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Improving Sustainability Concept in Developing Countries

Constructed Wetlands as a Sustainable Wastewater Treatment Method in Communities

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Abstract

Water scarcity and wastewater management are two major challenges that affect the ecosystem and the urban environment. In an arid country such as Egypt, wastewater reuse should be encouraged whenever it is safe and economically feasible. There are many methods for wastewater treatment. This research examines the use of constructed wetlands as a sustainable wastewater treatment method in urban communities. The research methodology consists of a theoretical study about water reuse, treatment and constructed wetlands. It then uses the analytical approach, by studying some examples that have used constructed wetlands for wastewater treatment and concluding their benefits to the community.

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Keywords: Sustainable Communities; Constructed Wetlands; Urban Water; Gray water; Sustainability; Water Resources; Water Reuse.

1. Introduction

Cities cannot be sustainable without ensuring reliable access to safe drinking water and adequate sanitation. As cities are becoming more and more densely populated and industrialized it is indispensable to improve the sanitary and ecological conditions and at the same time introduce a system of urban green spaces for recreational reasons. In developing countries, communities hardly afford any privileged landscapes of parks and gardens and expensive technical infrastructure systems. The basic necessity of infrastructure provision can be used by landscape architects as the most important and maybe the only possible generator of public green spaces which is otherwise getting lost for other construction developments (Stokman, 2008).

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In the case of Egypt, an arid country with an increasing population that is concentrated in the Nile Valley and Delta, one of the important development issues is the redistribution of the population outside the Nile Valley. Thus, it is essential to reclaim new lands in the desert for building new communities. Egypt also faces water scarcity and quality issues. The Nile, which is the major drinking water source is often below the minimum quality standards due to the release of large quantities of untreated wastewater into it (Carr, Blumenthal and Mara, 2004). In addition, by 2007, Egypt fell below the 700 m^3 international water poverty limit (FA0, 2007). The design of new communities imposes additional stress on managing the water resources in urban areas. Communities should seek new water resources, such as reusing gray water for non-potable purposes. To avoid the problems of costly infrastructure, sewage and water resources, new technologies and ideas should be applied in these new communities. Several methods exist for the treatment of gray water. Centralized and decentralized treatment methods are used, depending on different factors in the community. Natural treatment methods include stabilization lagoons and constructed wetlands.

Constructed Wetlands (CWs) are engineered systems that have been designed and constructed to utilize the natural processes involving wetland vegetation, soils, and the associated microbial assemblages to assist in treating wastewaters. They are designed to take advantage of many of the same processes that occur in natural wetlands, but do so within a more controlled environment (Vymazal, 2010). The research studies the treatment method of CWs as a decentralized natural treatment method that can be used in communities for wastewater treatment, along with providing other benefits. The effects of using CWs on the community are studied through some examples to conclude recommendations for further applications in Egypt and the possible limitations.

2. Sustainable Communities and Urban Water

The Royal Institute of British Architects (RIBA) defines Sustainable Communities as communities that meet the diverse needs of existing and future residents. Their children and other users, contribute to a high quality of life and provide opportunity and choice. They achieve this in ways that make effective use of natural resources, enhance the environment, promote social cohesion and inclusion and strengthen economic prosperity (RIBA, 2004). For citizens and their governments to move towards sustainable communities, several components should exist to support such a move, Williams in 2000, stated the components of a sustainable community to be parks, open green areas, solid waste management, energy efficiency, good air quality, an effective transportation system, a sustainable planning and land-use plan, providing a high quality of life and high quality housing opportunities and creating an economic development plan. Finally the community should provide an efficient water supply system for all inhabitants and a proper sewerage system (Williams, 2000).

In Egypt, three generations of new cities have been established to reduce the overpopulation in the Nile Delta. The success of the new cities was limited in many ways. New communities should be of smaller sizes, with sustainable infrastructures and services. A feasibility study should be carried out and continuous monitoring and evaluation should be held. Water scarcity and the irresponsible use of water are considered two of the major challenges facing future developments (Ellahham, 2014).

Urban water refers to forms of water that are found in an urban area including rain water, drinking water, groundwater, surface water and wastewater. Wastewater is known as water whose physical, chemical or biological properties have been changed as a result of the introduction of certain substances which render it unsafe for some purposes such as drinking (Amoatey and Bani, 2011). Urban wastewater is classified into gray water (includes water from baths, showers, hand basins washing machines, dishwashers and kitchen sinks, but excludes streams from toilets and urinals) and black water, which includes wastewater from toilets and urinals.

