Health aspects of wastewater reuse for irrigation in an industrial community

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Abstract

A system of waste stabilization ponds serves an oil and gas production community along Egypt’s Red Sea coast. Effluent from the system is used for irrigation of non-edible food crops amidst the desert surroundings. The purpose of this work was to determine the suitability of this reuse application by evaluating the performance of the pond treatment system and the current irrigation practices at the site. Wastewater flows as well as chemical and biological parameters were monitored for the pond system for a period of fifteen months. Effluent generally satisfies criteria for irrigation of non-food crop plants with respect to chemical parameters. However, fecal coliform levels typically do not meet microbiological guidelines established by the World Health Organization for the flood irrigation method being used at the site. Awareness training of agricultural and other workers is required related to safety measures, personal hygiene, and soil and effluent handling to reduce both the high-risk exposure due to utilization of the flood irrigation technique, and a low-risk exposure as a result of transmission of pollutants within the worker community.

1 Introduction

Agricultural water withdrawals in Egypt represent over 83 % percent of the total withdrawal. Irrigation in many locations in Egypt is known to be inefficient in terms of water use, with substantial losses attributed to evaporation from over 30,000 km of canals, leaking of water from canals, discharge of water to non-crop areas, and discharges well in excess of uptake required by the crop [1].
There are also significant environmental challenges to the sustainability of water resources in Egypt. The most prominent in this context include salinity and the decline in fresh water as a result of the continuous discharge of untreated or partially treated domestic and industrial wastewater into the Nile system. In addition, water logging caused by flood irrigation deprives plants of oxygen and decreases crop yields. Future expansion of irrigation in the Nile basin will require innovative management of water resources to meet increasing demands and to face the associated environmental consequences. In this regard, several countries in the arid region of the Middle East practice wastewater treatment and reuse, including Kuwait, Saudi Arabia, Oman, United Arab Emirates, and Egypt [2]. However, only Israel and Tunisia, and to a certain extent Jordan, already practice wastewater treatment and reuse as an integral component of their water management and environmental protection strategies. Of Egypt's total wastewater produced, about 19% is treated and only 5.8% is reused [1].

Unfortunately, there is also documented evidence of potential problems associated with wastewater reuse in agriculture, among them health risks to irrigation workers and communities with prolonged exposure to untreated wastewater and consumers of food crops irrigation with contaminated water. Other potential problems include surface and groundwater pollution, and partial damage to certain soils. Of highest priority is addressing the threat to public health. To this end, the World Health Organization first published guidelines for the safe use of wastewater in agriculture and aquaculture in 1989 [2]. These were subsequently revised in 2000 [3]. The guidelines identify necessary treatment levels depending upon the nature of the irrigation project; for example, type of crop or terrain being irrigated, age of workers, anticipated levels of exposure, etc. Even the type of treatment is prescribed in some instances. Experience demonstrates that acceptable levels of biological and other pollutants can be reliably achieved in well designed waste stabilization ponds [4,5]. Specifically in Egypt, laboratory-scale research on the reuse of oxidation pond effluent for aquaculture proved successful, demonstrating that above average fish yields were achievable [6]. Another study focused on the microbial quality of wastewaters in Ismailia, highlighting the positive implications for the reuse of effluent for irrigation [7]. With proper management, effluent from waste stabilization ponds can be productively reused as a vital resource while protecting public health and groundwater quality [8]. Health and environmental risk assessments of wastewater reuse can thus aid in capitalizing on its benefits while mitigating its potentially negative impacts.

In view of the above considerations, a primary objective of this study was to document the performance of an existing waste stabilization pond system in an arid, coastal environment in Egypt for treatment of site sewage with respect to key wastewater indicators; namely organic concentration (measured as BOD5), solids, and coliforms. There is currently a particular concern over the high number of coliforms in the pond effluent. While coliform reduction does not constitute the sole basis for design of pond treatment processes, suitable die-off can occur if the ponds are operated properly and is closely tied to organic
loading-treatment and, to a lesser degree, to solids loading-removal. Current practice is to reuse the pond effluent for irrigation of nearby green areas for the growth of non-foodcrop plants. While this is a very desirable goal, there are unanswered questions regarding possible risk to workers engaged in wastewater treatment operations, irrigation, and cultivation.

