Small-Scale Wastewater Treatment Systems and Reuse Studies in Oman

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Abstract
Currently Oman mostly uses Membrane Bioreactor (MBR) and Activated Sludge systems for wastewater treatment. For many installations that are not part of the network, wastewater treatment becomes a challenge. Cost of treatment as well as efficiency of treatment for further reuse of treated wastewater are important considerations. Different approaches have been taken to treat wastewater in small-scale. A system using both filtration and wetland was trialed for treating the poultry wastewater of A'Saffa Foods to produce effluent for reuse in irrigation. In addition to the current system of simple aeration, sand filtration, activated carbon filtration and a subsurface wetland was installed. The main challenge was to build a wetland without any exposed water to avoid attracting any birds which might bring disease to the million chickens that live there. A study was conducted to treat 500 m^3/day of wastewater of a textile mill. The treatment system consisted of screening, equalization, sedimentation, sand filtration and UV/Ozonation. Another integrated system is currently under trial using wastewater from fish tanks for growing crops after simple filtration. A system was designed for low cost greywater treatment from individual houses and apartment blocks to treat greywater onsite and reuse. The system is based on physical and chemical processes and has been successful in field trials. The system is cheap, easy to operate and maintain. A simple system was also installed in a mountain village to clean water stored in reservoirs that has become eutrophic. Studies were done on irrigating wheat with treated wastewater using drip and raised bed furrow system. Both were proven successful.

Keywords
Oman; wastewater; treatment; wetlands; textile effluent; greywater; aquaponic

INTRODUCTION

Currently Oman mostly uses Membrane Bioreactor (MBR) and Activated Sludge systems for wastewater treatment. For many installations that are not part of the network, wastewater treatment becomes a challenge. Cost of treatment as well as efficiency of treatment for further reuse of treated wastewater are important considerations. Small-scale wastewater (domestic, industrial and low quality reservoir water) treatment systems have been tried in few places in Oman mostly as part of research projects undertaken at Sultan Qaboos University.

Considerable amount of research has been done in Oman on various issues related to wastewater. Wastewater research focused on growing crops, impacts on soil, aquifer recharge using treated wastewater and other relevant issues (Alkhamisi et al, 2015, 2016; Al-Busaidi and Ahmed, 2014; Abdelrahman et al, 2011). Whereas, sludge produced as by-product of wastewater treatment was investigated for its quality and likely use in crop production and remediation of contaminated sites (Al-Busaidi et al, 2015; Padmavathiamma et al, 2014; Al-Busaidi, 2014).

USE OF TREATED WASTEWATER IN AGRICULTURE

Al-Busaidi et al (2015) conducted research to evaluate the suitability of treated wastewater for irrigating date palms and monitoring the partitioning of some heavy metals (e.g., Cu, Cr, Cd, Pb, Mn, Fe, Zn etc.) among soil, plant and fruits. Results showed that the concentrations of heavy metals in both groundwater and treated wastewater were within the international standards. There were significant variations in heavy metal concentrations in soil at studied locations. In most of the cases, the concentrations of heavy metals were relatively higher in soils irrigated with treated wastewater compared to the soils irrigated with groundwater. Generally, the concentrations of heavy metals in date palm leaves were not significantly different in plants irrigated with treated waste water or groundwater. However, there were significant differences in the concentrations of heavy metals in date fruits irrigated with different sources of water. The concentrations of some metals (Fe, Zn, and Ni) in date fruits were higher in waste water irrigated plants whereas other metals (Cu, Cd, Pb, and B) were higher in ground water treated plants. In all cases the concentration were within the permissible limits. Thus, the long-term effects of treated wastewater did not indicate any adverse effects of irrigation using groundwater and waste water on fruit mineral composition, including heavy metals.

