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Afshin Ebrahimi
Isfahan University of Medical Sciences

Amir Mahvi

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Feasibility Study of Wastewater Reuse for Irrigation in Isfahan, Iran

[1]Fazel Mohammadi Moghadam, [2]Mokhtar Mahdavi, [3]Afshin Ebrahimi,
[4]Hmid Reza Tashauoei and[5,6]Amir Hossein Mahvi

[1]School of Public Health, Shahrekord University of Medical Science, Shahrekord-Iran
[2]Environment Research Center Isfahan, Student Research Center and School of Public Health, Isfahan. University of Medical Sciences, Isfahan, Iran
[3]Environment Research Center and School of Public Health, Isfahan University of Medical Sciences, Isfahan, Iran
[4]Assistant Professor, School of Public Health, Islamic Azad University, Tehran Medical Branch, Tehran, Iran
[5]Center for Solid Waste research, Institute for Environmental Research, Tehran University of Medical Sciences, Tehran, Iran
[6]School of Public Health, Tehran University of Medical Sciences, Tehran, Iran

Abstract: Wastewater reuse is one of the main options that can be considered as a new source of water in regions where water is scarce. The main purpose of this study is to determine the feasibility of Isfahan's north wastewater treatment plant effluent for agricultural irrigation. To evaluate suitability of treated wastewater for irrigation, important indicators like Sodium Adsorption Ratio (SAR), Soluble Sodium Percentage (SSP)and Potential Salinity were investigated. In this study the SAR value for effluent was 2.62 and according to approved criteria by Food and Agriculture Organization (FAO) it was excellent for irrigation,SSPwas 39.7% so it has good quality for irrigation usage and the potential salinity was 4.81 meq/L, thusaccording to approved criteria by FAO it is medium for soil permeability.Also the EC value of effluent was 1250 µS/cm (1.25 dS/m) and according to approved criteria by FAO it was permissible for irrigation.

Key words: Agricultural irrigation · Environment · Isfahan · Wastewater reuse · Water reuse · Wastewater treatment plants

INTRODUCTION

Problems related to water are increasingly recognized as one of the most critical and serious environmental threats to humankind [1]. Water shortage is one of these problems that have various reasons and leading cause. Now a day water reuse is implemented in many urban areas in the world to cope with this increasing water shortage.

Agriculture is the largest user of water in the entire world. Agriculture receives 67% of total water withdrawal and accounts for 86% of consumption in 2000 [2]. In Africa and Asia, an estimated 85 to 90% of all the freshwater use is for agriculture. By 2025, agriculture is expected to increase its water requirements by 1.2 times [3].

Over usage of groundwaterhas also changed the quantity and quality of water. Inadequate water management is accelerating the depletion of surface water especially groundwater resources [4].Drivers for treated wastewater reuse include increasing demand of water due to population and economical growth [5], water stress and adaptation to water scarcity and climate change [6], overuse of groundwater for agricultural purpose [7] and existence of some useful materials like nutrients (nitrogen and phosphorous), [8-9].

Wastewater contains undesirable chemical constituents and pathogens (Table 1) so; the application of inappropriate treated wastewater for agriculture product could endanger human's health [10-11]. Environmental concerns to soil texture, plants, change in groundwater quality and ecosystem were related to

Corresponding Author: Amir Hossein Mahvi, Center for Solid Waste research, Institute for Environmental Research, Tehran University of Medical Sciences, Tehran, Iran. E-mail: ahmahvi@yahoo.com.

Table 1: Biological hazard in wastewater [14]

Type	Example
Waterborne bacteria	*Salmonella sp, Vibrio cholerae, Legionellaceae*
Protozoa	*Giardia lamblia, Cryptosporidium sp*
Helminths	*Ascaris, Toxocara, Taenia (tapeworm), Ancylostoma (hookworm)*
Viruses	*Hepatitis A virus, Rotaviruses, Enteroviruses*

Fig. 1: Landscape of Isfahan's north wastewater treatment plantwith farms

quality of consumed water for irrigation [12]. Many guidelines have been developed to give a quality criteria, indicators and guidance on how treated wastewater (effluents) should be reused for irrigation purposes [13].