2 Site description

The study site is an oil and gas production community, 370 km southeast of Cairo. The isolated industrial community, with a population of about 1000, generates approximately 650 m³/day of sewage which is treated by two matching lines of waste stabilization ponds. Each consists of a square-shaped anaerobic pond with total volume ~2,000 m³, rectangular facultative basin of volume ~7,200 m³, and rectangular maturation pond with volume ~1,400 m³. The corresponding full depths are 2.8 m, 1.8 m, and 1.1 m, respectively. Flow is equally distributed to the two lines by a header weir station. Flow through the ponds is regulated by exit weirs in each pond, thereby maintaining a nearly constant liquid volume, and the effluent from the two maturation ponds is combined and piped through a single line for discharge. The site represents the unique natural elements of an arid, coastal climate and landscape, with oft-high temperatures and winds producing high evaporation rates.

The community's industrial and domestic wastes are completely segregated with only the domestic wastewater piped to the waste stabilization ponds. Effluent from the system was formerly discharged to the sea. However, since Egypt's Law for the Environment (Law 4/94) was promulgated in 1994, a comprehensive program was established to utilize the pond effluent for irrigating non-edible crops (mainly cacti, succulents and garden flowers in addition to trees and grass) and maintaining plantations amidst the desert surroundings. The plant discharge is pumped through a network of pipes feeding furrows that workers use to flood irrigate the plantations near the treated ponds and throughout the community. A dedicated tank truck is used to transport irrigation water to distant plantations not accessed by the pipe network.

3 Results and discussion

3.1 Pond performance

The pond system was monitored for conventional wastewater parameters over a one-year period (August 2000 – August 2001). For each sampling event, samples were collected at the influent header, the effluent weirs from each of six ponds, and a discharge valve downstream of the combined effluent from the maturation ponds. At each sampling point, grab samples were collected according to the following: (1) 1-L in sterilized glass bottle for organics (BOD₅ and COD) and NH₃-N analysis; (2) 100-mL in sterilized polyethylene bottle for biological (coliform) analysis; and, (3) 1-L cleaned polypropylene bottle for
other inorganic analyses (TSS, alkalinity, hardness, chloride, nitrate, phosphorus, iron, manganese). Samples were stored in an ice chest immediately after collection and transported to the laboratory for immediate analysis in the case of biological and organic parameters. Initial events also analyzed for the heavy metals Pb, Cu, Cr, and Cd by atomic absorption spectroscopy. In every instance, analytical procedures were conducted according to Standard Methods [9]. Temperature, pH, total dissolved solids, and dissolved oxygen were measured directly on site using field probes.

Due to the arid climatic conditions characterized by high temperatures and winds, evaporation was measured and incorporated in subsequent analysis. To estimate evaporation from the ponds, an evaporation pan was installed on site. Monthly average influent flow to the plant during the study period ranged from 538 to 800 m$^3$/day with an average of 648 m$^3$/day. Measurements from the evaporation pan yielded monthly averages ranging from 11 mm up to 26 mm, an average monthly rate of 17 mm, and a corresponding monthly average evaporation rate of 206 m$^3$/day using water surface areas calculated for the ponds. The evaporation typically peaks in July or August and may amount to nearly 40% of the inlet flow. This drops to less than 15% during the winter months. The seasonal variations in evaporation are dampened somewhat by the fact that overall sewage flows are higher during the summer months. While this considerable evaporation concentrates water quality parameter values, it also serves to proportionally increase the residence time for the ponds, lending an advantage to decay processes such as coliform reduction.

Seasonal variations are also depicted in Figures 1 and 2. Figure 1 illustrates the strong seasonal (i.e., temperature) dependence of sewage inflow and evaporation. Figure 2 is a companion plot illustrating seasonal variations in effluent fecal coliform concentrations, the focus of the investigations in this paper. Matching the plots and associated variables indicates that the actual number of fecal coliforms in the effluent corresponds closely to the temperature; i.e., the numbers are higher in summer than winter. However, concentration of fecal coliforms is masked somewhat by the higher outlet flow rates during the summer months. Nevertheless, the trend is still visible.

