Using Municipal Wastewater For Irrigation: Environmental Hazard or Opportunity

SARFRAZ MUNIR*, MUHAMMAD ANJUM AMIN**, MUHAMMAD RIZWAN ASLAM***, MEHMOOD-UL-HASSAN****, AND JEROEN ENSINK*****

ABSTRACT

Wastewater irrigation has been practiced since long in the vicinity of the large cities, towns and municipalities. Like most developing countries, the municipalities in Pakistan are not financially strong enough to spend money on treatment plants for wastewater. There are only two options for wastewater disposal, i.e. dumping into the agricultural drains, which mostly end up in irrigation canals, or irrigating the adjacent lands, and therefore localizing hazards associated with its use. However, wastewater irrigation may degrade the soils and groundwater. A research is being undertaken in the vicinity of Haroonabad Municipality where wastewater irrigation has been practiced since 1960. The objectives of the study are: estimation of Chemical and Biological quality of waste water, prediction of the potential hazards on groundwater, and risk assessment for the workers and users.

The analysis of wastewater samples shows the existence of some heavy metals, Co and Cr were found more than the FAO standard for irrigation. The comparison of the groundwater samples from the ww (wastewater) irrigated lands and the cw (canal water) irrigated lands manifests slightly higher accumulation of the heavy metals in the groundwater of ww irrigated lands. The microbiological analysis of groundwater exhibited higher number of E.Coli *in ww site's sample than groundwater from the cw irrigated lands, but these* E.coli *are not important from agricultural point of view. In addition to this the Total Colifrom and helminth eggs were also detected in higher quantities in wastewater which are higher than the WHO/FAO standards for wastewater irrigation. The hookworms and roundworms were also detected in the wastewater samples. The EC of ww was higher than the cw and contrary to this the DO, was less than the CW. Diarrhea. Dysentery cases and Nail problems were higher in the wastewater users and their families than the canal water users. By dumping the wastewater in the nearby drain, the quality of the drainage effluent will be degraded, effecting a larger part of the community in terms of health risks, and environmental hazards.*

1. INTRODUCTION

The global water shortages and food security issues related to population explosion necessitate shifting fresh water away from agriculture to more pressing uses. Therefore, search for new water resources for irrigation is required, among which is the re-use of wastewater for agricultural purposes. Wastewater irrigation has long been adopted in the developing and developed countries, due to its high fertility, as well as due to lack of infrastructure and facilities for disposal of wastewater effluent. A typical wastewater effluent is composed of dissolved solids, many organic and inorganic substances, pathogenic organisms, nutrients and heavy metals.

* Junior Researcher Water Management, ** Junior Agricultural Engineer , *** Water Resource Engineer, ****Senior Social Scientist, and ***** Consultant,
International Irrigation Management Institute (IIMI) Pakistan, Multan Road, Chowk Thokar Niaz Baig, Lahore

The use of wastewater effluent for irrigation has manyfold benefits for farmers: one the availability of excess amount of nutrient rich water; and on the other hand prevention from environmental pollution caused by disposing the wastewater effluent off into the drainage and the irrigation networks. Wastewater irrigation also serves as a "natural" treatment method. The wastewater is also considered the best substitute of the freshwater shortages. Together with these benefits, the wastewater irrigation also has some potential hazard such as health risks for the irrigators, groundwater and soil contamination by NO_3 leaching and the heavy metals accumulation. The heavy metal accumulation is much serious environmental concern, which causes the toxicity to the plants and the animals.

These environmental threats require the disposal of wastewater effluent after proper treatment, which seems impossible in the prevailing deplorable financial conditions of the municipalities. The municipalities in developing countries even do not have enough money to pay their staff. So in this depressing scenario the best and the most environmental friendly wastewater disposal options are limited to wastewater irrigation or dumping it in the drainage network. From public health standpoint, the chemical constituents and pathogenic organisms are of major concern in the wastewater that may cause adverse long-tem health effects for workers and the people dwelling around wastewater irrigated sites. However little knowledge is available in Pakistan about the actual risk of wastewater due to absence of analytical facilities.

The paper aims at comparing the two most commonly used alternatives for wastewater disposal by estimation of chemical and biological quality of wastewater, prediction of the potential hazards on groundwater; and risk assessment for the workers and users.

