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Nature's Answers to the Sanitation Challenge: The Application of Constructed Wetland Technology for Wastewater Management

Abstract: The coastal zone of the Western Indian Ocean region is the site of most major cities, harbours, industries and other socio-economic infrastructure, which increasingly affect the environment. One of the technologies being promoted by UNEP-GPA WIO-LaB project is that of constructed wetland treatment systems. This note describes several completed demonstration projects. The projects have led to a number of important lessons learnt, covering: cost-efficiency, learning from experience, stakeholder buy-in and ownership and technology. The note also addresses replication issues, including selecting the right technology for the right conditions, ensuring adequate stakeholder buy-in and building upon experience. These demonstration projects are not the first examples of such systems in the WIO region, however they have made an important contribution to extending the knowledge and understanding of this promising technology to other countries in the region. Furthermore, with the establishment of a regional center for wetland technology at the University of Dar es Salaam, the projects are expected to have very important spin-off, in providing countries in the region with an effective and cost-efficient alternative to existing wastewater treatment technology.

Peter Scheren

Peter.Scheren@unep.org

Addressing Land Based Activities in the Western Indian Ocean

Nature's Answers to the Sanitation Challenge: The Application of Constructed Wetland Technology for Wastewater Management

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PROJECT DESCRIPTION

The Project entitled "Addressing land-based activities in the Western Indian Ocean" (shortly referred to as "WIO-LaB") addresses some of the major environmental problems and issues related to the degradation of the marine and coastal environment due to land-based activities in the Western Indian Ocean (WIO) region. The project involves eight countries in the WIO region (Kenya, Tanzania, Mozambique, South Africa, Comoros, Madagascar, Mauritius and Seychelles) and is executed jointly by the UNEP/Nairobi Convention Secretariat and the United Nations Office for Project Services (UNOPS). The total duration of the WIO-LaB project is 4 years (2005-2008). Its total budget of 11,413,465 USD is contributed by the GEF, the Norwegian Government, UNEP and participating countries.

The WIO-LaB project is designed to serve as a demonstration project for the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA/LBA). The project has three main objectives: 1) Improve the knowledge base, and establish regional guidelines for the reduction of stress to the marine and coastal ecosystem by improving water and sediment quality; 2) Strengthen the regional legal basis for preventing land-based sources of pollution; and 3) Develop regional capacity and strengthen institutions for sustainable, less polluting development.

A key part of the WIO-LaB Project is to provide assistance to participating countries to implement demonstration projects at a number of hotspots and sensitive areas in the WIO region. These projects are intended to demonstrate innovative, appropriate and cost-effective technical and managerial approaches for addressing the impacts of land-based sources and activities. One of the focal areas of these demonstration projects is the challenge of addressing the need for proper sanitation and wastewater management in the increasingly populated but socio-economically still poorly developed coastal urban centers of the region.

ISSUES AND CHALLENGES

The issue

The marine and coastal environment in the Western Indian Ocean (WIO) is of high ecological and economic value. Its natural bounties, including beaches, mangroves, coral reefs, plant and animal life are the basis for the growing tourism sector, attracting visitors from over the world. Its marine waters, and in particular its continental shelves, coastal margins, lagoons and estuaries are important fishing grounds. The total economic value of the goods and services provided by the natural environment in the region is considerable, with estimates ranging between 4.6 and 26.1 billion US$ annually.

However, the coastal zone of the WIO region is also the site of most major cities, harbours, industries and other socio-economic infrastructure, which increasingly affect the environment. Pollution from domestic, industrial and agricultural sources causes the degradation of water and sediment quality, resulting in loss of biological diversity, human health problems and a reduction in fish stocks. Countries in the region currently lack both the capacity and regulatory framework to adequately manage these environmental threats.

The challenge

One of the challenges being addressed by the WIO-LaB Project is the need for appropriate (low-cost) approaches for sanitation and wastewater management. The majority of WIO countries are classified as 'poor' by World Bank criteria. At the same time these countries are also experiencing rapid population growth and urbanisation in coastal areas. The consequent inadequacy of appropriate wastewater management infrastructure leads to severe consequences for the health and living conditions of the population as well as the general quality of the environment.

The experience
UNEP, through the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA), is an active promoter of the application of appropriate low-cost technologies for wastewater management in developing countries. One of the technologies being promoted by UNEP is that of constructed wetland treatment systems. UNEP, through its International Environmental Technology Center (IETC) has been actively promoting the constructed wetland technology, among others through the development of various tools, including guidelines, manuals and models for wastewater management (http://www.unep.or.jp/ietc/ws/publications.asp).

