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Contribution Towards Improvement of Getting Rid of Heavy Metals and Toxic Substances in Wastewater Operations: The Case of Soba / Khartoum Treatment Plant

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ABSTRACT

Growing demand for and limitations to traditional water sources (surface-groundwater) led to the development of non-conventional sources. This research assessed the waste stabilisation pond treatment system built in the Green Belt, GB, in Khartoum state and the prototype model that was constructed simulating the same dimensions of the GB plant. The study took into account the system's hydraulic symmetry, rheological simulation, organic loadings conditions and some parameters applied at the station. Wastewater reaching the GB station is domestic in addition to industrial waste from tanning plants and Khartoum's coin manufacturing industry. Monthly laboratory analysis results for heavy metals and toxic substances at the GB station and model farm were monitored and recorded for two years. Attained values were not in conformity with the specifications of treated effluent reuse and reclamation, particularly in the GB station. This research applied a case study to upgrade wastewater treatment in an experimental field model using natural means. This is through introduction of a system of aquatic plants as an advanced biological treatment following natural ponds. The achieved results indicated high-quality of wastewater treatment with low-cost, which is suitable for agricultural irrigation or other beneficial uses without exposing stakeholders to any health risks or environmental ailments. Shouldered research advocates broader implementation of this advanced biological treatment system for gray wastewater using vegetation and plants. This is due to sound socio-economic rewards and ease of operation and maintenance. The purpose of re-use of such treated effluent reduces

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health risks and ill-environmental impacts. This is besides supports to traditional water sources, contribution to integrated water resources management and mitigation of any potential environmental pollution.

Keywords: Wastewater, heavy metals, toxic substances, oxidation ponds, soba

INTRODUCTION

Water is the most important requirement of life. Allah Almighty has said in the Holy Quran, "And We made from water every living thing. Will they not believe?"[1]. Water is the basic element of human life, animals and plants. In addition, its existence has outlived the earth and civilisations thrive wherever it is available.

The problem of lack of water in the Arab world is considered to be one of the most important challenges facing both safety of water and food. This is because water as a natural but meagre resource is of paramount importance in human life, continuation of life and achievement of socio-economic progress. World population increased by around 3% during the third millennium. This increase in population requires an increase in food production. This is to be achieved by increasing cultivated areas, intensifying agricultural activities and augmenting the amount of production per unit area. This will be achieved by escalating the amount of water available for use in agricultural irrigation through natural treatment means or wastewater reclamation and reuse as an inexpensive method compared with desalination of sea water and brackish groundwater. Treatment of wastes by natural systems is considered to be one of the effective methods, of low cost and suitable for reaching sound high quality water treatment specifications for agricultural purposes and other beneficial reuse and activities (Roberts & Greenwood, 2002; Kirkham, 2004; APHA, 2012; AWWA, WEF & Rice, 2012; FAO, 1990, 2012; Goyal, 2014).

RESEARCH OBJECTIVES AND ITS IMPORTANCE

This research aimed to assess the treatment system that is based on natural waste stabilisation ponds at the Green Belt in Khartoum state and the model prototype, which was implemented with the same dimensions in ratio as those of the Green Belt station i.e. ratio of length to width. The model was constructed in the vicinity of the station of the Green Belt. The system's hydraulic similarity, rheological and organic loading simulations were taken into account together with other actions that could be applied at the Green Belt plant. Physico-chemical, microbiological and biological views were kept in focus. The built model at the station was the only one applied in Khartoum state at such a large scale. This was to serve as a suitable field research case. The idea was to determine governing reasons that obstruct proper operation of the Green Belt station at required efficiency and to find ways to develop plant treatment units according to specifications and prevalent environmental,

[1] The Prophets-alAnbiya: 30

economic and social conditions. Such a precaution would enable the station to reach its desired efficiency for removal of organic and microbial contaminants, particulate matter, toxic substances, heavy elements and compounds of nitrates and phosphates. The research aim was to get treated effluents of high quality but low cost suitable for agricultural irrigation and/or other beneficial uses, without any health or environmental risks. The importance of this work is reflected in the apparent shortage and availability of water for agricultural purposes, especially in arid and semi-arid zones.