2. REVIEW OF LITERATURE

As for as water quality is concerned the Electrical Conductivity, pH, Total Dissolved Salts, Dissolved Oxygen, Biochemical Oxygen Demand, and pathogenic organisms are important to study. Their importance has been described in the following.

According to Westcot and Ayers [1], pH of wastewater affects metal solubility as well as alkalinity of soils. Normal range in municipal wastewater is pH 6.5-8.5, but industrial wastes can alter pH significantly. In most of the city surface water supplies generally have lower levels of salt than ground waters. The majority of cities, however, take their water supplies from ground water, which varies greatly in quality. The restricted value of more than 3.0 mS/cm for EC with 10 to 20 % may be of little significance. TDS values more than 2000 mg/l are not considered suitable for wastewater irrigation. Above normal values of pH 6.5-8.5, can effect the crop yields. Occasional problems of abnormal pH are corrosion of pipelines and equipment, irrigation water system clogging, and high residual chlorine occurs. pH outside the normal range is an indicator of abnormal waters.

The work of Broadbent and Reissenauer [2] on nutrients and their presence in the municipal wastewater suggests that it provide fertilizer benefits to the crops and land production but in certain instances when in excessive amount would cause problems related to excessive growth, delayed or uneven maturity. The most beneficial and the most frequently excessive nutrient is nitrogen. The concentration of wastewater containing 20, 40, 60 mg/l considered weak to strong concentrated. Phosphorous is an essential element in the growth of plants and facilitates flowering and maturity.

In small quantities, many elements are essential for plant growth but their high concentration leave negative effects by causing toxicity to plants and animals. In wastewater effluent the high concentration of heavy metals is considered harmful for the plants utilizing this water, soils and groundwater. The major sources of Heavy metals in municipal wastewater effluent are their use in industrial processing and the wear of household plumbing fixtures and community water supply systems [3].

The epidemiological diseases can be transmitted either by contact, ingestion, or by inhalation of infectious agents. The contact with infectious microorganisms does not always result in illness. The illness occurrence depends upon the interrelationships between the host and the infectious agent. Crook, [4], defined illness causing variables as following

(i) Number of the invading micro-organisms (dose)

(ii) Number of the organisms necessary to initiate the disease (infective dose)

(iii) Organisms ability to cause the disease (Pathogenicity)

(iv) The degree to which the organism can cause the disease (virulence)

(v) And the relative susceptibility of the host.

Chughtai and Ahmed [5] specified the number of infective doses of the microorganisms causing diseases. For example 10^8 Enteropathogens, *E.coli* are necessary to cause disease, 10 *shigella* can cause infection and 20 cysts of *E. histolytica* are essential to cause infections.

Nitrate in water is considered a final oxidation product of nitrogen-containing matter. Nitrate concentration of several parts per million may indicate contamination by sewage water. The effect of nitrate on industrial and agricultural use of water is negligible but excessive nitrate in drinking water is a main cause of a condition in infants known as methemoglobinemia "blue baby disease". This disease is much common in ruminant animals than in humans (Broadbent and Reissenauer, [2]). The nitrate content in excess of 45 mg/l should be regarded as unsafe for infant feeding.

Adequate concentrations of dissolved oxygen are necessary for the life of fish and other aquatic organisms and the prevention of offensive odors. Dissolved oxygen levels are considered the most important and commonly employed measurement of water quality and indicator of a water body's ability to support desirable aquatic life.

3. METHODS AND MATERIALS

3.1 Study Area

The study was carried out on wastewater area of Haroonabad town, Bahawalnagar district in southern Punjab. It is situated at the edge of the Cholistan desert with a population of approximately 79,000 (Department of Public Health). Groundwater is brackish having EC of 3 - 3.5 mS/cm and unfit for drinking purposes. The climate in the area is characterized by large seasonal fluctuations in temperature and rainfall. Rainfall is mainly limited to the monsoon period of July, August with average of 200 mm/year. The ground water table, that was upto 30.48 meter below the surface before the introduction of the canal irrigation system, has risen drastically and is between 0 and 1.5meter below the surface in 70 % of the area (WAPDA, [6]). The main crops of the research area are a variety of vegetables during both *Rabi* and *Kharif* seasons, wheat, cotton and sugarcane are also cultivated in the wastewater irrigate area.