The treatment and reuse of gray water has many benefits, such as saving freshwater resources, irrigation of agricultural lands, reducing the need of fertilizers (Zhang, 2006). Treated gray water can be used in creating recreational and aesthetic impoundments and domestic use such as toilet flushing (Nazari, Eslamian and Khanbilvardi, 2012). Water reuse reduces its price and the energy needed for transporting water as the recycling is usually on-site (The Clean Streams Law, 2012). In addition, the treatment and reuse of gray water reduces the presence of pathogenic organism and inorganic micro pollutants which could impose serious threats to human health (Miller, 2006).

Wastewater treatment methods can be classified into traditional (centralized) methods and decentralized methods. Traditional (centralized) treatment methods refer to the wastewater reuse systems that are applied on a large scale.

While decentralized treatment methods refer to the wastewater reuse systems that are applied on a small scale. They can be on-site or cluster systems. Decentralized methods are less costly, more flexible, and resilient. They can rely on private financing, therefore saving money for municipalities (Bakir, 2001). They have less environmental damage in case of failure and they reduce the discharge of pollutants (Clean Water Act, 2007). Natural wastewater treatment systems are all waste management processes that depend on natural responses, such as gravity force for sedimentation, or on natural components, such as biological organisms (Abdel Ghaffar and El Saadi, 2007). They include constructed wetlands (CWs), which are the main focus of the research.

3. Concept and Sustainability of Constructed Wetlands

CWs technology is considered a holistic approach, integrating wastewater treatment, flood protection and storm water management. Figure 1 shows the components of the CW system, where gray water is collected from households to a primary treatment system (usually a septic tank) and is then transported to the CW via the inlet to pass through the filter media, allowing settlement of solids and coming into contact with the bacterial populations on the surface of the media and plant stems. Wastewater then reaches the outlet with a better quality to be reused (Ulsido, 2014).

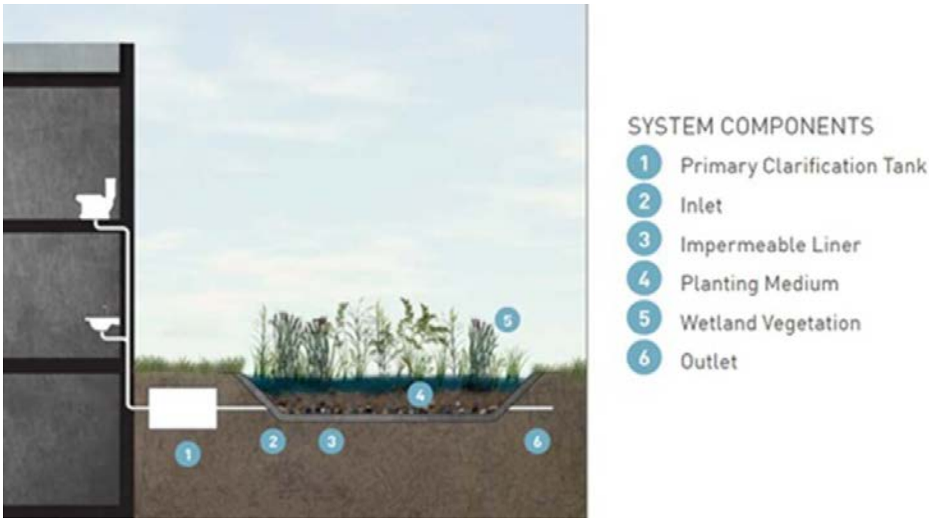

Fig. 1. Constructed wetland system components for a residential unit. Gray water is collected and primary treated in a septic tank. It is then transferred to the CW to be secondary treated. On reaching the outlet it is ready to be reused (Cascadia Green Building Council, 2011)

Vegetation in CWs plays a very important role in purifying the wastewater. Their roots provide a huge surface area for attaching microbial growth, allowing for the decomposition and uptake of pollutants from the wastewater. Another benefit for the vegetation is the aesthetic value they provide, as they provide a wildlife habitat and an additional green area (Wetlands International, 2003). Plants such as reeds, cattails and Papyrus can be used in CWs.

There are two main types of CWs; free surface flow and subsurface flow. Free surface flow CWs require more land area (5-10 m^2), but cost less (Rousseau, 2013), while subsurface flow CWs depend on the flow of wastewater under a layer of filter media, thus they are more suitable for urban areas. Subsurface flow CWs require land area of 1-5 m^2 per person and they are divided into horizontal and vertical flow CWs (Hoffmann, et al; 2011) as shown in figure 2.