Another study aimed to identify means/tools to optimize treated wastewater reuse in conjunction with other available water resources by taking into consideration their quantity and quality, in addition to the agronomic, environmental, and economic components. The study was done in open field at Sultan Qaboos University, Oman. Three types of crops (radish, okra and eggplant) were grown and irrigated by four types of waters (A: 50% groundwater and 50% treated wastewater, B: 100% groundwater, C: 75% treated wastewater and 25% groundwater, and D: 100% treated wastewater). Soil physicochemical properties did not show significant differences with treated wastewater irrigation as compared to groundwater. On other hand, some chemical properties significantly increased ($p<0.05$) when treated wastewater was applied such as total carbon and some major elements (N, P, K). Crop physical analysis showed significant increases in plant productivity when plants were irrigated with treated wastewater with insignificant changes in heavy metals between treatments and no biological contamination in crop yield was recorded (Al-Busaidi and Ahmed, 2015).

The growth of bio-fuel plant was evaluated under treated wastewater irrigation. It was found that Jatropha plants irrigated with treated wastewater gave the best growth in term of plant height and green yield compared to groundwater (Al-Busaidi, 2014).

WASTEWATER TREATMENT FACILITIES IN OMAN

Large number of wastewater treatment plants (STPs) are working in Oman producing large amount of treated wastewater annually. Table 1 lists some of these plants and their production data. Most of these plants use activated sludge method although in recent years bigger city based plants are using MBR process.

Table 1. Capacity of treated wastewater plants in different regions in the Sultanate and their production rates (m^3/day) in 2010

S. No	**Wilayat (Locality)**	**STP Capacity (m3/day)**	**Treated wastewater (m3/day)**	**Treated wastewater (m3/year)**
1	Nizwa	250	164	59,860
2	Nizwa (new)	450	219	79,935
3	Green Mountain	120	95	34,675
4	Bid Bid	250	98	35,770
5	Izki	180	131	47,815
6	Alhamra	120	38	13,870
7	Bahla	600	42	15,330
8	Manah	180	80	29,200
9	Adam	250	176	64,240
10	Samail (new)	2,700	962	351,130
11	Nizwa (new)	5,600	2,480	905,200
12	Ibri	1,800	1,412	515,380
13	Yanqal	250	185	67,525
14	Dhank	250	132	48,180
15	Hamra Droa	180	39	14,235
16	Mahdhah	2,500	197	71,905
17	Buraimi	2,500	980	357,700
18	Buraimi (New)	3,000	2,100	766,500
19	Khasab	600	258	94,170
20	Diba	120	107	39,055
21	Boukha	180	59	21,535
22	Sur	2,000	526	191,990
23	Jalan Bani Bu Hassan	600	224	81,760
24	Alkamil wa Alwafi	250	99	36,135
25	Jalan Bani Bu Ali	600	198	72,270
26	Masirah	1,800	1,392	508,080
27	Sur (New)	1,400	924	337,260
28	Ibra	4,500	770	281,050
29	Snaw	120	76	27,740
30	Mudhaibi	600	88	32,120
31	AlQabil	250	84	30,660
32	Bidiya	300	115	41,975
33	Aljaza	180	8	2,920
34	Shinas	600	211	77,015
35	Liwa	450	279	101,835
36	Saham	5,000	2,077	758,105
37	Suwaiq	120	56	20,440
38	Khabourah	120	90	32,850
39	Rustaq	7,200	2,520	919,800

40	Almusanah	450	193	70,445
41	Barka (new)	2,000	1,978	721,970
42	Barka	250	180	65,700
43	Haima	120	70	25,550
44	Mahout	120	55	20,075

Source: (Alkhamisi, 2013b)

SMALL–SCALE WASTEWATER TREATMENT

Different approaches have been taken to treat wastewater in small-scale isolated areas where easy connection to network may not be possible. Sometimes entities generating wastewater are also interested to reuse such treated wastewater for their own needs, which is not possible if wastewater is sent through network for central STPs. Another area which has generated considerable research interest is the treatment of greywater in individual houses. In the following pages, five (5) such systems are described.