The Haroonabad town is dependent upon irrigation water from Hakra-4/Rcanal for agriculture, industrial and drinking purposes. At present, the water supply scheme consists of one permanent connection with Hakra 4-R canal. It consists of five sedimentation tanks, filter beds, clear water well, pumping house and overhead storage, several main, lateral pipelines. According to the city map about 80% of the households has a household connection and 182 l/day/capita water supply has been observed (Ensink *et al*, [7]).

Irrigation in and around Haroonabad happens at several sites with raw sewage sometimes in combination with the canal water. Some of these sites are only recently irrigated with wastewater others, including the main site, already for over last thirty years. At present a pumping house is in functioning near the bus station, which disposes the sewage from the main sewer. The Main disposal scheme consists of two pumps (40HP) work for round the clock. An area of 149 hectares is irrigated with wastewater. The total discharge from the main sites is approximately 3456 m^3/day of raw wastewater (Ensink *et al*, [7]).

3.2 Methods

3.2.1 Sampling

A 24hr wastewater monitoring was conducted at the wastewater disposal site in April, 2000 for EC, pH, DO, NPK and Heavy Metals analysis. The EC, pH and the DO were measured at the spot with an interval of two hours whereas samples for other chemical analysis were collected in the bottles with the same interval.

For groundwater analysis, 28 observation wells were installed in the waste water irrigated land, among which 13 were installed at a distance of 100 meters and rest of the wells were installed one per 10 hectares. These wells were installed at a depth of 7.62 and 4.57 meters respectively with filter at a 3 meter depth from the soil surface. A handpump with a tube was used for collecting the water samples from wastewater area, whereas IWASRI observation well was used to get the sample from the canal water irrigated lands.

Nasco Whirl-Pak sampling bags were used in water sampling for *E.coli* analysis. For helminths and protozoan analysis the wastewater samples were brought 24 hr before the centrifugation of the sample for settlement of all the micro-organisms in the bottom.

3.2.2 Chemical Analysis

Portable Data Logging Spectrophotometer (HACH DR/2010 [8]) were used for the analysis of Nitrate (NO_3-N), Ammonia (NH_3) and Total N, P, K. HACH CO150 conductivity meter and TRANS pH meter were used to measure EC (Electric Conductivity) and pH respectively. HACH CO150 conductivity meter or DO 175 meters were used for the measurement of temperature in situ. HACH DO175 Dissolved Oxygen meter was used for the measurement of DO (Dissolved Oxygen). BOD Track apparatus was used for BOD analysis. The procedures as recommended by HACH company,1996, was followed.

3.2.3 Biological Analysis

For the measurement of *E.Coli*, water samples were filtered with a Millipore filter system (Millipore, USA) using a 0.45 mm Millipore filter type HA, inserted in a sterile Microfill 100 ml. funnel (Millipore), under a vacuum pressure of 10 cm Hg. The vacuum was created through a hand-pump connected to two 10-liter flasks in order to have constant vacuum during the filtration. Gelman petri dishes, GN-6 metrical membrane filters (0.45 mm/47 mm) and Agar (M-Coli Broth Blue 24) of HACH were used. Hach Portable Incubator was used for the E.Coli incubation. Erma Colony Counter was used for the counting of *E.Coli* colonies.

The number of helminth eggs per liter was collectively determined by the centrifugation flotation method, which detects ³ 20 eggs per liter. After centrifugation of the wastewater samples the slides were prepared in saline solution for detecting the pathogens under phase contrast microscope.

4. RESULTS AND DISCUSSION

4.1 Salinity Levels in Wastewater

Results reveal that the average values for pH, EC and TDS in wastewater is in permissible limit and can be used for irrigation purposes. If this effluent is directly disposed into the drain it might increase or disturb the salinity level of drainage effluent in the surface drains. The pH, EC and TDS measurements during the 24 hr monitoring have been given in Figs. 1-3 respectively. The pH values do not change much during the 24 hour period, reflecting that major activities related to water use do not change much. The values of EC and TDS are relatively lower during the peak water use hours (Table 1).