A Brief Site Description of the Green Belt Station and Experimental Prototype Farm at Soba-Khartoum, Sudan

The treatment plant built in the area of the Green Belt in Khartoum addresses treatment of wastewater (a mixture of domestic and industrial wastewater collected from the tannery and the coin manufacturing laboratory) connected to it through a sewerage system with 16 lift stations and pumps. The plant operates using natural oxidation ponds (waste stabilisation ponds) designed for a flow of about 31420 m^3/day. The plant process incorporates an initial treatment stage based on a bar screen consisting of two paths (east and west). Each of the tracks consists of two in parallel anaerobic ponds followed in series by one facultative pond proceeded in series by one polishing (maturation) pond (See Fig.1). Table 1 shows the general specifications of the oxidation ponds of the Green Belt station in Khartoum. Photographs 1 and 2 and Table 2 show descriptions of natural oxidation ponds (natural waste stabilisation ponds) for the field experimental model (See Fig.2). Raw wastewater was pumped into the model out of the same wastewater entering the oxidation pond plant in the Green Belt. Prototype model units included an inspection chamber entrance, screen racks followed by a distribution chamber to the oxidation ponds. A metallic box was placed in the wastewater distribution chamber. It was made of a metallic net of spacing 0.2 cm to prevent cogging of the tube and tap by suspended plankton. The head of the tube, of diameter 0.5 inches, was placed in the box to ease gravitational flow of the wastewater to the experimental field model. A flow control tap was placed at the end of the tube to control the amount of flow (1.58 m^3/day) entering the model farm. Natural anaerobic, facultative and maturation oxidation ponds were then connected in series.

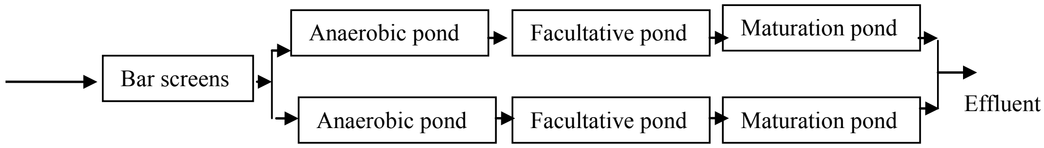

Fig.1: Green belt WWT.

TABLE 1
Specifications of oxidation ponds in Green Belt Station in Khartoum

Pond Specification	Anaerobic	Facultative	Maturation
Number	2	1	1
Length (m)	174	785	220
Width (m)	100	240	240
Depth (m)	3	1.2	1.2
Detention time (day)	3.3	14.4	4

صورة(1) لبركة للاهوائية في الانموذج لتجريبي لحقلي

Photograph 1: Descriptions of natural waste stabilisation ponds of field experimental model.

صورة(2) تنفيذ الانموذج لتجريبي لحقلي

Photograph 2: Descriptions of natural waste stabilisation ponds of field experimental model.

TABLE 2
Description of Aquatic Plant Oxidation Ponds of the Experimental Field Model

<table>
<tr><th>Pond / Specification</th><th colspan="2">Anaerobic</th><th>Facultative</th><th>Maturation</th><th colspan="2">Aquatic plants</th></tr>
<tr><td></td><td>Track 1</td><td>Track 2</td><td></td><td></td><td>Bamboo</td><td>Papyrus</td></tr>
<tr><td>Number</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td>Length (m)</td><td>1.5</td><td>0.24</td><td rowspan="2">7.85</td><td rowspan="2">2.65</td><td>2.0</td><td>2.0</td></tr>
<tr><td></td><td colspan="2">1.74</td><td colspan="2"></td></tr>
<tr><td>Width (m)</td><td colspan="2">1</td><td>2.4</td><td>2.4</td><td>1.5</td><td>1.5</td></tr>
<tr><td>Depth (m)</td><td colspan="2">3</td><td>1.2</td><td>1.2</td><td>0.6</td><td>0.6</td></tr>
<tr><td>Detention time (day)</td><td colspan="2">3.3</td><td>14.4</td><td>4</td><td>2.2</td><td>2.2</td></tr>
</table>