Table 1 presents average effluent values and percent removals based on inlet concentrations for five key wastewater quality parameters. These data represent eleven sampling events over the study period. Effluent from the pond system by-and-large satisfies criteria for irrigation of non-food crop plants with respect to chemical parameters. Total suspended solids, ammonia nitrogen, and pH are all well within acceptable limits. Measured COD values are a little high, but BOD values are within an acceptable range. Chloride is also high, but this is expected given the coastal environment. The plantations being irrigated at the site are capable of handling these elevated levels of chlorides. Furthermore, despite the high chloride, TDS values in the effluent are within acceptable limits. Metals, including Fe, Mn and four heavy metals, were all well below published criteria for irrigation reuse. The primary problem is coliform bacteria levels which are an order of magnitude higher than preferred values.
Figure 1: Seasonal variations in temperature and flows for the pond system.

Figure 2: Seasonal variations in effluent fecal coliform concentration.

Table 1: Effluent from Pond System

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Influent</th>
<th>Effluent</th>
<th>% Removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOD₅</td>
<td>mg/L</td>
<td>88</td>
<td>22</td>
<td>75</td>
</tr>
<tr>
<td>TSS</td>
<td>mg/L</td>
<td>121</td>
<td>23</td>
<td>81</td>
</tr>
<tr>
<td>NH₃-N</td>
<td>mg/L</td>
<td>34.3</td>
<td>10.3</td>
<td>70</td>
</tr>
<tr>
<td>Total Coliforms</td>
<td>/100 mL</td>
<td>1.42×10⁷</td>
<td>6,260</td>
<td>&gt; 99.9</td>
</tr>
<tr>
<td>Fecal Coliforms</td>
<td>/100 mL</td>
<td>1.18×10⁷</td>
<td>5,340</td>
<td>&gt; 99.9</td>
</tr>
</tbody>
</table>
4 Health aspects of wastewater reuse in irrigation

Given the typically high pathogen reductions in waste stabilization ponds, with removal levels of 100% for Protozoan cysts and Helminth eggs [10], monitoring of bacteria and viruses may suffice as an indicator of treatment effectiveness. Moreover, due to the dominance of fecal coliform bacteria in human wastes and its relative ease of enumeration, it has gained wide acceptance in assessing wastewater treatment performance.

The means of exposure to a contaminant dictates both risk levels and protection measures for that specific contaminant. Therefore, the means of handling and exposure to pond effluent must be addressed in assessing worker health risks from fecal coliform contamination. In addition, irrigation methods and practices will also dictate the ultimate fate of the contaminant in the environment. Most of the effluent from the ponds at the site is used to irrigate plantations in the vicinity of the ponds. Gravity flow across weirs maintains continuous flow between successive ponds; however, effluent from the maturation ponds is combined and pumped during daylight hours. The pump serves to deliver the water to a small network of pipes that are used to transport water to the irrigation plots. These pipe outlets feed into furrows that workers use to manually flood-irrigate isolated basins (approx. 3 x 4 m). Several sprinklers are connected to the supply lines, but their use has recently been discontinued. Irrigation is rotated weekly, with each plantation basin being irrigated every two to three days. Even though workers use protective wear (coveralls, boots, and gloves), the dependency on manual irrigation methods results in their frequent and direct contact with pond effluent.