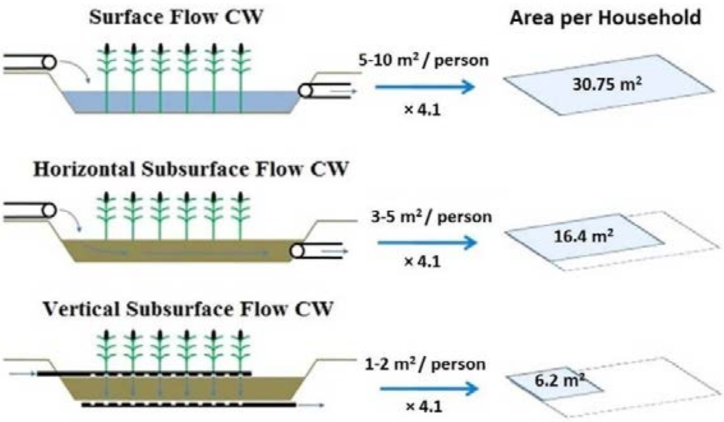

Fig. 2. Different types of CWs and the area required by each to treat water resulting from a household of 4 persons (By Author). The average household size is 4.1 persons. It is clear that the vertical flow subsurface CW requires the least surface area for treatment (1-2 m^2), while the free surface flow CW requires the largest surface area (5-10 m^2) (UNICEF, 2014).

An economical comparison was held in Mexico, between Activated Sludge Systems (ASS) and CWs (as a low cost and low maintenance effort technology). The results as in figure 3, show that the average investment costs of CWs are 110 €/p.e. (population equivalent). The municipal ASS costs 190 €/p.e. As for operation costs, CWs cost on average 1.30 €/p.e annually, while ASS costs 6.50 €/p.e annually, thus, CWs have less investment and operation costs (Seyring and Kuschk, 2005).

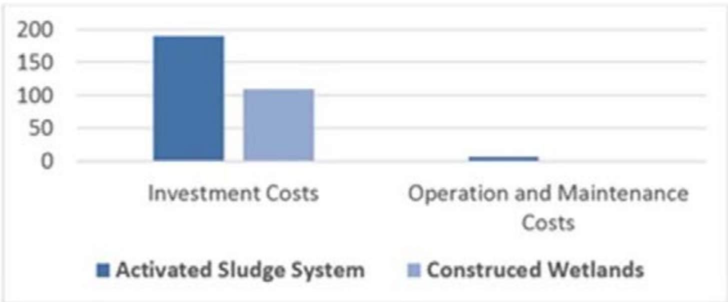

Fig. 3. Comparison between the average investment and operation costs for Activated Sludge System (ASS) and CWs in Mexico. Both the investment and operation and maintenance costs of the ASS are very high compared to that of CWs, making it clear that using CWs is more economic that the traditional ASS (Seyring and Kuschk, 2005).

The use of CWs for wastewater treatment has many benefits. Environmental benefits include adapting to specific site conditions and targeting specific pollutant loads (California State Water Resources, 2002), dependence on solar energy for the treatment processes (UNEP, 2004), protecting vital ecosystems such as rivers and lakes, providing wildlife habitat, creating green areas and eliminating the use of chemical products. Social benefits include integration in the design of buildings and landscape, leading to society interaction with wastewater treatment, increasing awareness and education about water problems, providing great public spaces at low costs, such as outdoor lunch time areas, making them favorably viewed by the general public and regulatory agencies. Economic Benefits include less construction, operating and maintenance costs. Construction costs are 1/3 the costs of a conventional wastewater treatment plant (WWTP), while maintenance costs are 1/4 +/- of WWTP. They are more durable as they have no or few moving parts, resulting in longer life cycles of about 15 years minimum (Nelson, 2014).

A life cycle assessment (LCA) was conducted to compare a CW system and an activated sludge process. The study included the production of components (equipment and accessories), construction and assembly, operation and maintenance and dismantling and final disposal of the wastewater treatment components. The two treatment systems used in the study are CWs in Spain and an activated sludge system in Portugal. Figure 4 shows the contribution of life cycle phases (construction, operation and maintenance, dismantling and final disposal) for the two systems. CWs provide an overall less contribution in the three phases. The activated sludge method, therefore has a higher environmental impact during operation and maintenance. CWs display a higher impact in the dismantling and demolition phase (Machado, et al; 2007).