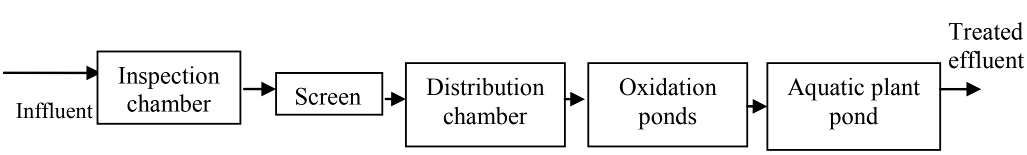

Fig.2: Green belt experimental model.Bar screens

MATERIALS AND METHODS

Samples were taken for laboratory physico-chemical, microbiological and biological analysis from both the Green Belt station and the experimental model at a daily rate, every month, for a period of two years, generally during the period between 10 and 12 morning hours. All measurements were conducted according to the American standard methods for the examination of water and wastewater (Pommerville, 2013). Laboratory tests were carried out at the Corporation of Cities Waters at Khartoum State, Environmental and Construction Center Laboratories and the Environmental Laboratory of the Faculty of Engineering of University of Khartoum. Measurements of heavy elements were conducted at the Corporation of City Waters of Khartoum State, Geological Research Laboratory of the Ministry of Petroleum and Mining and the National (Estak) Laboratory of the Ministry of Health. Physical analysis (temperature, dissolved oxygen, electrical conductivity, etc.) were carried out directly onsite using relevant field kits and instrumentation.

RESULTS AND DISCUSSION

Assessing Efficiency of the Treatment Plant and Experimental Farm Model/Soba (Maturation Pond Output)

Tables 3, 4 and 5 illustrate monthly average changes of bio-chemical oxygen demand (BOD_5) and chemical oxygen demand (COD) at the entrance and exit of both the Green Belt station and the experimental model during the study period. Temperature has an obvious effect on removal rate as displayed in Tables 6 and 7. Removal values were considered low in relation to the natural waste stabilisation pond systems, with an efficiency not less than 90% for the station in particular due to lack of appropriate conditions to carry out effective photosynthesis. This is in addition to the discharge of wastewater of certain factories, such as a coin manufacture factory and tannery, in the wastewater sewer entering the plant without being processed prior to its discharge with the domestic wastewater.

TABLE 3
Quality of Raw Water Entering the Green Belt Plant and Experimental Farm Model

Month / Analysis	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
BOD_5(mg/l)	300	255	335	575	480	520	275	260	270	250	240	220
COD(mg/l)	830	790	960	800	640	480	490	515	525	540	560	730
TSS (mg/l)	360	410	497	340	392	360	370	490	410	340	315	320
T.C No/100 ml	2.1×10^7	3.9×10^7	4.2×10^7	5.8×10^7	7.3×10^7	8.2×10^7	5.7×10^7	7.4×10^7	8.0×10^7	5.0×10^7	4.4×10^7	2.5×10^7
F.C No/100 ml	3.0×10^6	5.1×10^6	4.2×10^6	6.0×10^6	6.8×10^6	8.0×10^6	6.0×10^6	6.6×10^6	7.3×10^6	4.3×10^6	4.0×10^6	3.2×10^6
Helmineth eggs No/1000 ml	28	30	27	23	21	26	24	19	21	23	25	26

TABLE 4
Quality of Treated Effluent Emerging from a Maturation Pond in the Experimental Farm Model

Month / Analysis	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
BOD_5(mg/l)	45	39	48	69	57	58	42	45	55	46	42	43
COD(mg/l)	139	121	150	117	102	75	110	112	103	115	112	128
TSS (mg/l)	60	66	86	63	74	73	63	87	81	69	60	66
T.C No/100 ml	6.5×10^2	7.2×10^2	6.0×10^2	4.3×10^2	3.2×10^2	0	3.3×10^2	4.5×10^2	5.6×10^2	3.8×10^2	2.5×10^2	4.6×10^2
F.C No/100 ml	1.4×10^2	1.0×10^2	0.9×10^2	0.3×10^2	0.7×10^2	0	0.8×10^2	1.2×10^2	1.3×10^2	0.8×10^2	0.8×10^2	1.2×10^2
Helmineth eggs No/1000 ml	0.02	0.01	0	0	0	0	0.01	0.03	0.03	0.01	0.02	0.02

TABLE 5
Quality of Treated Effluent Coming Out of Maturation Pond at Green Belt Station

Month / Analysis	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
BOD_5 (mg/l)	73	75	67	61	58	60	54	65	63	62	63	70
COD (mg/l)	154	136	120	132	149	150	145	152	165	159	125	143
TSS (mg/l)	78	71	65	76	79	93	66	92	74	85	65	73
T.C No /100 ml	6.5×10^6	5.7×10^6	3.8×10^6	3.8×10^6	3.9×10^6	3.4×10^6	3.7×10^6	5.7×10^6	3.9×10^6	2.8×10^6	4.8×10^6	7.0×10^6
F.C No / 100 ml	5.9×10^5	5.2×10^5	3.1×10^5	2.8×10^5	2.2×10^5	1.0×10^5	2.3×10^5	3.7×10^5	3.8×10^5	2.6×10^5	3.7×10^5	5.3×10^5
Helmineth eggs No / 1000 ml	3.2	3.2	3	6.9	9	8.7	2.8	3.3	3.6	7	6.7	3.3