In Iran, about 80% of water consumption belonged to irrigation whereas only 5.8% and 1.2% belonged to Drinking and industrial consumptions, respectively.The fundamental precondition for water reuse is that, applications will not cause unacceptable public health risks [15] because wastewater contains various types of pollutants. In Iranaccording to geographical, cultural and availability of technological condition, some guideline release as environmental criteria for treated wastewater and return flow reuse [16]but,unfortunately many farm-lands around the metropolises in Iran are irrigated illegally with wastewater treatment plant effluents. Most of the farmers do not have any knowledge about hazards related to this water. On the other hand,some of the wastewater treatment plants didn't meet the designated standards for effluents discharge. So, it is very important to investigate the quality characteristics of this valuable water source and prevent adverse consequences to health and environment.

This study aims to evaluate the quality and suitability of Isfahan north wastewater treatment plant effluent for reuse in agriculture.Isfahan has hot and dry climate. This city has limited capacity of fresh water resources. The annual precipitation rate in this city was 212 mm/year. Isfahan's north wastewater treatment plant (Fig.1) has 65 hectare area with activated sludge treatment process. This plant treats 180000 m^3/ day of wastewater. Downstream of plant has greatfarm-land for agriculture.

MATERIALS AND METHODS

In this study the suitability of Isfahan's wastewater treatment plant effluent for agricultural irrigation was investigated. The guideline that recommended by Iranian department of environment selected as leading criteria for our study.Sampling from effluent had been done quarterly in 2013. The composite wastewater samples were gathered four times a day (with equal intervals of 6 h) at each month through each season and were sent to the laboratory (in the Isfahan water and wastewater company).All the examinations wereaccomplished according to the procedures described in standard methods for the examination of water and wastewater [17].

In order to determine the quality of the Isfahan's wastewater treatment plant effluent for being reused in the agricultural irrigation, important physiochemical parameters like TDS, EC, Boron, pH, chloride, sulfate, alkalinity, BOD_5, COD, TSS, TDS, Ca, Mg, Na, K, Cl, SO_4, NO_2^-, NO_3^-, PO_4, Fe, Mn, Cd, Cr, Pb, Ni and microbial parameters includedtotal coliforms, fecal coliforms and parasitic eggs were studied. Finally important indexes like sodium content, sodium adsorption ratio and Potential Salinity were taken into account.

Turbidity, TDS and EC and pH of samples were measured by TN-100(EUTECH) Turbidimeter, EC meter SENSION5 (HACH LANGE) and pH-meter CG 824 model respectively. Ca, Mg and Na were measured by Flame photometer Jenway (model PFP7). Concentrations of Mn, Fe, Cr, Ni and Cd were determined by an Atomic Absorption Spectrometer GBC Scientific Equipment (model savant AA AAS). Calcium and Magnesium were determined titrimetrically using standard EDTA. Chloride was determined by standard $AgNO_3$ titration. Sodium and Potassium were measured by flame photometry. Sulphate was determined by spectrophotometer turbidimetry. NO_3 was measured by Spectrophotometer PG Instruments Ltd (model T80). BOD was determined by the 5 day BOD test while COD was determined in the laboratory by the standard Open Reflux Method.

Equation-1 $SAR = \frac{Na}{\sqrt{\frac{Ca+Mg}{2}}}$

Equation-2 $Na\% = \frac{Na \times 100}{Ca+Mg+Na+K}$

Equation-3 Potential Salinity = $[Cl^{-} + (SO4^{-2}/2)]$

concentrationsare as milliequivalents/liter.

RESULTS AND DISCUSSION

Examination results of effluent from Isfahan's North wastewater treatment plantare presented in Table 2.

Hydrogen Ion Activity (pH) and Alkalinity: The pH of water describes how acidic or alkaline it is. This parameter can affect plant growth, irrigation equipment and soil characteristics. Alkaline water with pH 8 or = 9 may contain high concentrations of bicarbonate and carbonates, respectively. High bicarbonate and carbonate

Table 2: Comparison of Isfahan's North wastewater treatment plant effluent characteristics with Iran standards for agricultural reuse