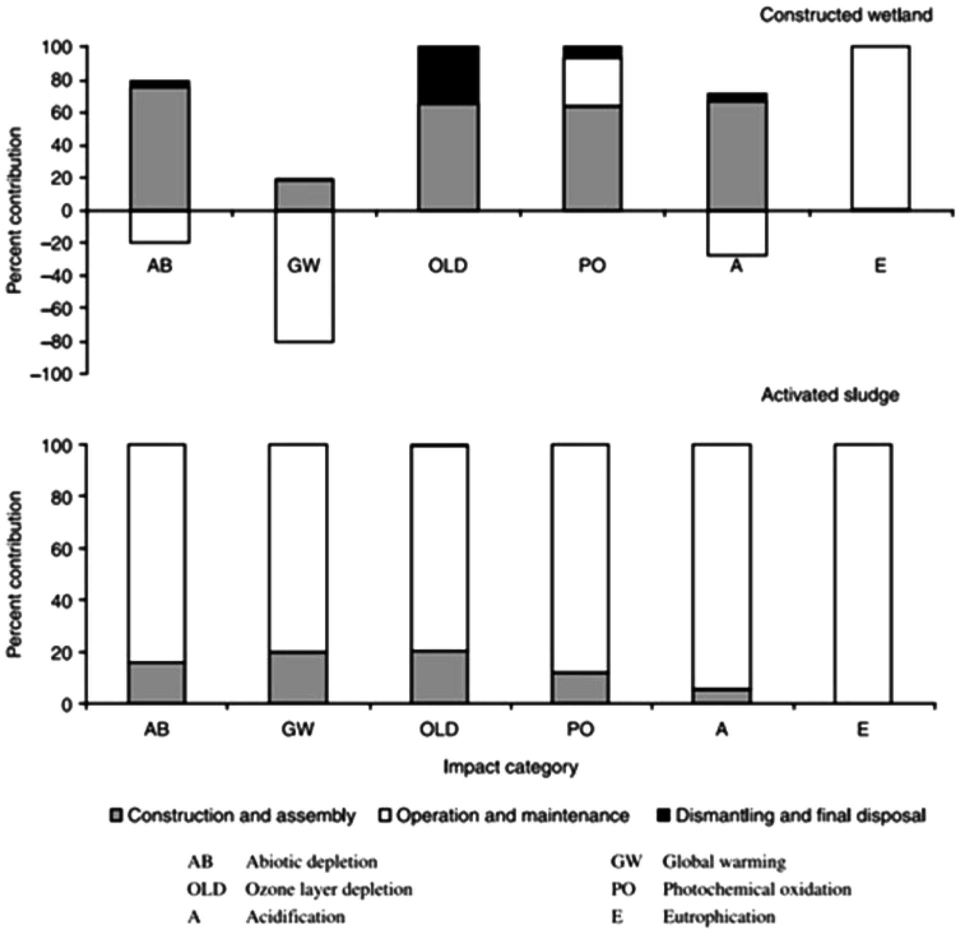

Fig. 4. Contribution of life cycle phases of wastewater treatment systems to environmental impact categories (Machado, et al; 2007). Abiotic means non-living. Photochemical oxidation is usually known as summer smog which is caused by chemical reaction between hydrocarbons (organic materials) and NOx under the influence of UV light. The CW has an overall lower impact on the environment than the activated sludge system, though the specific impact may vary in different stages (Liu, 2010).

4. Using Constructed Wetlands in Communities

CWs can be applied on-site or on larger scales, such as communities. To conclude the effects of using CWs for wastewater treatment, some examples should be studied to illustrate how they impact the community environmentally, socially and economically, in addition to their effect on the urban design of the community. An example in Egypt is also studied to show the convenience of using CWs in the local climate and the efficiency of wastewater treatment under such conditions.

4.1. Shahre Javan Community

The Shahre Javan Community is located in the Islamic Republic of Iran, which is facing two major challenges. Both are related to the research problem. The first is the increasing population, rising from 67 million in 2003 to 80 million in 2011. The second challenge is the water shortage, as the demand for water is increasing, while the existing water resources are polluted by insufficient treated wastewater and leakages (Seelig, 2009). The pilot area is a 35 hectare (ha) neighborhood with a population of 8,000 inhabitants (approx. 2,000 residential units) in the city of Hashtgerd NewTown (Mohajeri and Vocks, 2011). The design reference the traditional Iranian urban form, characterized by a low-rise, high-density form (Seelig, 2011). The design consists of 28 compact clusters organized in four rows as illustrated in figure 5.

Fig. 5. The distributed areas of the CWs, green areas and water bodies in the urban form of Shahre Javan Community, showing the decentralized nature of the system, creating green areas through the community and eliminating the need for long transmission lines and the leakage of water. The system also allows on-site treatment and raises the public concern (Weber, et al; 2013).