Use of Wetlands for Poultry Farm Wastewater Treatment

An innovative system using both filtration and wetland was tried for treating the poultry wastewater of A'Saffa Foods at Thamrait to produce effluent which satisfies requirements for wastewater reuse for irrigation purposes (Ahmed et al, 2014). The current produced wastewater volume is 1200 m3/day and expected to reach 1500 m3/day due to future expansion. The effluent from preliminary treatment (simple aeration tank) showed biochemical oxygen demand (BOD) of 472 mg/L, chemical oxygen demand (COD) of 1336 mg/L, Nitrates of 9.27 mg/L and Fecal Coliform bacteria of 158 x 10^6/100 mL (Table 2). In addition to the simple aeration tank system, sand filtration, activated carbon filtration and a subsurface wetland have been installed. The main challenge was to build a wetland without any exposed water to avoid attracting any birds which might bring disease to the million chickens that live there. The effluent quality when compared to raw water shows significant improvement with huge reduction in Turbidity, COD, BOD, Suspended Solids, Phosphate. Although few parameters show increase such as pH, salinity (EC), Nitrate and Sulphate. In normal constructed wetland we expect pH, EC to remain unchanged, and Nitrate and Sulphate to decrease. In this case the use of large amount of chicken manure and saline soils in the wetland is contributing the excess pH, EC, Nitrate and Sulphate. As time progresses, pH, EC, Nitrate and Sulphate would certainly come down as the stored salts and organics will be exhausted. The effluent (treated wastewater) failed to meet Omani standards for wastewater reuse in some parameters. Omani standards were established based more on public health considerations (protecting people) rather than agricultural considerations. A qualitative risk assessment shows very little risk to people, environment and plants to be grown (date palms). As such it was recommended that the project be continued and irrigation of date palms should commence on trial basis with the approval of the concerned Ministry.

The system consisted of sand filter, aeration tank, reed bed unit, activated carbon pond, and chlorine chute. However, the experimental work was done over two periods: (1) System A: Sand filter, activated carbon pond, and chlorine chute, and (2) System B: Sand filter 1, aeration tank, reed bed unit, Sand filter 2, activated carbon pond, and chlorine chute (Figure 1). For both systems, the water from the aeration tank is received in a small collecting tank to allow for part of the solids to settle before entering the sand filter (to reduce blockage process of the sand filter due to high solid content of the received water). The filtration system was designed using locally available materials.

Synthetic sand was used in the sand filters. The reed beds used a mixture of sand (40%), soil (50%) and some chicken manure (10%) to enhance the growth of the reeds.