TABLE 6
Mean Values for % Removal (Entering to Model and Outgoing from the Maturation Pond of the Model) Depending on Climatic Seasons

Time period / Analysis	I	II	III
BOD_5 (mg/l)	82	83	88
COD (mg/l)	79	83	85
TSS (mg/l)	81	82	81
T.C No/100 ml	99.999	99.998	99.999
F.C No/100 ml	99.997	99.997	99.999
Helmineth eggs No/1000 ml	99.90	99.94	100

TABLE 7
Mean Values for % Removal in the Green Belt Station Depending on Climatic Seasons

Time period / Analysis	I	II	III
BOD_5 (mg/l)	76	72	81
COD (mg/l)	70	73	76
TSS (mg/l)	Influent > effluent	Influent > effluent	Influent > effluent
T.C No/100 ml	93.83	81.42	94.15
F.C No/100 ml	94.88	86.87	96.35
Helmineth eggs No/1000 ml	81	85	72

Key:

I: From July to October (rainy period)
II: From November to February (moderate period, cold)
III: From February to June (warm period)

Total suspended solids (TSS) are of particular importance as one of the important indicators in determining effectiveness of separation of impurities and their deposition in treatment plant units (Stesland, 1976). They also offer a direct idea of pollutant loads and suspended impurities in the sample water. This is because suspended solids contain heavy metals as a result of linkage of the latter by several different mechanisms. Their disposal greatly impairs the quality of sewer wastewater with toxic heavy metals. The values of TSS in the effluent are generally high as shown in Tables 3, 4 and 5. This is due to the presence of algae in the treated effluent as per treatment regimes of natural oxidation ponds.

High values of pathogenic indicators (TC and FC), during the study period, were noticed in the influent raw wastewater flowing during the summer months (Table 3). This was due to availability of favourable factors for pathogen growth and multiplication such as sunshine rays and alleviated temperatures (Heimlich & Ogg, 1982; Spurlock & Clifton, 1982). An increase in numbers of these pathogens was observed during the rainy season (during the months of August and September). Such occurrence necessarily pointed to the role of rainfall in increasing the number of pathogens by atmospheric and soil washing during storm water runoff through agricultural land and industrial areas. This was besides other factors like erosion and corrosion.

The heat factor had an evident effect in increasing the effectiveness of treatment during the summer season as compared to the winter and rainy seasons. This was clearly illustrated in Tables 6 and 7. It ought to be noted that the absolute value of number of FC bacilli in many of the measurements taken from the Green Belt station did not satisfy the standards in the event of use of treated effluent for indefinite or unrestricted agricultural irrigation purposes. World Health Organisation guidelines (WHO, 2006) limit the maximum allowable level of number of fecal coliform bacilli (FC) to be 1000 bacillus in each 100 ml in case of use of treated effluent to irrigate agricultural crops that are eaten raw. It is to be noted that this value has become unacceptable in most countries of the world as a precaution to effectively ensure healthy conditions. As such, the American Environmental Protection Agency (EPA, 1992) has limited the allowable value for (FC) bacilli to 14 in every 100 ml.

Helminthic eggs (Tables 3, 4, 5) were absent from the experimental model effluent during the hot season (March to June) and in all months it was satisfactory as per permitted standards. In the Green Belt station their presence was realised to be unsatisfactory by allowable standards for agricultural irrigation water, which is one egg or less in each 1000 ml according to WHO guidelines.