Each cluster has a central courtyard, surrounded by four building groups. The concept of mixed-use was implemented to provide all amenities in a walking distance of every resident and creating a decentralized neighbourhood centres. The dense urban form provides the ability to create efficient infrastructure and enhances resource use efficiency as the water supply and sewage networks are shorter, reducing water leakage and infrastructure costs. In addition the decentralized treatment system for gray water allows for efficient water reuse in the irrigation of parks and green areas (Demouth, Eitzen and Garske, 2013). A separate sewage system was implemented to separate gray water (from sinks, showers, washing machines and bath tabs) from black water (from toilets and kitchen sinks). The gray water is treated in decentralized CWs and reused for irrigation, toilet flushing and other non-potable uses (Weber, et al; 2013). Figure 6 shows the wastewater treatment concept in the community.

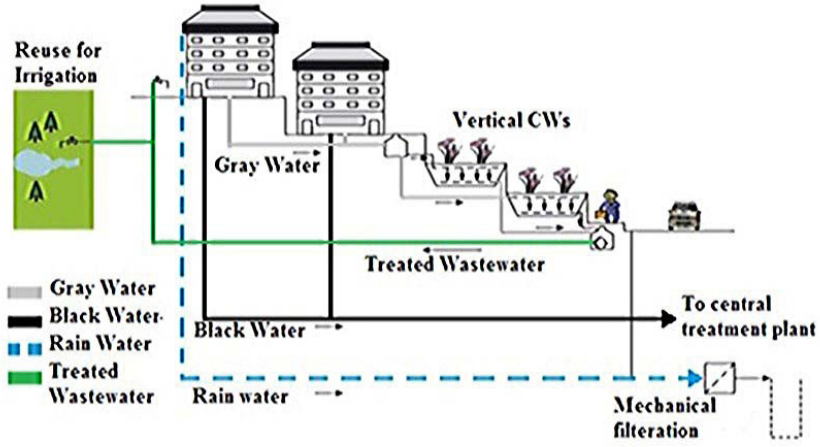

Fig. 6. Scheme of the drainage system of Hashtgerd. Gray water is treated in vertical CWs to be reused later. Black water is collected and treated in a central treatment plant, while rain water is filtered to be reused. The vertical CWs were selected to fit the slope in the neighborhood so that water can flow by gravity without the need for pumps (Vocks and Goerschel, 2011).

The system allowed reuse of 70% of the water in the city of Hashtgerd in irrigation, artificial water bodies, cleaning streets and cars and groundwater infiltration (Weber, et al; 2013). The system provides more green areas. In addition, the decentralized system can be constructed in phases, thus it can be easily financed instead of creating the whole infrastructure before the completion of the development phases. The CWs provided low investment costs, about 50% less per capita compared to an activated sludge plant (Mohajeri and Vocks, 2011).

4.2. Sunga, Nepal

The project is located in Sunga, Thimi Municipality, one of Nepal's oldest settlements, is a small municipality, with a population of around 48,000, covering 11.11 km^2 with 20% residential area, 70% agricultural land and around 10% vacant land. The untreated municipal wastewater is discharged directly into the nearby water bodies, resulting in water surface pollution and affecting the agricultural lands irrigated by the rivers. Nepal is facing an increasing water scarcity (Wateraid, 2006).

A community-based wastewater treatment system in Nepal was constructed in 2005 in Sunga. The system comprises of a coarse screen and a grit chamber as preliminary treatment, an anaerobic baffle reactor as primary treatment, subsurface CWs as secondary treatment, consisting of a horizontal water flow (HF) CW and a vertical water flow (VF) CW (figure 7) and a sludge drying bed. The local community has formed a committee for construction and future operation and maintenance of the system (UN-Habitat, 2008).

Monitoring of the performance of the system over its first year of operation shows that it removes organic pollutants highly efficiently. Maintenance works at the wetland comprised of weekly removal of unwanted vegetation from the beds and monthly cleaning of the inlet/outlet systems. The harvesting of the vegetation is carried out twice a year. The system improved the river quality, as the Sunga CWs treat the wastewater to an optimum standard before discharging into the nearby streams thereby avoiding the possible pollution in the water body and saving water resources. The treated effluent is used for multiple purposes, such as gardening and cleaning. In addition, the school adjacent to the treatment plant, agreed to use some portion of the treated wastewater effluent for toilet flushing and cleaning the surroundings of the school during the dry season, thus saving freshwater resources. The system also benefits the community as the site where the wastewater treatment plant has been constructed was previously used for dumping of solid waste and open defecation by the community. However, after the construction and operation of the treatment plant, the surrounding environment has improved to a large extent. This has benefited not only the community, but also the school children. This improvement has thus discouraged other people to continue with the traditional habit of defecation and waste dumping. The entire area now seems to be healthier and aesthetically attractive with an enhanced environment. The community was found to be very positive about the establishment of the treatment plant, as reflected in the inhabitant's request to the municipality to construct similar treatment plants (UNWAC, n.d.).