Parameter	Unit	Average in WWTP effluent	SD	agricultural reuse standard in Iran
pH	-	7.5	0.08	6-8.5
Turbidity	NTU	43	3.5	50
EC	µs/cm	1250	258	-
TSS	mg/l	90	0.9	100
TDS	mg/L	770	10	-
BOD_5	mg/L	80	1.6	100
COD	mg/L	240	1.3	200
Alkalinity(as $CaCO_3$)	mg/L	395	10	-
NO^{-}_2 (Nitrite)	mg/L	0.006	0.9	10
NO^{-}_3 (Nitrate)	mg/L	2.09	0.8	50
PO_4^{-3} (Phosphate)	mg/L	1.7	0.4	-
SO_4^{-2} (Sulfate)	mg/L	70	4.2	400
Na^+ (Sodium)	mg/L	108	1.1	-
K^+ (Potassium)	mg/L	18	0.9	-
Ca^{+2} (Calcium)	mg/L	107.6	0.5	-
Mg^{+2} (Magnesium)	mg/L	19	0.8	100
B^- (Boron)	mg/L	0.09	0.003	1
Cl^- (Chloride)	mg/L	147	3.1	600
Cd^{2+} (Cadmium)	mg/L	0.007	0.002	0.05
Cr^{3+} (Chromium	mg/L	0.009	0.003	1
Pb^{2+} (Lead)	mg/L	0.01	0.002	1
Ni^{2+} (Nickel)	mg/L	0.008	0.003	2
Fe^{2+} (Iron)	mg/L	0.11	0.04	3
Manganese	mg/L	0.05	0.003	1
Total coliforms	MPN/100ml	4×10^5	2×10^3	1000
Fecal coliforms	MPN/100ml	2×10^4	2×10^2	400
Parasitic eggs	No/L	0	0	0

Table 3: Typical recommendation values for irrigation water according to SAR index

SAR Values (meq/L)	Sodium Hazard to Soil
0-10	Low
10-18	Medium
18-26	High
> 26	Very high
2.62	Isfahan's WWTP Effluent

Table 4: Criteria for irrigation water by FAO and comparison by obtained results [23]

Water Quality	B^- (mg/L)	Cl^- (mg/L)	Na %	EC (µs/cm)	SAR
Excellent	0.5	< 70	< 20	< 250	< 10
Good	0.5-1	70-140	20-40	250-750	10-18
Permissible	1-2	140-280	40-60	750-2000	18-26
Doubtful	2-4	> 280	60-80	2000-3000	> 26
Unsuitable	> 4	-	> 80	> 3000	-
Isfahan's WWTP Effluent	0.02	147	39.7	1250	2.62

levels can cause magnesium reduction and precipitation of calcium from the soil so the soil's exchangeable calcium content decreased or soil sodicity increased. Finally the loss of soil calcium and magnesium will affect plant growth. Results showed that effluent pH was 7.5 (Table 2) and it located at normal pH range for irrigation water.

When calcium precipitated magnesium replace it and if manganese didn't have enough amounts the relative proportion of sodium is increased that is very hazardous for soil and plants [18]. This hazard can be evaluated by Table 3. According to results at this table, Isfahan's treated effluent has low hazard to its farm land soil.

Turbidity: Turbidity in wastewater is a measure of water clarity and anindicator of the quantity of suspended solids along with microorganism. The major problem for application of turbid water in irrigation include: blocking irrigation spray nozzles, build-up of sludge in drippers and pipes, deposit heavy sediment on leaves and finally reducing photosynthesis. In this study the effluent's turbidity was 43 NTU and it could meet the Iran standard for irrigation.

Salinity Hazard: One of the most important effects on the environment that caused byagricultural wastewater is the increases in soil salinity, which can decrease productivity in long term[19]. This parameter affects the osmotic properties, which limits the ability of plants to take up water.Salinity is measured by electrical conductivity (EC), which is a measure of the concentration of ions in water or solution.EC and TDS mean values of experimental samples was 1250 µS/cm (1.25 dS/m) and 770 mg/l respectively. According to approved criteria by FAO (Table 3) EC amount of effluent are permissible for

Table 5: Potential Salinity value by FAO/UNESCO-1973 to ensuresustainability

Potential Salinity (meq/L)	Desirable soil permeability
5-20	Good
3-15	Medium
3-7	Low
4.81	Isfahan's WWTP Effluent

irrigation. Iran had not published any standard for TDS but TDS concentration of IN-WWTP effluent (770 mg/L) is in the acceptable ranges according to FAO standard (Usual TDS range in irrigation water was 0 to 2000 mg/l).

Sodium Hazard and Sodicity: Sodium content is the important factor in irrigation water quality evaluation. Excessive sodium leads to development of an alkaline soil that can cause soil physical problems and reducing soil permeability. Also irrigation with water containing large amounts of sodium is of special concern due to absorbed sodium by plant roots which is transported to leaves, accumulate there and cause injury [20].

Sodium hazard is expressed in terms of Sodium Adsorption Ratio (SAR) and it can be calculatedfrom equation 1. Sodic soil commonly considered as a soil that contains an exchangeable sodium percentage (ESP) of = 15% or have SAR of 13 or more [21]. So according to Table 3 Isfahan wastewater treatment plant effluent (SAR=2.62) didn't have any sodic effect on adjacent soil. In this study SAR value for effluent was 2.62 and according to approved criteria by FAO (Table 4) and table 5 it was excellent for irrigation. Soluble Sodium Percentage (SSP) or Na content is another parameter that can be use to evaluate sodium hazard (equation 2).