Results of measurements for heavy elements and toxic substances presented their existence as detected in wastewater to concentrations not satisfying allowable standards to use water for agricultural irrigation. Tables 8 and 9 show changes of concentrations of copper and cadmium in raw wastewater and in the outlet of the treated effluent from Green Belt treatment plant and the outlet of the maturation pond in the experimental model. The values of ions of copper in the outlet of the Green Belt plant did not conform to the specification of use of treated effluent for irrigation, which was 0.2 mg/l. Likewise were the values of cadmium ions, which was 0.01 mg/l in the case of use of treated effluent for continuous irrigation in most months. It should be noted that the ions of copper and cadmium were found in the industrial wastewater for the paint and ink industry i.e. from the Coin Manufacture Laboratory in Khartoum. This finding is in agreement with the study of Alasfary (Asfari, 1996). This was the same for lead (Tables 8 and 9). Some of the values were found not to be able to cope with the use of treated effluent for irrigation specification in the maturation pond of the experimental model. At the outlet of the Green Belt plant most values did not satisfy the specification of use of treated effluent for irrigation, which was 5 mg/l in the case of continuous use of treated wastewater in irrigation. It should be noted that lead was present in the wastewater of the coin industry in Khartoum as it was in waste from film developing, the battery industry, welding and glass processes just as stated by AlAsfari (1996) and Rustam (1989). The increase in the values during the rainy period in raw wastewater was due to the presence of open garbage dumping without any treatment. As for chrome (Tables 8 and 9), the values of chromium ions in the outlet of the maturation pond of the experimental model and in the outlet of the Green Belt plant did not satisfy the specification for use of treated effluents for irrigation, which was 0.1 mg/l in the case of continuous use of treated effluents in irrigation and 1 mg/l for the use of treated effluents for a period of 20 years in a soil of a soft fabric with a pH=6-8.5. It should be noted that chromium is present in the wastewater of the leather tanning industry (White Nile tannery in Khartoum and AlNasr tannery) and the wastewater of the paint, ink and dyes industry. This agrees with what AlAsfari (1996) noted in his study. Also found to be present was arsenic (Tables 8 and 9) as some of the values in the outlet of the maturation pond of the experimental model did not satisfy the specification for use of treated effluenst for irrigation. While in the outlet of the Green Belt plant all values did not satisfy the specification for use of treated effluents for irrigation, which was 0.1 mg/l in the event of continuous use of treated effluent in irrigation and 2 mg/l when using treated effluents for a period of 20 years in a soil of a soft fabric with a pH=6 to 8.5. It should be noted that arsenic was present in the wastewater of the paint, ink and pesticide industry (Tchobanoglous *et al.*, 2002); pesticide is used for spraying rodents, insects, fields and agricultural land. These results agree with research findings outlined by Alnunnah (2000) and Asfari (1996).

TABLE 8
Concentration of Heavy Metals in the Raw Wastewater Entering the Experimental Field Model and the Green Belt Station

Month / Analysis	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Fe	1.35	1.9	0.79	0.85	0.69	0.57	2.24	2.96	2.19	1.13	0. 9	1.01
Cu	0.09	0.12	0.25	0.30	0.34	0.08	0.1	0.15	0.21	0.13	0.15	0.11
Cd	0.05	0.048	0.055	0.042	0.027	0.02	0.037	0.043	0.044	0.033	0.030	0.041
p_b	6.4	5.9	5.1	5.9	5.1	5.7	6.3	7.2	7.3	7.1	5.8	6.0
Cr	0.76	1.0	1.09	0.96	0.72	0.91	0.89	0.72	1.06	0.7	0.92	0.77
As	0.94	0.88	0.79	0.73	0.44	0.3	0.45	0.51	0.69	0.96	0.95	0.92

TABLE 9
Concentration of Heavy Metals in Treated Effluent Outgoing Maturation Pond of the Experimental Field Model and Green Belt Station

Month / Analysis	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Fe*	1.3	1.5	0.6	0.63	0.37	0.15	1.9	2.39	1.92	1.01	0.71	0.92
Fe**	1.4	1.72	0.68	0.76	0.32	0.29	2.08	2.36	2.03	1.09	0.84	0.95
Cu*	0.054	0.044	0.038	0.032	0.025	0.0	0.04	0.048	0.043	0.03	0.042	0.037
Cu**	0.069	0.01	0.18	0.27	0.31	0.06	0.08	0.1	0.16	0.09	0.09	0.06
Cd*	0.028	0.025	0.022	0.016	0.011	0.01	0.026	0.031	0.025	0.021	0.016	0.018
Cd**	0.035	0.031	0.04	0.028	0.02	0.015	0.03	0.033	0.03	0.026	0.02	0.031
P_b*	3.1	2.7	3.3	2.8	2.3	2.4	3.6	5.5	5.2	5.5	2.9	3.2
P_b**	5.3	6.1	6.0	5.1	4.6	4.8	5.0	6.0	4.8	5.3	5.1	5.2
Cr*	0.76	0.77	0.73	0.7	0.46	0.61	0.55	0.5	0.82	0.52	0.61	0.53
Cr**	0.91	0.9	0.92	0.87	0.63	0.76	0.75	0.62	0.96	0.63	0.79	0.65
As*	0.3	0.21	0.15	0.1	0.09	0.07	0.12	0.16	0.18	0.3	0.28	0.27
As**	0.6	0.57	0.5	0.47	0.25	0.2	0.27	0.38	0.44	0.6	0.62	0.6