Economically, the sludge produced from the treatment system can then be used both as a fertilizer and as fuel by converting it into briquettes, thereby generating income for the management of the plant. The reed plants grow to a considerable height, they are then trimmed down. These trimmings can also be used as fuel (Davies, 2013). Another benefit is the attention received from different national and international visitors, policy makers, researchers, professionals, students and journalists, who have visited this site to observe and share experiences on community based wastewater treatment plant for replication, research and knowledge (Wateraid, 2006).

Fig. 7. Subsurface CW at Sunga for the secondary treatment of the gray water. The system creates a green area and raises the environmental awareness. The combination of horizontal and vertical flow leads to better treatment efficiency of the wastewater (UN-Habitat, 2008).

4.3. SEKEM Farm, Egypt

The project is located in Bilbeis area at east of Sharquiya Governorate 55 km northeast of Cairo. The main objective is to combine the European experience with the Egyptian practice for wastewater management and water reuse for irrigating timber plantations as well as protecting the groundwater (Abdel-Shafy and El-Khateeb, 2013). The target area for the pilot project included the school and boarding school of the farm, a few office buildings, the campus kitchen and a laundry room. The system consists of a septic tank, a pumping well, a divisor, a subsurface CW, an outlet well and a storage pond. Wastewater production in the target area was 15 m^3 / day. An additional 5 m^3 / day flow was added, considering the constant increase of the population in the last few years. Thus the total design flow rate was 20 m^3 / day (AEE, 2008).

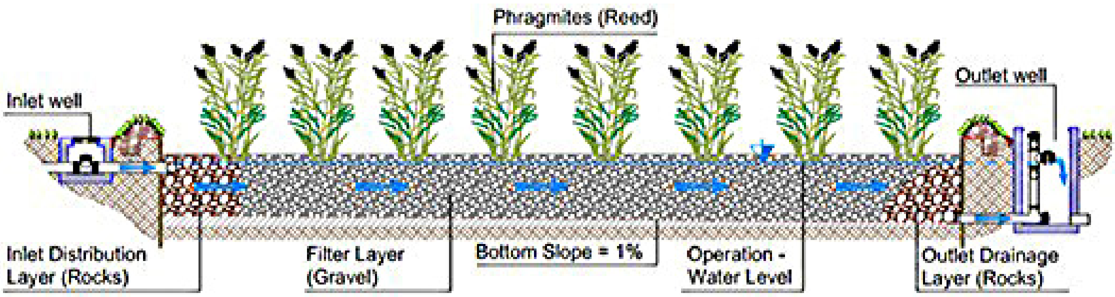

Fig. 8. Cross-section of the horizontal CW in SEKEM farm. Wastewater enters from the inlet well to the filter layer, where it is treated as it flows horizontally in contact with the roots of plants. The treated water reaches the outlet and is then stored in a well for later reuse (AEE, 2008).

The treatment system is fully operated and the treated water is reused for irrigating Eucalyptus trees that are used for manufacturing packaging boxes. The study proves that CWs are important treatment systems, particularly in decentralized areas. The implementation of an efficient primary and secondary treatment system has improved the quality of the wastewater (WW) effluent. The use of treated WW on the sandy soil, improve its physical quality. The treatment of WW resulted in an achievement towards the protection of the public health, the environment, and the groundwater. The quality of the treated wastewater is within the permissible limits of the Egyptian standards (Abdel-Shafy, et al; 2008). About 10 m^3/d of freshwater was saved for irrigating the agricultural area by using the efficiently treated wastewater (Abdel-Shafy and El-Khateeb, 2013).

Under similar conditions, i.e. collected wastewater and enough space for a constructed wetland, such a system is considered a very cost effective and robust system. The SEKEM administration is going to extend the scheme to all the schools in the municipality (MED WWR WG, 2007).

Fig. 9. Raw wastewater to the left and the treated wastewater to the right. The comparison shows improvement in the clarity of the water as the pollutants and organic materials are removed in the primary and secondary treatment stages (Abdel-Shafy, et al; 2008).

Figure 10 shows the net present value of the system over the life time. As time passes, the net present value of the system increases, showing its economic sustainability (AEE, 2008).