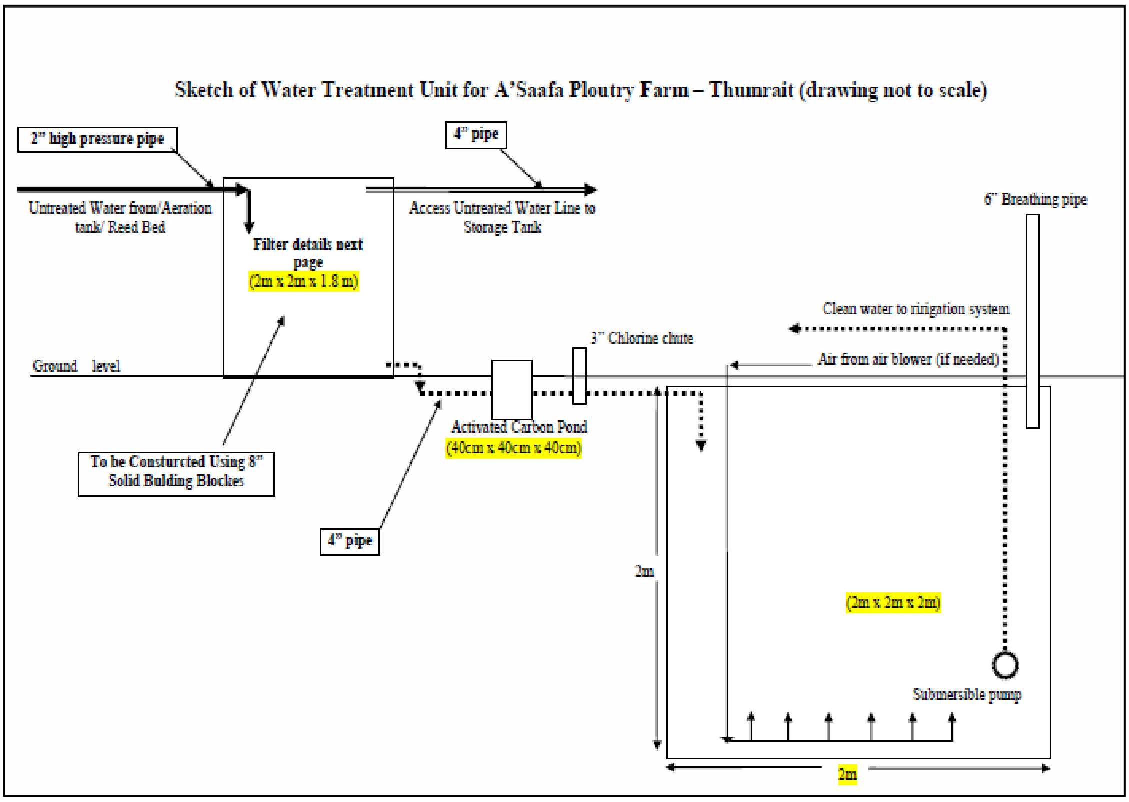

Figure 1. Sand filter system design

Table 2. Water quality results from Al-Saffa Company (before and after treatment)

Wastewater sample	**Before treatment sampling 21/12/13**	**After treatment sampling 21/12/13**	**After treatment sampling 29/12/13**
Parameter			
pH	7.09	7.19	7.37
Electrical Conductivity – mScm^{-1}	4.45	9.43	7.94
Turbidity (NTU)	335	72	47
Ammonical Nitrogen as NH_3-N mg/l	194.6	344.2	209.7
Total Suspended Solids-mgl	345	23	17
Volatile Suspended Solids-mg/l	325	21	11
% Volatile Suspended Solids	94.2	91.3	64.7
Chemical Oxygen Demand mg O_2/l	1336	328	180

BOD-5 (mg O_2/l)	472	72	48
Dissolved Organic Carbon- mg/l	227	112	187
ANIONS- (ppm)			
Fluoride	4.56	4.72	4.97
Chloride	634	1703	1503
Nitrate	9.27	76.57	87.47
Phosphate	10.57	20.84	11.78
Sulphate	3.09	245.7	1744.8

Textile Mill Effluent Treatment

500 m^3/day of textile mill wastewater can be treated and reused based on the treatment technology developed in this research work, which consists of screening, equalization, sedimentation, sand filtration and UV/Ozonisation operations (Feroz et al, 2015). The major constraint in adopting the proposed treatment was high cost. An approximate cost of OMR 280,000 (USD 725,000) was estimated to implement the technology developed in this research work. The treatment consisted of Ozonisation and UV treatment on four different concentrations of effluent and analysis was carried out. 10, 30, 50 and 100 ml of saturated ozonised distilled water was mixed and stirred for 120 seconds with textile mill filtered effluent to make a final volume of 500 ml of four different control samples. This 500 ml each sample was exposed to short wave length 254 nm UV rays for 180 seconds duration (Table 3). Based on the laboratory experiments a treatment system was proposed (Figure 2) and cost estimated.

Table 3. Water quality analysis of textile mill effluent using filtration, ozonation and UV treatment (before and after treatment)

Parameter	**Raw Water**	**After Filtration**	**(490+10) ml**	**(470+30) ml**	**(450+50) ml**	**(400+100) ml**
pH	9.52	7.70	8.28	8.27	8.26	8.28
COD, mg O_2/l	737	278	Low	Low	Low	Low
TSS, mg/l	128	32	Low	Low	Low	Low
Color	Light Blue	Pale Yellow	Colorless	Colorless	Colorless	Colorless
Turbidity, NTU	23.4	26.0	0.80	0.65	0.59	0.47
Total Hardness, mg/l	167	79	38	27	26	23