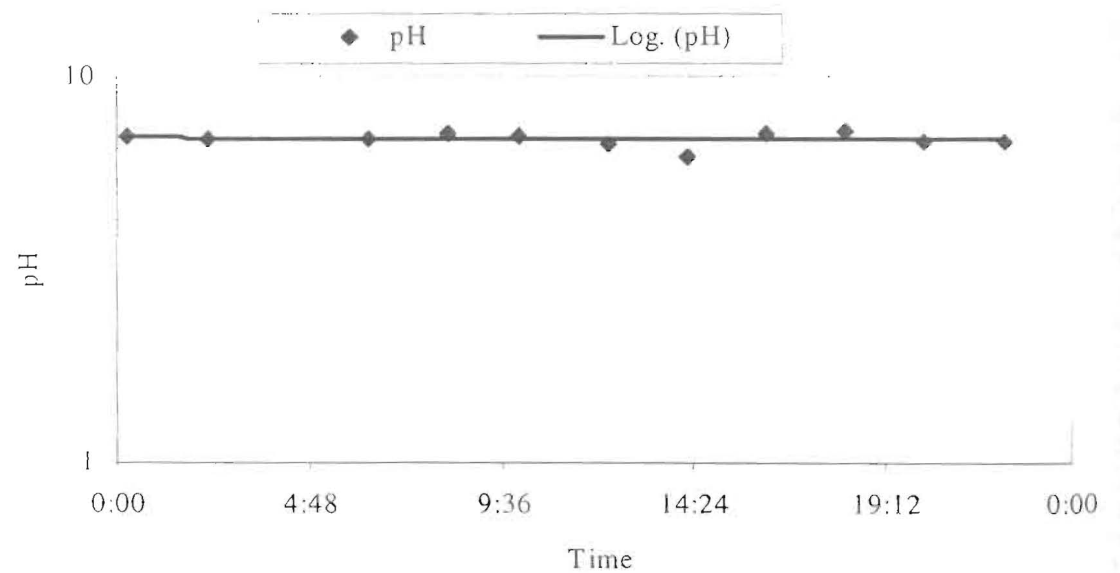

FIG. 1. TEMPORAL VARIATION IN PH DURING 24 HR MONITORING

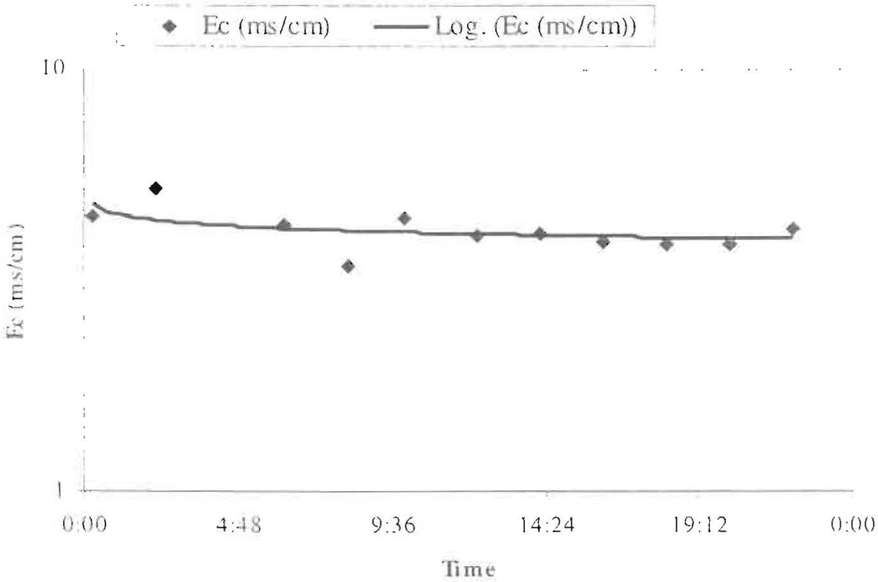

FIG. 2. TEMPORAL VARIATION IN EC DURING 24 HR MONITORING

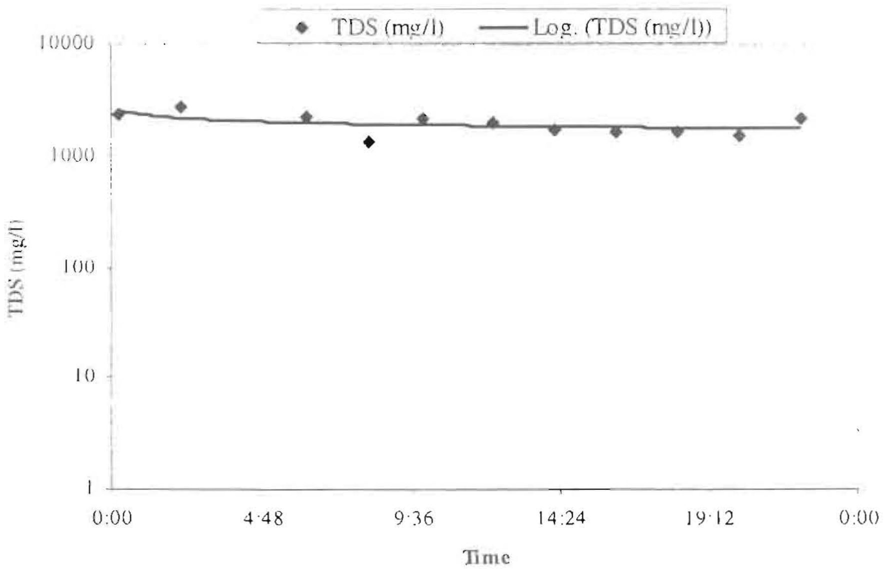

FIG. 3. TEMPORAL VARIATION IN TDS DURING 24 HR MONITORING

TABLE 1. SALT CONTENTS IN WASTEWATER EFFLUENT OF HAROONABAD TOWN

Constituent	Unit	Average values	Typical Ranges
Electrical Conductivity	(mS/cm)	4.2	0-3
Total Dissolved Salts	mg/l	1960	0-2000
pH		6.9	6.5-8.5

4.2 Crop Nutrient Status of the Wastewater

The NPK level in the wastewater has been given in the Table 2. The total nitrogen content in the wastewater was 81 mg/l. This concentration is placed in strong nitrogen concentration category. Total P and K were observed as 8.07 and 37 mg/l respectively. This shows that the water contained high amount of fertilizer. Broadbent and Reissenauer, [2] opines that wastewater application increased the crop productivity and therefore it saves the money on purchasing the artificial fertilizers. The disposing off this nutrient rich wastewater in the surface drains would on one hand waste the precious nutrients available in it, and on the other hand substantially increase vegetation in the drain and growth of weeds/reeds. The vegetation blocks the flow and ultimately reduces the efficiency of the surface drains and increase the cost of maintenance. A contemporary study on malaria found more mosquito larvae causing malaria in the water with aquatic plants than other water sources (personal communication with Muhammad Mukhtar Baig).

4.3 Heavy Metals in the Wastewater Effluent

