding for low cost waste technologies like CW should be encouraged by the Kenyan government.

- Increased financial support for research and training of wetland specialists aimed at understanding the complex processes occurring in existing CW in Kenya. Funds can be sought from the private sector. Companies traditionally offer funding for business related studies. They should be encouraged to also fund environmental experts who will help their companies with waste disposal that meets the required national environmental standards. Hotels and lodges would also be willing to invest in sustainable waste water management which in turn improves their ecorating hence attracting guests.

- Government regulations and legislation need to be enforced in order to ensure that polluters meet environmental standards of waste discharge into water systems. The National Environment Management Authority (NEMA) a government parastatal exercises general supervision and co-ordination over all matters relating to the environment. The Authority implements all policies relating to the environment as outlined in the Enviromental Management and Coordination Act (EMCA). EMCA 1999 outlines the "polluter-pays principle" which states that the cost of cleaning up any element of the environment damaged by pollution, compensating victims of pollution, cost of beneficial uses lost as a result of an act of pollution and other costs that are connected with or incidental to the foregoing, is to be paid or borne by the person convicted of pollution under this Act or any other applicable law.

  While relevant environmental laws do exist, enforcement is usually weak. The present legislation on water pollution lacks concrete regulatory measures and enforcement mechanisms. This leaves polluters with no motivation to search for cheaper ways of controlling pollution (Oketch, 2006).

- Work in partnership with local communities to ensure proper embedment of technology in the local setting and sustain its functioning. Participation of the intended users of the CW at all stages from planning to implementation is important for the success of the system. Its generally best to work through with local grassroots organizations that are successful and well known within the community (Winblad and Simpson-Hebert, 2004).

vii) Future research needs

- There is a need for further GIS analysis to produce maps with a higher resolution that can be used to effectively determine exact areas for CW establishment
- The effect of high seasonal variability in precipitation with prolonged dry months and heavy rains during the rainy season on CW performance
- Further investigations are needed to identify and characterize tropical plant candidates in terms of their tolerance to high nutrient levels and suitability in regional climatic conditions and wastewater types
- There is need therefore, to investigate the ways residents can minimize the risks of the much valued grey water and maximize the benefits at no additional cost
- The long term effect of grey water irrigation on the soil

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