Total Organic Carbon, mg/L	199.9	119.4	33.90	33.09	31.70	28.55

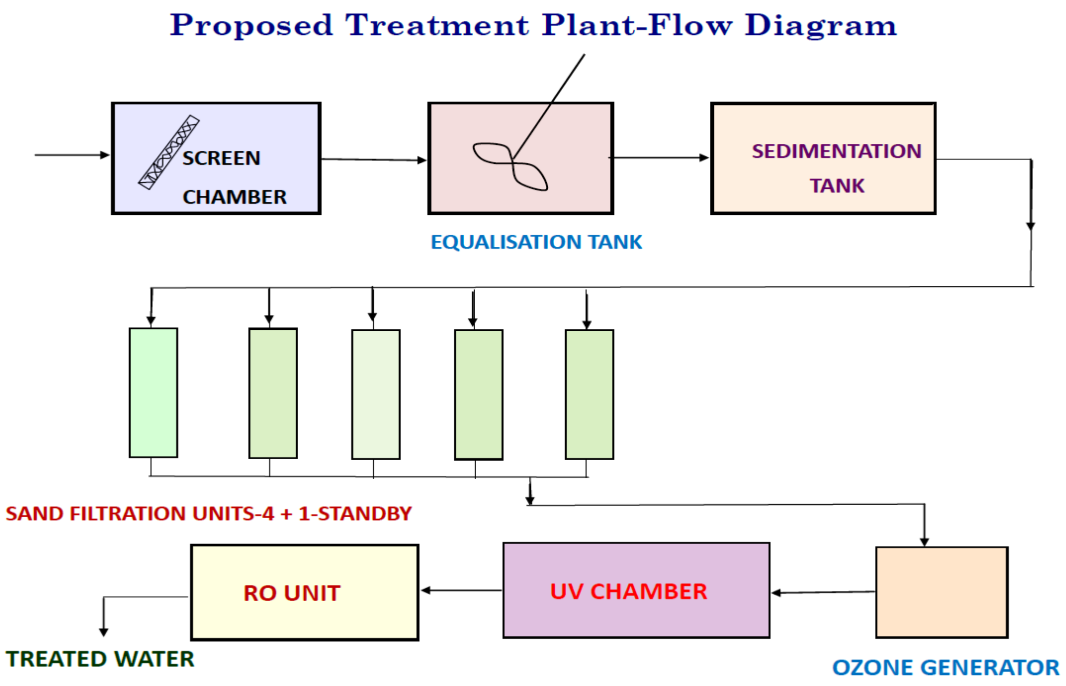

Figure 2. Proposed design of treatment system for textile mill wastewater

Long-term Study of Greywater Reuse in Residential Buildings

Treatment of greywater and reuse has been extensive studied by researchers in Oman (Ahmed et al., 2008; Jamrah et al, 2008; Prathapar et al, 2005; Ahmed et al, 2005; Ahmed et al, 2004; Prathapar et al, 2004; Ahmed et al, 2003; Ahmed et al, 2012). These studies convincingly showed that greywater in individual households can be utilized in Oman considering both technical, economic and environmental aspects. A project was completed to see the feasibility of using treated greywater from households for home-gardening (Ahmed et al, 2014b). These systems are easy to build and require low maintenance. In order to study the treatment efficiency, irrigation performance of greywater and maintenance protocol, a GW treatment system was installed in a newly-constructed house in Muscat, Oman and studied over a two year period. In this system, raw GW was collected in a storage tank and then pumped to a sand filter which is a regular 300-Gallon (1136 liters) polyethylene water tank. The GW, which undergoes physical treatment through the filter, is then passed through chlorine tablets in the chlorine chute for disinfection (Table 4). At this stage, the treatment process was over and the recycled GW was ready to be used for irrigating kitchen garden crops and other plants. This water was found to be suitable for irrigation as per Omani standards. Greywater was found to be more nutrient rich for plants when mixed with kitchen wastewater. Chemical and biological analysis of fruit samples from greywater-irrigated crops did not show any harmful contamination. It was also observed that greywater irrigation added more nutrients in soil in comparison to freshwater. The capital cost of the system was OMR 490 (USD 980) and operating cost annually was OMR 30 (USD 78) with annual income and savings from the system being OMR 220 (USD 572) indicating a payback period of only 2.1 years. It was found out that the system required simple but regular maintenance especially with regards to cleaning of the top layer of the filter. Overall conclusion from this study is that such a greywater system should be technically, economically and environmentally feasible in Oman.