Table 3 presents the concentration of heavy metals in the wastewater. Except Co and Cr all the heavy metals are in the range of FAO [9] standards for irrigation but Cd, Ni and Pb are in higher amounts than the drinking water standards set by WHO [10]. The concentration of these heavy metals above drinking standards restricts the option for dumping of wastewater in the drains as the communities living near the drains installed hand pumps for tapping seepage for drinking water. During extreme drought periods and canal closures, the drainage effluent is directly used for drinking both by human as well as by animals.

Though the Co and Cr have slightly higher concentration than the irrigation standards but not higher enough to cause damage to the plant tissues(Page and Chang, [3]). The relatively low concentration of heavy metals in the wastewater effluent might be due to the absence of industry using heavy metals. The occurrence of these heavy metals is due to the domestic water use, as heavy metals always exist in small amounts in the domestic wastewater (Page and Chang, [3]). The detailed fluctuations in the concentration of heavy metals during the 24 hr wastewater monitoring has been shown in the Fig. 4, revealing that the concentration of iron increases during peak work hours. The other metals do not seem fluctuating much.

Though the heavy metals are in the range of FAO standards for irrigation but their disposal to the drainage effluent will not be appreciated. In case of re-use of drainage effluent the conventional water treatment methods are not able to remove the heavy metals as they are adsorbed or precipitated by suspended solids. They are effectively removed by removing the suspended solids (Page and Chang, [3]).