Key:
* Values of the experimental model **Values for the Green Belt station

Development of Natural Treatment Systems by Oxidation Ponds Method

There are several research possibilities for the development of natural treatment systems using oxidation ponds in achieving best removal of persistent organics, microbial pollutants, heavy metals and compounds of nitrates and phosphates, suspended solids and some algae (16-21). In this research work, aquatic plants were applied for the treatment of wastewater as an advanced biological treatment method following natural oxidation ponds. Two aquatic plant basins were designed and constructed parallel to one another other and in series with the maturation pond of the experimental farm model. Table (2) represents the dimensions of each of the two basins and related detention time.

The aquatic plants absorbed the heavy metals from the wastewater. This is clearly demonstrated by the analytical tests, which showed accumulation of these metals in tested aquatic plants as shown in Table 10.

As a result of analysis for measurements that were conducted on effluents emerging from the basins of aquatic plants, it was noted that the basins were identical in achieving removability. Nonetheless, the papyrus basin contributed to better removability for BOD_5, COD and TSS. Both basins contributed together to achieving additional intermediate removability in values of contaminants and heavy metals as depicted in Table 11.

Helmineth eggs and pathogenic bacillus FC, TC and heavy metals (cadmium Cd, copper Cu, lead Pb, chromium Cr and arsenic As) were negative.

TABLE 10
Concentration of Heavy Metals in Aquatic Plants

Plants / Analysis	Papyrus		Bamboo	
	Leaves	Roots	Leaves	Roots
Fe	0.81	0.53	0.86	0.48
Cu	0.019	0.012	0.017	0.012
Cd	0.015	0.02	0.014	0.022
p_b	2.8	2.6	2.7	2.5
Cr	0.29	0.43	0.36	0.51
As	0.09	0.11	0.12	0.13

TABLE 11
Contribtion of Both Basins in Additional Removability of Contaminants and Heavy Metals

Pollutant	Removability per season		
PO_4^{---}	72 % during rainy season	79 % during cold season	83 % during hot season
SO_4^{--}	66 % during rainy season	64 % during cold season	69 % during hot season
NO_3^-	64 % during rainy season	62 % during cold season	66 % during hot season
BOD_5	60 % during rainy seaon	62 % during cold season	79 % during hot season
COD	56 % during rainy season	61 % during cold season	71 % during hot season
TSS	71 % during rainy season	71 % during cold season	77 % during hot season