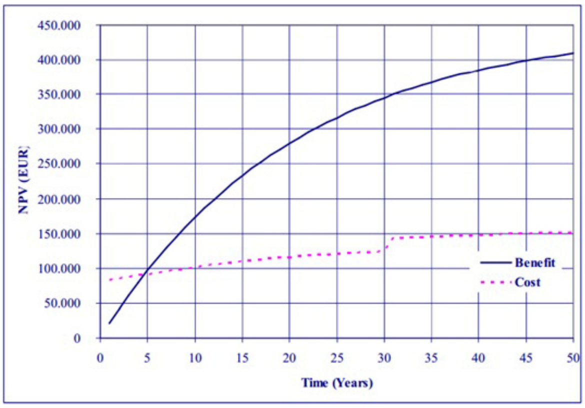

Fig.10. Net present value of the wastewater treatment system SEKEM over the life time, break-even after 4 years. The figure shows that the system is economically efficient on the long term as its long term benefits are more than the cost of the system (AEE, 2008).

The previous examples can provide us with some guidelines for using CWs in communities as a sustainable wastewater treatment method. "Shahre Javan" community shows that a compact urban form of clusters allows for a decentralized approach in water supply and treatment, which allows the CWs to be a design element in the community. Being part of the landscape adds an aesthetic value and provides recreational and green areas at no additional costs, thus reducing the heat island effect as it provides shade and humidity. The integration of CWs in the urban form allows the inhabitants to perceive the treatment process for wastewater, raising the environmental awareness and the concern for water conservation, thus decreasing the water demand. The CW in Sunga played an important role in shifting harmful social behaviors and encouraged other buildings to use the treated wastewater. In the Egyptian example, the CW was used in a low density community successfully. The awareness of the SEKEM community could be increased by allowing students of the nearby school to examine the CW and its performance. The project could be applied in urban communities to achieve more benefits for the inhabitants.

Table 1. Constructed wetlands as a sustainable wastewater treatment method in the previously studied examples. Each example is evaluated on the three pillars of sustainability. The three examples shows high level of sustainability as the CW provides a suitable treatment solution in the three cases.

● Fulfilled point O Unknown

	Aspect	Shahre Javan Community	Sunga, Nepal	SEKEM Farm, Egypt
Economic	Investment	●	●	●
	Population Density	●	●	●
	Technology Efficiency	●	●	●
	Operation and Maintenance	●	●	●
	Residuals Management	●	●	O
Environmental	Environmental Protection	●	●	●
	Resource Conservation	●	●	●
	Water Reuse	●	●	●
	Nutrient Recycling	O	O	O
Social	Public Health Protection	●	●	●
	Government Policy and Regulations	●	O	O
	Human Settlements	●	O	●
	Planning	●	●	●

Table 1 shows the appropriateness of using CWs in each of the studied examples, according to the factors set by Massoud, Tarhini and Nasr in 2008 (Massoud, Tarhini and Nasr, 2009) to describe the most appropriate technology for wastewater treatment. These factors can be used to evaluate the technology for wastewater treatment used in a specific community to state its convenience economically, environmentally and socially, thus specifying and choosing the sustainable method. It is found that the Shahre Javan community achieved the most benefits, as CWs were considered early in the design stage, allowing more economical, environmental and social benefits.

5. Potential for Further Use

The strategy for the future development plan in Egypt aims for the redistribution of population to allow the use of the unexploited resources and protection of the existing depleted resources (GOPP-Egypt, 2014a). Phase 1 of the plan (2012-2017) suggests the development of the Suez Canal, involving three main development centers: the East Port Said area; Ismailia and Al-Amal district along with Technology Valley and New Ismailia; and northwest Suez Gulf. The plan includes establishing new cities at these regions. Centralized wastewater treatment and desalination plants are proposed to serve these cities as shown in figure 11. Desalination plants may generate noise and gas emissions, they require large energy consumptions, increasing the air pollution. In addition the construction of desalination plants is time-consuming and disruptive to the environment. The large infrastructure of piping are expensive and resource consuming, they can also cause leakage of water (Younos, 2005).