4.4 Biochemical Oxygen Demand and the Dissolved Oxygen in the Drainage Effluent

The ideal dissolved oxygen level for fish is between 7 and 9 milligrams per liter (mg/l); most fish cannot survive at levels below 3 mg/l of dissolved oxygen. The amount of DO in the wastewater effluent was 3.12 mg/l which is satisfactory for aquatic life. But extremely higher value of BOD, 668 mg/l is not desirable and in case of dumping this water in drain. With this demand level, it will be a serious threat for aquatic life.

TABLE 2. NPK IN THE WASTEWATER SAMPLES

Constituent	Unit	Concentration
Total N	mg/l	81.00
Total P	mg/l	8.07
Total K	mg/l	34.00

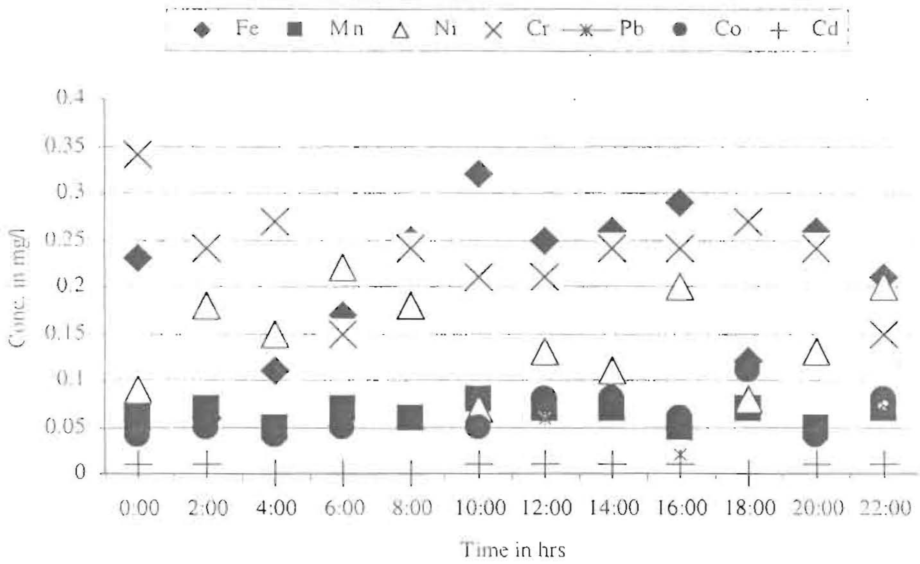

FIG. 4. HEAVY METALS CONCENTRATION DURING 24 HR MONITROING OF WASTEWATER

4.5 Pathogenic Organisms

4.5.1 Fecal Coliforms

Biological factors are significant in determining the quality of water. According to the WHO standard, the presence of fecal coliform organisms especially *Escherichia Coli* in a water sample indicates the bacterial pollution and it should be 0 count/100ml for drinking purposes. Its presence indicates health risks such as dysentery, diarrhea, typhoid, and cholera. Results revealed that wastewater contains >1000 count/100 ml of *fecal coliforms* and *Total coliforms*. If this water is directly disposed into the surface drainage systems, it would increase the microbial quantity and ultimately contaminate the quality of drainage and will effect the larger areas/communities who come in contact with this drainage effluent.

4.5.2 Helminths and Protozoan

The principle infectious agents in the wastewater are classified into bacteria, protozoa, helminths and viruses (Crook, [4]). The detected organisms have been presented in the Table 3. Among the detected organism, the protozoa, *E. histolytica* is the most serious of all the pathogens causing the amoebic dysentery and ameobic hepatitis. The other protozoan, the flagellate *Giardia lamblia* is the cause of the disease giardiasis, which is responsible for gastrointestinal disturbances, diarrhea and discomfort. The hookworm and the roundworm (helmenthic parasites) are the major cause of the diarrhea, especially in the children under 12. The eggs and larvae of helminths are resistant to environmental stresses and can be expected to survive during usual wastewater disinfecting procedure. So in drains the helminths can prove more dangerous for the communities dealing with drainage effluent.