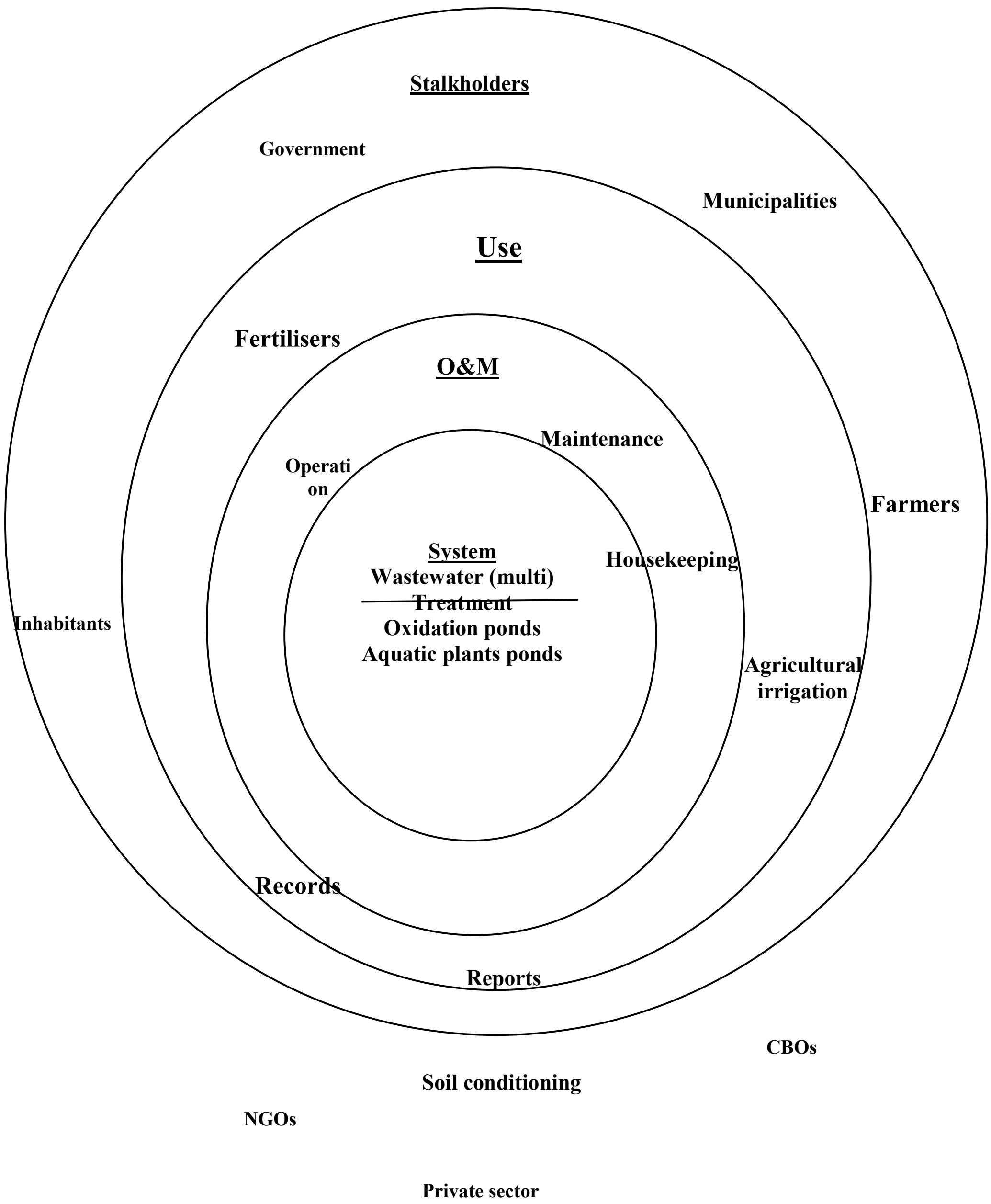

Fig.3. Interactive use of aquatic plants.

CONCLUSION AND RECOMMENDATIONS

From this research work the following conclusions may be drawn. Firstly, Green Belt wastewater treatment plant that operates via natural wastewater stabilisation ponds system did not achieve the required efficiency in reducing chemical and organic pollutants. On average basis and at best climatic conditions (hot climate) removability did not exceed 81% for BOD_5, 76% for COD and 76% for TSS.

Secondly, the efficiency of the Green Belt wastewater treatment plant did not decrease beyond 96% at best conditions for the reduction of bacteriological or pathogenic pollutants (FC) and 85% in removing helminthes eggs. However, it did not achieve the required efficiency for pathogenic standard needed for continuous use of treated effluents for unrestricted agricultural purposes as recommended by WHO.

Thirdly, the climate (rainy, cold or hot period) had a clear role in influencing the efficiency of the biological treatment of the oxidation ponds. It was clear that the operation of the ponds was better during the warm period (March-June) than during the cold and rainy period, which was almost equal (July to February).

Fourthly, it was a times observed, in both serial tracks of the Green Belt station, that there was an increase in values of helminthic eggs, FC and BOD5 in the treated effluent from maturation ponds than when compared to influent wastewater from facultative ponds. This may be a direct result of external contamination from the residents living in the vicinity of the plant maturation ponds when using them as toilets, swimming purposes and for watering their livestock and so on.

Fifthly, the experimental field model of oxidation ponds at the area of the green belt was constructed with same dimensional ratios to the adjacent Green Belt wastewater plant. This is by taking into account system's symmetry, hydraulic and organic load simulation. The achieved quality improvement of treated maturation pond effluent is apparent. This is as a result of the appropriate operation as per design of Green Belt plant, prohibiting inhabitants from its misuse, sludge cleaning, dead algae removal from surface of ponds, placement of a screen after bar racks before influent of raw wastewater to anaerobic pond and splitting the anaerobic pond into two to adjust and control flow entering the facultative pond. These measures alleviated removal rates to 88% for BOD_5, 85% for COD and 81% for TSS.