Table 4. Physico-chemical characteristics of raw and treated greywater

Parameters	Raw greywater	Treated greywater
EC (µs/cm)	495	494
Temperature (ºC)	24.9	24.1
pH	7.4	7.9
Turbidity (NTU)	16.1	9.65
Coliform (MPN/100 ml)	>200	0
E-coli (MP/ 100 ml)	129.8	0
Residual chlorine (mg/l)	-	0.4

Use of Fish Processing Plant's Wastewater for Aquaculture

Aquaponic is attracting attention from researchers to produce fish in small area at a very high yield. The design of aquaponic systems closely mirrors that of recirculating systems in general, with the addition of a hydroponic component and the possible elimination of a separate biofilter and devices (foam fractionators) for fine and dissolved solids removal. The essential elements of an aquaponic system consist of a fish rearing tank, a settleable and suspended solids removal component, a biofilter, a hydroponic component and a sump. A project is currently underway which is designed according to Figure 3 (Personal Communication, Gil Ha Yoon, 2016). Effluent from the filter gathers into the reservoir tank first to reduce organic matter concentration in the form of settleable and suspended solids. It then transfers to fish-rearing tank where it is treated. Next, the culture water is nitrified by the fixed-film in the hydroponic unit. Then some dissolved nutrients are recovered by plant uptake. Finally, water collects in a reservoir (sump) where it is returned 95% of water go back to fish culture tanks and other 5% of water transferred to agriculture farm for irrigation.