4.6 Effect of Wastewater Irrigation on Groundwater Quality

4.6.1 Effect of Heavy Metal Contamination

The results have been presented in the Table 4, which show the slightly higher concentration of the almost all heavy metals in wastewater site's sample except Ni. This table shows that the wastewater irrigation slightly increases heavy metal contamination in the groundwater. From these groundwater analysis it can be predicted that the wastewater dumping in the drain would not exert grave influences on groundwater quality. The relationship between wastewater and groundwater heavy metal contamination is presented in Fig. 5 (Table 5).

TABLE 3. OCCURRENCE OF PATHOGENIC ORGANISMS IN THE WASTE WATER EFFLUENT

Pathogen	Class	Average Number Per Slide
Escherichia coli	Bacteria	2
Ancylostoma duodenale (Hookworm)	Helminths	4
Ascaris lumbriocoides (Roundworm)	Helminths	2
Giardia lambia	Protozoa	10
Entamoeba histolytica	Protozoa	1

TABLE 4. AVERAGE HEAVY METALS CONCENTRATION IN (MG/L) IN THE WASTEWATER

Element	WW Samples	Maximum Irrigation Standard (FAO)
Iron, Fe	0.22	5.00
Manganese, Mn	0.07	0.20
Nickel, Ni	0.14	0.20
Chromium, Cr	0.23	0.10
Lead, Pb	TA	2.00
Copper, Cu	0.04	5.00
Cobalt, Co	TA	0.20
Cadmium, Cd	0.06	0.05
Zinc, Zn	0.01	0.01

4.6.2 Nitrate in Groundwater

Results show that the wastewater contained the nitrogen amount in the range of 192-320 mg/l. The nitrate concentration in the ground water ranges between 2-192 mg/l. If the wastewater is allowed to directly dispose off in the surface drains, it would ultimately raise the nitrate level. People use seepage water from drains for drinking, and in extreme drought conditions, drink it directly. The high nitrate level is dangerous for human infants and also for ruminant animals. Disposal of wastewater will raise health risks for them.

4.6.3 Total Coliform in Groundwater

In ground water the total Coliforms were in the ranges of 25->1000 count/100 ml. Under most conditions wastewater irrigation does not present a microbiological threat to ground water since it is a process similar to slow sand filtration; most of the pathogens are retained in top few meters of the soils (Crook, [4]). But results show that certain soils allow to pass the *E. coli* to the groundwater, which might be due to the intensive irrigation and soil types.

4.7 Health Risk from Pathogenic Micro-Organisms in Wastewater

To observe the effect of these pathogenic micro-organisms on human health two villages were selected, one belonged to the wastewater irrigators and the other one of canal water irrigators. A disease survey was conducted in which all the agricultural related individuals were interviewed including the farmers, women and children visiting fields regularly. The results of the disease survey have been presented in the Fig. 6, which indicates higher prevalence of diarrhea, dysentery and nail problems among the wastewater irrigators than the canal water irrigators.