4.1 Pathogenic organisms

Domestic sewage contains a large range of gastrointestinal pathogens including viruses, bacteria, protozoa, and helminthes, known to be responsible for a multitude of diseases within humans. Based on the results reported above, the constituents of concern with respect to human and environmental exposure as a result of reuse of treated wastewater are pathogenic bacteria, most notably fecal coliforms. In particular, *Escherichia Coli* (E. Coli), a type of fecal coliform, is considered a strong indicator of the presence of many other types of disease-causing organisms. Even though typical sewage will contain varying amounts of bacteria, viruses, and parasites, *Escherichia Coli* will always be present. If identification of E. Coli is achieved, then further analysis is required to assess the availability of viruses and parasites. But the reverse is not true. Testing for E. Coli is therefore of extreme importance in assessing sewage related pollution and health risks, and is recognized in setting the WHO wastewater reuse standard as discussed below. While coliforms respond similarly to environmental conditions and treatment conditions as many bacterial pathogens, it must be borne in mind that they may not adequately predict the presence or concentration of pathogenic viruses or protozoa [3].
4.2 Guidelines for the reuse of reclaimed wastewater

Several guidelines have been published on the use of wastewater in agriculture and aquaculture [3,12,13]. The common objective is to encourage safe use while protecting the health of the workers involved and the public as a whole. Distinction must be made between domestic (or municipal) and industrial wastewater. This distinction is important since industrial waste could include a large number of pollutants, each of which could be the scope for a detailed risk analysis study. The focus of this work is on reclaimed domestic wastewater for use in agriculture that does not contain substantial industrial input.

For municipal wastewater, guidelines aim to prevent transmission of communicable diseases while optimizing resource conservation and waste recycling. Most guidelines assume a degree of treatment be applied to the wastewater to remove pathogenic organisms prior to reuse. Emphasis is therefore on control of microbiological contamination rather than on avoidance of the health hazards of chemical pollution. Current World Health Organization (WHO) guidelines are more lenient than in the past, reflecting an effort to apply more realistic approaches to the use of treated wastewater and consideration of recent epidemiological evidence [5]. Total and fecal coliform organisms are often used in conjunction with specified requirements for treating wastewater in order to reduce expensive and time-consuming monitoring of treated water for pathogens. In practice, however, this approach has led to guidelines of zero fecal coliform bacteria per 100 mL for water used to irrigate crops that are eaten raw, in addition to a requirement for secondary treatment, filtration, and disinfection. The U.S. Environmental Protection Agency (USEPA) and the U.S. Agency for International Development have both taken this approach, and consequently have recommended strict guidelines for wastewater reuse [13,14].

The WHO coliform guideline is less stringent than earlier recommendations, but is in accord with modern standards for bathing waters and more than adequate to protect the health of consumers. Effluents complying with both WHO and EPA guideline values can be simply and reliably produced by treatment in a well designed series of waste stabilization ponds [3]. The WHO and USEPA guidelines are both categorized based on the type of application. In the case of hot climates, studies indicate that the WHO guidelines are appropriate, particularly in the instance of arid or semi-arid environments where the lack of humidity or moisture content in soil is detrimental to the survival of organisms [2,10]. Other important variables are the presence of soil organic matter, temperature, the amount of solar radiation, pH, and the presence of microbial or floral competitors. Typical survival times for fecal coliforms are 30 days in freshwater and sewage, 15 days in crops, and up to 20 days in soil [15].

4.3 Occupational health risks

Effluent guidelines are categorized based on the type of reuse where, for example, unrestricted irrigation refers to irrigation of trees, fodder crops, fruit
trees and pasture, and restricted irrigation refers to edible crops, sports fields and public parks. It is important to note that crop restriction provides protection to consumers but not to workers and their families. Measures for their protection are separately covered under occupational health and safety guidelines.

Flood irrigation is the most extensively used irrigation method in Egypt [16]. Flooding involves the least investment but probably the greatest risk to field workers. Protective clothing, post work hygiene, and avoiding hand-to-face or hand-to-mouth habits can significantly avoid unnecessary risks. Of greatest risk is human contact with untreated wastewater. Local habits and practices can significantly increase worker risks, with this being most evident in bare-footed workers. However, awareness and personal hygiene training, along with occupational protective gear, as well as the recognition that work clothes remain contaminated after workers return to their homes, are effective worker defenses in handling reclaimed wastewater.