Practical applications of the technology are furthermore being demonstrated in Eastern Africa, within the framework of the Nairobi Convention and in particular through the UNEP-GEF Project 'Addressing Land-based Activities in the Western Indian Ocean (WIO-LaB)'; Using experts at the Center for Wetland Technology of the University of Dar es Salaam in Tanzania, the WIO-LaB project is in the process of implementing several constructed wetland treatment schemes in Eastern Africa.

The first of these demonstration projects is implemented in the Town of Chake-Chake in Pemba Island, Tanzania. The project, which is scheduled to be fully commissioned by June 2009, will serve a population of 4,000 people (650 households), or approximately half of the population of Chake-Chake. The project employs a system for collection of wastewater from households, restaurants, mosques, public and others commercial institutions in Pemba through an innovative modular sewerage system, using piping material donated by the European Council for Vinyl Manufacturers as part of a private sector participation scheme. The sewage thus collected will be lead into a coupled anaerobic lagoon – subsurface flow constructed wetland treatment system, which will be located on the outskirts of a natural mangrove wetland area, therewith expected to blend in very well wit the natural environment. Construction itself will in part be based on labour provided by the local community, which has also attributed 60,000 US$ in cash co-financing from its community development funds; a clear sign of local ownership and engagement. Once operational, the project is expected to make an important contribution to the health and livelihood of the local communities, as well as to the integrity of the marine ecosystem.

A second constructed wetland project is currently being implemented at Shimo La Tewa Prison in Mombasa, Kenya. The project, which is being implemented in cooperation with the Coast Development Authority (CDA), the National Environment Management Authority (NEMA) and the Prison Service (KPS) of Kenya, consists of a sewerage system and central septic tank coupled with a subsurface flow constructed wetland system. Wastewater and sludge generated will be used for aquaculture (fish ponds) and for agricultural purposes. The system will be commissioned by November 2008, from there on serving the 2,500 inmates and 1,500 staff population of the prison. In addition, a smaller but more innovative scheme will be implemented in the adjacent 'boy's prison', employing more advanced reuse schemes such as biogas production, ecosan toilets and rainwater harvesting. Once in place, the wastewater treatment system will substantially reduce the pollution of Mtwapa Creek, which supports a diversity of habitats such as mangrove forests, coral reefs and seagrass beds and is of large socio-economic importance for the surrounding population.

A third constructed wetland project is currently being designed for the purpose of serving high-density low-cost coastal housing schemes in the Seychelles. The scale of this demonstration project is much smaller (in the order of 150 persons), but very appropriate to the situation in Seychelles where numerous of similar housing complexes are requiring similar interventions.

RESULTS AND LEARNING

Although still in a stage of implementation, the demonstration projects have already led to a number of important lessons learnt:

Cost-efficiency: The projects, in particular the mediums-size facilities in Tanzania and Kenya are examples of cost-effective methods of wastewater management. The treatment systems as demonstrated cost approximately 5 US$ per person in investment (excluding the related sewerage infrastructure), as opposed to mechanized systems such as activated sludge which may require 10 times or more this value. In addition, maintenance and operation are relatively simple and cheap. Finally, the use of constructed wetland treatment systems provides opportunities for re-use in agriculture, aquaculture and forestry, thus having the potential of allowing for cost recovery.

Learning from experience: The technology of constructed wetland systems has by been recognized as proven technology, in particular in more tropical climates. Fortunately, one of the global knowledge centers in the region, the University of Dar es Salaam in Tanzania, is located in the WIO region. Through a 12-year collaborative project between the University of Dar es Salaam, the Royal Danish School of Pharmacy (currently known as The Pharmaceutical University of Denmark) and the University of Copenhagen, the "Waste Stabilisation Pond & Constructed Wetlands Research Project", the University of Dar es Salaam has been building up an extensive record in this field of expertise, both at research level and as consulting engineers for practical cases. Several of such schemes are already functional, including in Iringa (Ruaha Secondary School and Kleruu Teachers College), Shinyanga, Malya and Bariadi prisons, Moshi Municipality, Kibaha and Dar es Salaam (household wetlands). Frame 1 provides an example of one of such existing projects.

The three demonstration projects build strongly upon these experiences, engaging engineers from the University in the design and supervision of the works. Building upon such existing 'local' experience provides an enormous advantage, among others in terms of (i) potential for replication, (ii) adaptability to the local circumstances and culture and (iii) cost-efficiency (i.e. avoiding the high costs often related to international experts and consulting engineers). The experience of the University of Dar es Salaam has meanwhile been internationally recognized, among others as co-authors of the joint UNEP-DANIDA commissioned Design Manual on Waste Stabilization Ponds and Constructed Wetlands.