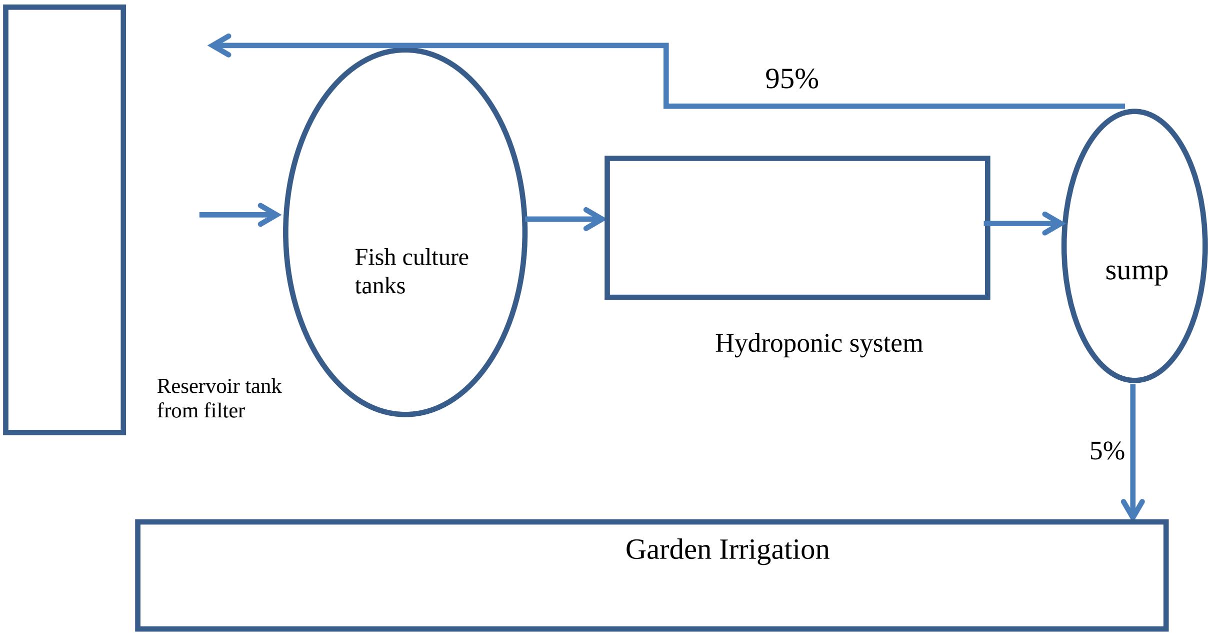

Figure 3. Suggested arrangement of aquaculture system

Improvement of Low-Quality Water in Mountain Catchments

An innovative treatment system was built as part of reaserch project in a mountain village in Jabal Akhdar, Oman (Ahmed et al. 2016). Jabal Akhdar receives more rainfall (300-400 mm) when compared to the desert plains. There are 24 retention reservoirs in the area, but most are eutrophic and the nutrient loading is due to input of animal fecal matter via surface run-off. As expected, these waters are contaminated with coliform bacteria and some also have pathogenic Escherichia coli. Drinking water needs of all the villages and the requirements of at least one large farm and a hotel are met by groundwater extraction. Because of poor quality, the surface water in the reservoirs is under-utilized. A low-cost low-maintenance treatment system was designed, constructed and operated in one village to clean the reservoir water for non-drinking human use. The treatment unit improved the water quality parameters. A survey among the adult male population of the village showed their eagerness to adopt this system and use the treated reservoir water for uses other than agriculture. The low quality reservoir water was sent through a sand trap (A), to allow settlement of soil particles (Figure 4). Subsequently, the water was conveyed by gravity to water storage tank (B), and the water dropped from near soil surface to the water level, aerating on its way. A submersible pump (C) was installed in the water storage tank, which was controlled by a float. Water lifted by the pump was sent through an irrigation filter (D). Subsequently, water enters a filter unit (E), which consisted of an activated carbon tray, 0.2 mm washed beach sand, gravel 0.3 cm, gravel 0.6 cm and stones. Following filtration, the water passed through a chlorination chute (F), packed with chlorine tablets. Filtered water mixed with chlorine was then dropped into the treated water storage tank, being aerated on its passage (Ahmed et al. 2016).