Sixthly, the experimental ponds of the aquatic plants farm model, constructed after the maturation pond, gave distinct improvement to the efficiency. Thus, the model contributed towards achieving maximum removal of BOD5: 79%, COD: 71%, TSS: 77%. Helmineth eggs and bacillus pathogens FC, TC and heavy metals (Cr, Pb, Cu, Cd, As) were always negative. This achieved the standards required for use of treated effluents for unrestricted agricultural purposes according to WHO guidelines.

Seventhly, the elimination or reduction of heavy metals, toxic substances and suspended solids in the treated effluent by natural oxidation ponds can be processed as an advanced treatment through use of aquatic plants.

Eighthly, the use of aquatic plants for treatment after the maturation pond was scalable by branching the linkage to improve treatment returns through serial connection of ponds.

Finally, the cost of building and operating treatment ponds by aquatic plants should be low as they do not rely on operation by machinery, equipment and technical instruments of high costs. In addition, they do not require skilled labour for their operation and maintenance. They can be carried out anywhere because the growth of higher plants makes it an integral part of nature and the surrounding environs.

Recommendations

From the results acquired from this research the following findings and recommendations are made in the hope of alleviating existing treatment problems and to increase treatment plant investment:

Firstly, generalisation of gained experience of natural biological oxidation ponds treatment systems (primary or secondary) followed by aquatic plants treatment deserves implementation. Thus, this work advocates more coverage of this kind of treatment system in all countries where wastewater contains an industrial wastewater component. This is in order to take advantage of using treated effluents for unrestricted agricultural purposes or other uses. This system is economical, easy to operate and maintain depending on availability of favourable climatic conditions. It should be noted that this experience would be more successful in countries with large open areas and a warm climate, which is available in most Arab countries.

Secondly, it is recommended to adopt an optimised operating treatment system with natural oxidation ponds, anaerobic ponds, followed by facultative ponds, followed by maturation ponds so as to ensure sufficient detention time for the growth of green algae. This is to be followed by aquatic plant basins at the end of these lines. As such, two maturation ponds should be installed in parallel after aquatic plant basins. One pond may be used for fish farming and unrestricted agricultural irrigation, and the other for swimming.

Thirdly, there should be the establishment of branched disposal stations to relieve pressure on the main network.

Fourthly, an awareness unit should be activated. This is to guide and direct farmers to analyse soil before planting. This will ease addition of the right amounts of chemical fertilisers. In this particular case, perhaps, there would be no need to add fertilisers that are available in the treated effluents.

Fifthly, sludge should be promoted for use as an agricultural fertiliser and soil conditioner.

Sixthly, close monitoring of farmers is needed. They should also be advised not to use treated effluents for irrigating vegetables, especially leafy ones, which are eaten raw. It is vital to be sure that effluent quality satisfies specifications before it is used for irrigation of crops that are eaten raw. This is in addition to the application of stringent laws regulating this matter.

Seventhly, there should be activation of private associations, NGOs and CBOs such that each member be a platform for the dissemination of knowledge about this plant and its objectives.

Eighthly, permanent awareness about non-disposal of all that may jeopardise the work of microorganisms that play a role in biological treatment, such as oils used more than once in the process of frying food and industrial oils, should be carried out. Such substances form an insulating layer that prevents oxygen access for treatment within the basins and thus the organisms are poisoned, decreasing the efficiency of the plant. Thus, it is necessary to propose separating oil from waste from the start to overcome repercussions of such wrong environmental behaviours.

Ninthly, sorting and cleaning up the site (good housekeeping) is necessary. Implementing internal arrangement procedures of good housekeeping such as continuous cleaning of site, buildings and pumps cabins, should be encouraged. The maintenance of green areas, parks and cultivated land to prolong the design period of the station and seeing to employees' psychological stimulus to work in a healthy and comfortable atmosphere should also be implemented.

Tenthly, there must be emphasis on operating records and reports. Records should be kept for the station, performance, equipment and maintenance reports in order to estimate plant treatment efficiency. In addition the safe-keeping of operating manuals for each unit of the station and for equipment must be emphasised.

Finally, with regards to the maintenance of the wastewater treatment plant, operations must be carried out hand in hand with maintenance. Maintenance time is normally one-third of operation time.

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