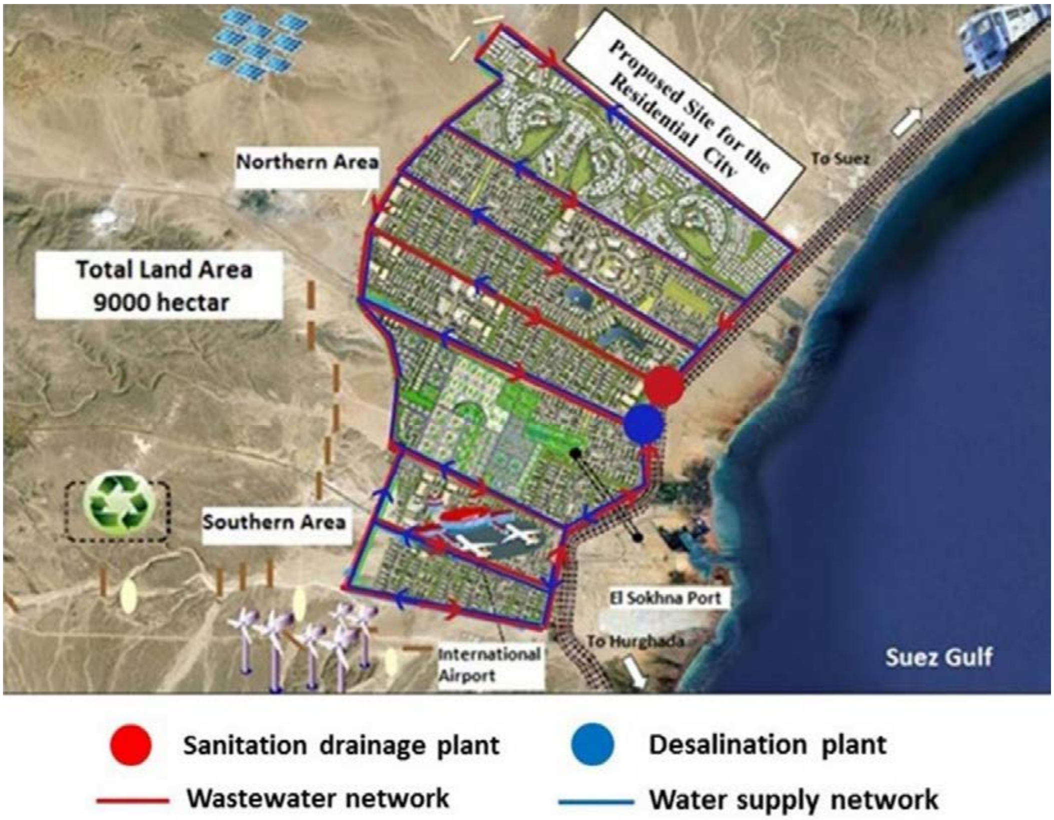

Fig. 11. North-west Suez Gulf future vision, showing the use of centralized treatment plant and desalination plant in the proposed project, leading to long transmission lines and high capital costs for the community, in addition to the environmental impact of both the treatment and desalination plants (GOPP-Egypt, 2014b).

The use of CWs for wastewater treatment in the new communities of the development plan would provide a new source of water, which is the treated gray water, allowing for irrigation of more green areas and protection of water bodies, as the treated water could be discharged safely. In addition to the many benefits of CWs as mentioned previously.

6. Conclusion

The use of CWs for wastewater treatment in communities is proved to be a sustainable approach for its environmental, economic and social benefits. CWs are convenient, especially for developing countries, where building huge infrastructures is not affordable. The reuse of treated wastewater is considered a new water resource that is needed in countries suffering from water scarcity such as Egypt. In addition, CWs can be applied in new communities to reduce water consumption, provide more green areas, recreational spaces, a better environment for the inhabitants, and reduce the price for water services, thus, attracting more residents and reducing the overpopulation and stress on the Nile Delta by building new successful self-sufficient communities. The new communities in Egypt should be of small to medium size. They should rely on decentralized water systems for their various benefits. Given that Egypt is an arid country, the courtyard cluster approach in the urban form suits the climate, while providing the potential of distribution of constructed wetlands over the community, thus decreasing the costs of piping, water leakage and energy required for the operation of centralized wastewater treatment plants and providing environmental and aesthetic values. New buildings should be designed with a dual distribution system and gray water and black water should be separated.

Public awareness campaigns should be held in new communities to inform the public about the importance of water conservation, reuse and the rising water scarcity issues, water subsidization should be reduced to encourage more rational water use and new laws and regulations should be set to prohibit the use of potable water for non-potable purposes. CWs should be considered early in the design process to provide an integrated design and to be used as a design element such as in the "Shahre Javan" community. They should be maintained and monitored regularly. Community members may participate in monitoring leading to the long term success of the system. CWs could be used in the new development regions such as the eastern Port Said region, New Ismailia City, Technology Valley and so on, to decrease the need for desalination plants, due to their high energy consumption and environmental impacts. The design of these new communities should consider the use of CWs in early design stages to reduce costs and areas of implementation after the construction is completed.

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