Stakeholder buy-in and ownership: A crucial aspect of many projects is the buy-in/ownership of local stakeholders. In the case of the three WIO-LaB demonstration projects on constructed wetland treatment systems, the need for local ownership is even more important, since it not only affects sustainability and chances of success, but also opportunities for replication. In all three projects, therefore, effort has been made to involve all relevant stakeholders throughout the process of identification, design, feasibility study and implementation. The effects of these efforts are clearly paying back:

- The Chake-Chake wastewater project in Pemba, Tanzania, addresses a very important problem of the local community, which is faced by frequent blockages and resulting overflow of its open drainage system, which causes severe health risks as well as nuisance to the surrounding population. The project is therefore very much local-born and the local population actually contributes both in terms of labour force as well as through a cash co-financing contribution of 60,000 US$ made from the communities own social funds.
- The Shimo La Tewa addresses a pressing need of the Kenyan Prison Services (KPS), which is frantically seeking appropriate solutions for its wastewater management problems in prisons all over the country; KPS is currently in court on such cases, being sued by the National Environmental Management Authority (NEMA) of Kenya. Thanks among others to such local pressure, the project has been adopted as a demonstration project within the context of the National Prison Reform Programme, and budgetary allocations to implement similar schemes in other prisons in Kenya have been made. In addition, the Coast Development Authority is making plans to implement similar schemes in both new and old coastal development projects.
- In Seychelles, finally, the project addresses a problem that is prominently affecting the population: due to unfavourable geological structure and groundwater flows, the existing system of septic tank and drain fields is frequently malfunctioning, resulting in nuisance and health risk to the population.

Technology: There are various types of constructed wetland systems. The main distinction is, however, made between Free

Water Surface (FWS) and Sub-Surface Flow (SSF) systems. In FWS systems, the flow of water is above the ground, and plants are rooted in the sediment layer at the base of water column. In SSF systems, water flows though a porous media such as gravels or aggregates, in which the plants are rooted. A further distinction in types of SSF systems is made into Horizontal flow SSF (HSSF) and Vertical flow SSF (VSSF). From research and applications in Tanzania, a few important lessons learnt have become apparent:

(1) Tropical wetlands are considerably more effective than non-tropical systems. BOD_5 removal rates achieved in Tanzania are almost a factor 10 higher than standard literature values. Consequently, wetland size may be reduced without loss of efficiency.
(2) In tropical areas SSF constructed wetlands is the type of choice, in particular because it eliminates the problem of mosquito breeding and hence risk of mosquito-born diseases such as malaria.
(3) In SSF systems, the most expensive component of the constructed wetland is the substrate. The aggregates used contribute about 60-70% of the total investment cost.
(4) While constructing a wetland, care has to be taken that the contractor does not allow soil or other fine materials to be introduced with the aggregates, in order to avoid clogging of the system and reduction of performance. Noted should be here that people often have difficulty understanding that plants can grow on stones without any soil; most people would therefore allow some fines thinking that they are crucial for the growth of the wetland plants.
(5) Mass transfer in wetlands plays a very significant role. Several design components may be introduced to enhance such transfer; to do so, wetlands must be narrow or baffled in order to increase the interstitial velocity and thus improve the performance.
(6) Inlet and outlet works need careful design considerations. Care must be taken to ensure that the inlet distributes the inflow uniformly.

Case Study: Kleruu Teacher's College Wetland Project

The wetland is located at Iringa town and is serving a Teacher's Training College in Tanzania. Before the introduction of the Constructed Wetland system the college was treating its wastewater through a combination of a mechanical aeration system (Fig. 1) and a pond. However, operation of the mechanical system failed because of high costs of electricity and lack of regular maintenance. Fig. 2 shows the situation that resulted; the pond was malfunctioning, ignored, lacked de-slugging and released untreated effluent to the downstream communities.

Fig. 1: Malfunctioning Mechanical Aeration System

Fig. 2: Condition of the Pond before the intervention

A HSSF Constructed Wetland was installed to replace the pond. A baffled system was introduced, as seen in Fig. 3. The need to operate the mechanical system ceased and the condition of the wetland after full growth of the plants is as show in Fig. 4.

Fig. 3: Constructed wetland replaced the pond

Fig. 4: Constructed wetland after full growth

The performance of the installed constructed wetland is very promising, with a BOD removal rate of 90%, 76% in nitrate and 69% in heavy metals (cupper and chromium). The effluents therewith easily meet internationally accepted standards for effluents from wastewater.