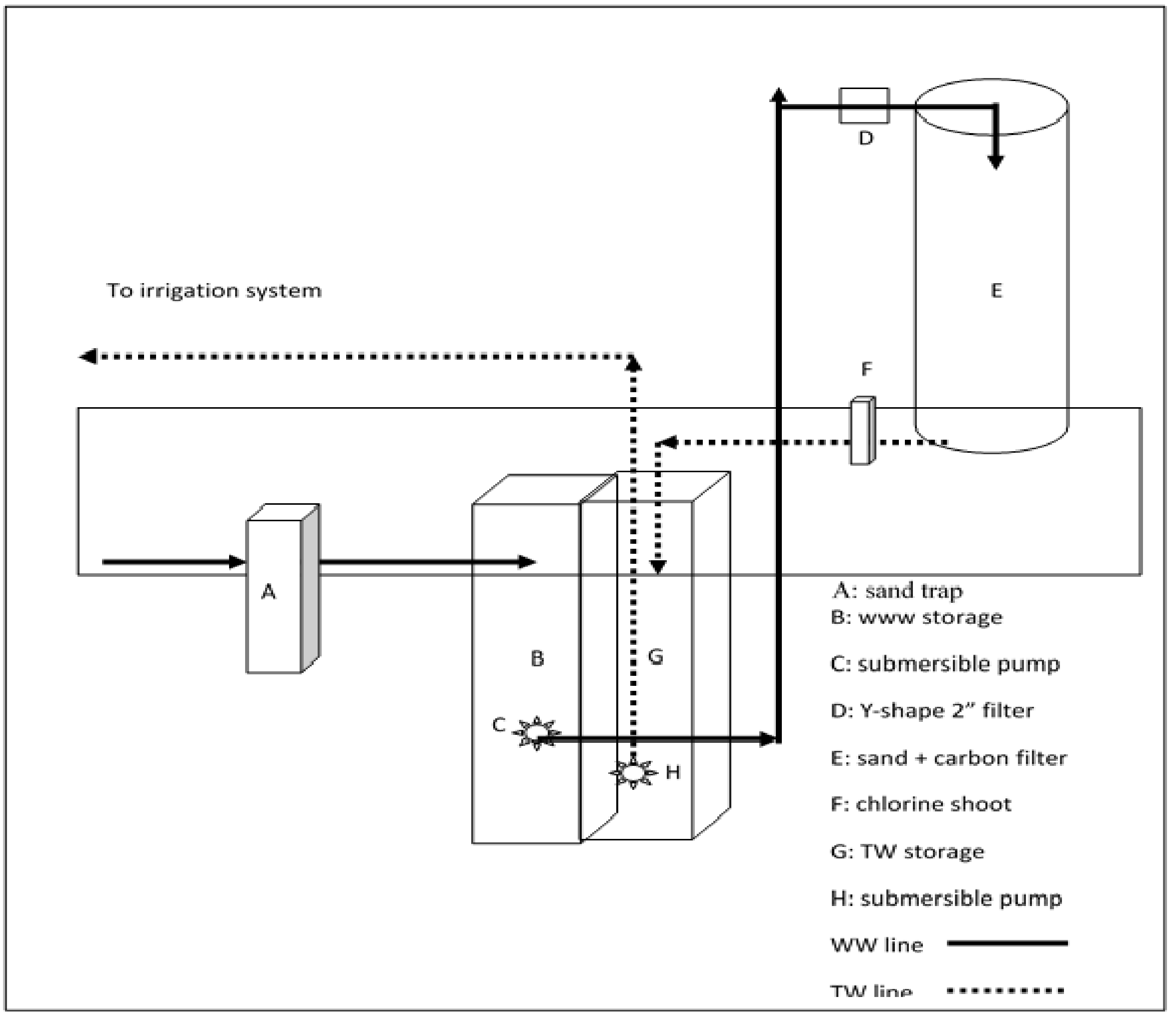

Figure 4. Proposed treatment system for reservoir waters (after Prathapar et al, 2006)

The treatment efficiency is important as well as the cost of the system. The total cost of the custom-made treatment system in the Muscat was 965 R.O (USD 2510 approx.) (Prathapar et al, 2006). Prathapar and his colleagues did a financial analysis of the treatment system. They calculated Internal Rate of Return (IRR) for 10 years effective life and it was 14.9%. However the total cost of the treatment system in Jabal Akhdar is more because of the materials need to be transported and price of construction materials had recently increased. The cost of fresh water in Jabal Akhdar is also higher than that in Muscat because it is brought by tankers.

The treatment unit significantly improved the quality of water with regards to COD, TSS and few other water quality parameters. Coliform and *E. coli* were completely eliminated. More than 85 % of the pH of the reservoir water was above 9. pH value after the treatment ranged between 8 and 8.6. The TSS (total suspended solids) value after the treatment in average was 7.16 mg/l. The value of total suspended solid before the treatment was 18 mg/l, which exceeded the Omani standard for irrigation (15 mg/l). The percentage of reduction on TSS due to treatment system was 86%. Reservoir water had a turbidity of more than 15 NTU with an average value of 17.30 NTU. An average of 39.8% reduction in the turbidity after the treatment was achieved. Chemical oxygen demand (COD) reduced by 59% after using the treatment system. Coliform and *E coli* were not detected in the treated water, but the reservoir was full of coliforms. Major cations, anions and trace elements were not reduced by the treatment system, but were within Omani standard for irrigation.

A questionnaire survey was carried out to assess the acceptability of the treatment system among the villagers. The system was first operated and was explained to them. The survey among the adult male population of the village overwhelmingly showed their eagerness to adopt this system and use the treated reservoir water for uses other than agriculture. Such change in water use pattern will definitely have an impact on groundwater extraction, as household requirement for groundwater is likely to decrease.

CONCLUSIONS

Research on small-scale wastewater treatment along with treatment of low quality water and greywater have shown mixed results in Oman. Wetlands although a proven technology in many places failed to quickly meet all the rigid government standards of wastewater treatment and reuse. Low cost physical treatment of greywater and low-quality reservoir water were successful. Treatment using Ozonation, UV and filtration along with Reverse Osmosis was proposed for textile mill wastewater. The high cost of such a system will make it unattractive for implementation. Ongoing trial of using aquaponic will allow fish factory wastewater for reuse in growing fish, vegetable and normal irrigation.

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