Pathogen levels in aerosols caused by spraying of wastewater may pose an additional human health risk. Airborne pathogens can also exist in localities with high wind speeds. Infection or disease may be contracted directly by inhalation or indirectly by aerosols deposited on food, vegetation, and clothes. In general, bacterial and viruses in aerosols remain viable and travel farther with increased wind velocity, increased relative humidity, lower temperature, and lower solar radiation. Aerosols can be transmitted for several hundred meters under optimum conditions. For reuse of inadequately disinfected wastewater, the general practice is to limit exposure to aerosols through design or operational controls. Design features include windbreaks (such as trees); low pressure irrigation systems or spray nozzles with large orifices to reduce the formation of fine mists; low-elevation sprinklers; and surface or even subsurface application. Operational measures include spraying only during periods of low wind, not spraying when wind is blowing toward sensitive areas, and irrigating at off hours when the public or employees would not be in areas subject to aerosols or spray. A significant precaution is the continuous awareness of field workers to wind direction, and to minimize their exposure by being upwind of the aerosol source.

5 Summary and recommendations

Even though the evidence signifies the inherent risks to the use of untreated wastewater in agriculture, it nevertheless promotes its use for appropriate crops. With the necessary occupational health precautions and measures to safeguard public health, untreated wastewater is a viable and economic option. By comparison, treated wastewater should be a desirable commodity.

Based on WHO microbiological guidelines for treated wastewater [2,3]), irrigation practices at the study site are Category B2; i.e., flood irrigation with restricted application to non-edible crops and exposure to adult workers only. Under these conditions, fecal coliform counts should be less than 1000/100 mL. As given in Table 1 fecal coliform levels in the treated effluent do not meet these conditions for the pond system as evaluated during the study period. Therefore,
adherence to the safety measures presented in Section 4 above is important to minimize negative health effects. In addition, an effort should be made to improve the treatment efficiency of the pond system, perhaps by installation of baffles in the facultative ponds to increase the retention time and, therefore, the destruction of bacteria.

The current disuse of elevated sprinklers for irrigation should be continued to mitigate exposure to contaminated aerosols. Moreover, personnel working in the vicinity of the ponds wear protective eye wear to guard against exposure to aerosols, especially during times of high winds common to the area.

In general, field practices at at the site are satisfactory from a public health viewpoint. However, awareness training of agricultural workers should be implemented in two major areas. The first should emphasize soil and effluent handling. Field workers should be aware that elevated levels of pathogens in the effluent water are transferred to the soil, and therefore safe practices need to be continued when handling the soil after irrigation. This is deemed a high-risk exposure as explained below. The second area is additional awareness regarding personal hygiene pertaining to risks associated with the transport of pollutants to other locations within the community by the workers themselves. In some instances workers return to communal gatherings and meal rooms during the day with the same working clothes used in the field. Workers exposed to reused irrigation water or soil may transmit contamination to the labor community and roommates via contaminated clothes. This is considered a low-risk exposure.

Even if fecal coliform concentrations within satisfactory limits can eventually be attained from the pond system, it is important to continue regular monitoring of coliform levels in the effluent. It may also be prudent to analyze for other parasites and viruses (e.g., nematodes, helminthes, or enteroviruses) on an infrequent basis (e.g., once per year or once every winter and summer).

In general, risks to populations are dependent on the irrigation method used. As indicated above, a high risk exposure to field workers has been identified, due mainly to practice of the flood irrigation technique (and from bacterial aerosols as a result of high winds year round at the site picking up and transporting contaminants from ponded water). In addition to posing health risks to workers and the community, flood irrigation also enhances potential for groundwater contamination compared to other irrigation methods. While it is unlikely that large-scale substitution of flood irrigation will not take place at the site for economic and other reasons, additional laboratory and field investigations yielded recommendations that should mitigate the negative features of flood irrigation. For instance, soil bacterial contamination was found to be at its highest levels within 48 hours from irrigation. Therefore, field workers should avoid handling irrigated soil entirely during this period. It is important to note that due to bacterial growth in the soil, concentrations of bacteria in soil well exceed (by as much as an order of magnitude) that of the ponded effluent, and that complete bacterial decay required 7 (seven) days from the time of irrigation. Therefore, irrigation cycles should be at 4- to 7-day intervals to allow enough time for natural decay of bacteria to occur in soil.
References