REPLICATION

The key factors in implementing constructed wetland projects of nature implemented by WIO-LaB naturally follow from the key lessons learnt as presented above:

a. **Selecting the right technology for the right conditions:** In the case of the WIO-LaB demonstration project the most appropriate treatment system appeared to be the horizontal sub-surface flow constructed wetland system. It should be noted, however, that whereas constructed wetland systems may have great potential under the right conditions, they do not provide the ideal solution for all situations; for example, where space is the issue, conventional mechanical treatment may be preferable. Also, natural systems such as constructed wetlands, work best in warm climate. Furthermore, a key factor in the selection of the sub-surface flow alternative for the WIO-LaB wetland systems was the risk of health impacts related to mosquito breeding as may occur in free surface systems. However, since free surface flow systems are relatively easier to construct, as well as often cheaper, it may well be that under different circumstances such systems are the preferred alternative.
b. **Ensuring adequate stakeholder buy-in:** As for many development projects, a crucial aspect of constructed wetland projects is the buy-in/ownership by local stakeholders. Although the systems are relatively easy to operate, the risk of failures due to inadequate operation and maintenance are real. In many cases, such impacts are due to upstream factors, such as inappropriate use of sewers and drainage channels leading to sediment and even solid waste clogging the system. The users of the systems, mostly the general population, need to be aware of such risk and take precautionary measures to protect ‘their’ system. Regulatory measures may be applied, but control is difficult without the necessary level of self-regulation by the users; Assuring adequate ownership/buy-in by local stakeholders is therefore the issue.
c. **Building upon experience:** The technology of constructed wetlands has been quite rapidly evolving in recent times. Yet, there are still many uncertainties related to the optimal design and constructions. Using existing knowledge centers avoids making mistakes already made, so should be highly recommended.

It should be noted that the WIO-LaB project is actively promoting the replication of its demonstration projects. As for all WIO-LaB demonstration projects, the three constructed wetland projects therefore involve wide stakeholder participation (especially of the local community and institutions) in planning, decision making and implementation. The projects furthermore incorporate replication strategies that will ensure that the lessons learnt will be widely disseminated through various expert networks and learning alliances established within the framework of the Nairobi Convention. Several initiatives are currently already underway the projects, including:

- Design and implementation of constructed wetland systems in other prisons in Kenya is

- being considered as part of the Prisons Reform Programme.
- The design of a constructed wetland system, based upon the WIO-LaB demonstration project in Pemba, Tanzania, is currently being undertaken for the City of Toliare in Madagascar. This replication project is being supported by the Norwegian Government, with technical support being provided by Stavanger University.
- Several other initiatives for replication are also being considered in Tanzania and Kenya.

Finally, in order to ensure long-term sustainability of the regional center of excellence on constructed wetland technology at the University of Dar es Salaam in Tanzania, the WIO-LaB Project and Nairobi Convention Secretariat are supporting a new initiative by the University that is targeting the transfer of wetland technology for decentralized wastewater treatment through various dissemination activities as well as through the establishment of a business unit. The latter project has meanwhile attracted considerable financial support from the Swedish BIO EARN innovation fund.

SIGNIFICANCE

The WIO-LaB demonstration projects on constructed wetland technology are not the first examples of such systems in the WIO region. However, so far such experiences have been confined to Tanzania only, where several systems are already operational and extensive experience is available at the University of Dar es Salaam. The WIO-LaB demonstration projects have therefore made an important contribution to extending the knowledge and understanding of this promising technology to other countries in the region, the fruits of which are already visible: several initiatives for replication are currently already ongoing.

Furthermore, with the establishment of a regional center for wetland technology at the University of Dar es Salaam, the projects are expected to have very important spin-off, in providing countries in the region with an effective and cost-efficient alternative to existing wastewater treatment technology.

REFERENCES

WIO-LaB Website: www.wiolab.org

Contact details:

WIO-LaB Project Management Unit
Dr. Peter Scheren
WIO-LaB Project Manager
C/o UNEP/ROA Rm. A-130
P. O. Box 30552
Nairobi, Kenya
Tel: +254 20 7621270/1206/1250
Mobile: +254 722509186
Fax: +254 20 7623203
E-mail: wiolab@unep.org / peter.scheren@unep.org

University of Dar es Salaam
Dr. Karoli Njau
WSP & Constructed Wetlands Research Project
P.O. Box 35131
Dar es Salaam, Tanzania
Tel: +25522 2410368
Mobile: +255 754 296 993
Fax: +255 22 2410114
Email: knjau@udsm.ac.tz

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