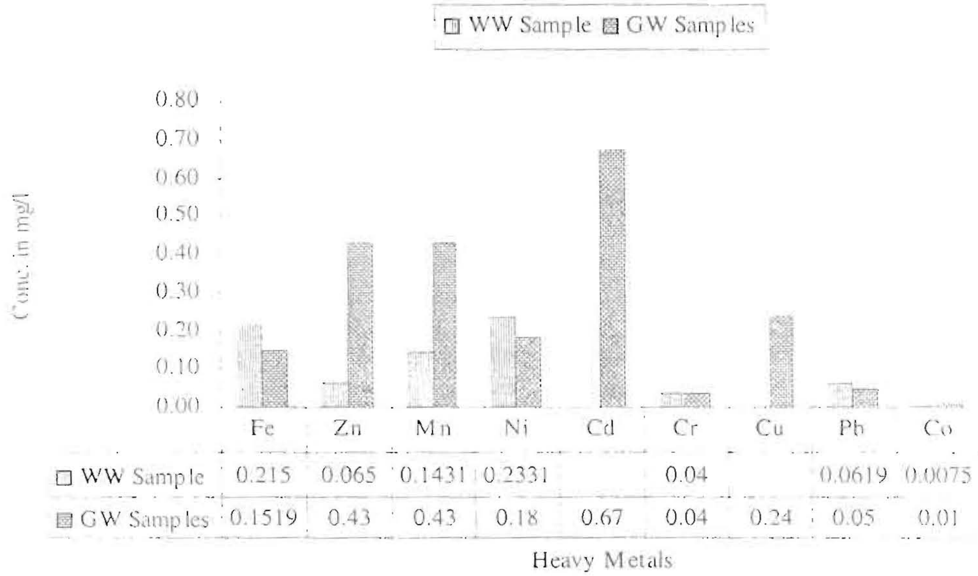

FIG. 5. RELATIONSHIP BETWEEN HEAVY METAL CONCERATION IN WATERWATER AND GROUNDWATER

TABLE 5. CONCENTRATION (MG/L) OF HEAVY METALS IN THE GROUNDWATER OF WASTEWATER IRRIGATED LANDS AND CANAL WATER IRRIGATED LANDS.

Elements	WW Irrigated (mg/l)	CW Irrigated (mg/l)
Iron, Fe	0.15	0.12
Manganese, Mn	0.43	0.1
Nickel, Ni	0.43	0.85
Chromium, Cr	0.18	0.15
Lead, Pb	0.04	TA
Copper, Cu	0.24	TA
Cobalt, Co	0.05	0.05
Cadmium, Cd	0.01	0
Zinc, Zn	0.67	TA

5. CONCLUSIONS

From these results it can be concluded that the wastewater re-use for agricultural purposes is more environment friendly as compared to disposing it off in the drains. Wastewater irrigation restricts the pollution to the directly irrigated areas, and irrigators, and therefore impacts on lower number of people and less area. Disposing the wastewater effluent off in the drains would affect larger areas and more people by increasing the concentration of NPK and pathogenic micro-organisms in the drains. The downstream users of the drainage systems will be at risk, who use the drain water for irrigation, livestock, and for drinking. The pathogenic organisms will effect the communities, which come into a direct contact with the drainage effluent either by crossing the drains in the absence of bridges and also by animal bathing. The higher values of NPK will cause

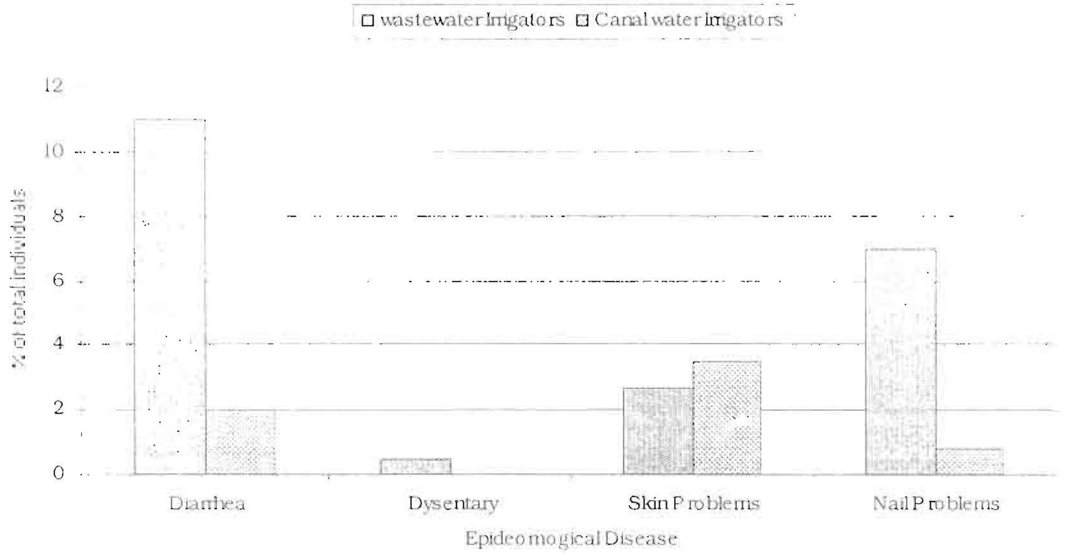

FIG. 6. DISEASE OCCURRENCE IN WASTEWATER AND CANAL WATER IRRIGATORS

the growth of undesirable weeds in drains, which will effect the drainage efficiency and would increase the maintenance cost. High level of Nitrogen will also cause the health risks if the drain water is used for drinking either directly or from seepage. The high values of BOD will be a serious threat for the aquatic life. Consequently all these factors will contribute to the environmental deterioration for larger areas.

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