Table 6: Chloride classification of irrigation water [25]

Chloride (ppm)		Effect on Crops
Below	70	Generally safe for all plants.
70-140		Sensitive plants show injury.
141-350		Moderately tolerant plants show injury
Above	350	Can cause severe problems.

Sodium causes soils to disperse or lose soil structure. Degradation of soil physical properties is caused by sodium and soil structure is considerably affected in the long run by the sodium content (equation 2) in the irrigation water. When sodium enters into cation exchange relationship with clay, this in turn tends to reduce the soil porosity which is very important for air and water movement. Attention to this parameter is very vital for farm land because in long term usage may have very adverse effects [22]. In this study, sodium content was 39.7% and according to Table 3 treated effluent has good quality for irrigation usage.

Chloride Hazard: Chloride is essential element to plants in very low amounts, but at high concentrationsit can causetoxicity to sensitive crops. After sodium, chloride is of most concern. Unfortunately Chloride is not adsorbed or held back by soils, so it moves readily with water and taken up by the crop or moves to ground water resources.

Chloride has no very effect on soil's physical properties but some plant is sensitive to chloride ions. Chlorides concentration up to 15 meq/L, on sandy-loam soils and up to 7.5 meq/L on clay soils has low risk [24]. The amount of chloride in this study was 4.1 meq/L (147 mg/l). Potential salinity of water has been suggested as equation-3. In this parameter chloride has important rule. Table 5 proposes ensure sustainability. The potential salinity of Isfahan's treated effluent was 4.81 meq/L, so it is medium for soil permeability.The mean concentration of Chloride in this study was 147 mg/l so according to table 4 it was permissible for irrigation and according to table 6 moderately tolerant plants show injury.

Boron: The most important source of exposure for human populations is ingestion of boron through food consumption. Occupational exposure to borate dust and exposure to borates in consumer products (e.g. cosmetics, medicines and insecticides) are other potentially significant sources [26]. Boron is necessary in small quantities for plant growth and 0.3 mg/L in irrigation is tolerable for most plants [24]. But, at higher concentrations it is toxic to most crops at very low levels. Here boron concentration in IN-WWTP effluent was 0.02 mg/L so its quality was excellent for irrigation usage.

Nutrient (N and P): Another important parameter in wastewater reuse for irrigation is the concentration of nutrient like N and P. approximately all of the experts consider this parameter as a strong point for wastewater reuses. Also EPA advocates wastewater as a nutrient-loaded resource.Dayanthi *et al.* studied the effect of nutrients in treated wastewater on rice growth. They founded that rice crop grown with treated wastewater with no additional fertilizer was found to have sufficient growth and harvest [28]. Nitrate, nitrite and phosphate concentrations in Isfahan's WWTP effluent were 2.09, 0.006 and 1.7 mg/L, respectively. All of this parameter concentration was acceptable by Iranian guidelines (Table 2). These nutrients don't have any adverse effect on plants. On the other hand they can act as a fertilizer to plants therefore it is possible to reduce the use of chemical fertilizer.

Heavy Metals: Chemicals and heavy metals present in wastewater are an important concern for wastewater reuse for irrigation of plant and crops because they pose a health risk. Wastewater from industries often contains heavy metals. These materials have very bad and adverse effect on human health. Evaporation and repeated irrigation by treated wastewater that have heavy metals may cause buildup of contaminants on crops or uptake of the chemical constituents through plants root. Also daily intake of Cd, Cr, Pb and Ni through consumption exceeded the recommended oral dose of metal for both adult and children. Crops grown in these soils were contaminated by heavy metals [29, 30]. Isfahan north wastewater treatment planteffluent didnot have any cadmium (Cd) and chromium (Cr) but the average value of lead (Pb) and Nickel (Ni) content was 0.01 and 0.008 mg/L, respectively. The standard for irrigation water approved by Iranian guidelines for Cd, Cr, Pb and Ni are 0.05, 1, 1 and 2 mg/L, respectively. Results show that Cd, Cr, Pb and Ni content of Isfahan north wastewater treatment planteffluent were found in safe range to use in agricultural irrigation. Amount of iron (Fe) and manganese (Mn) in the effluent was 0.11 and 0.05 mg/L, respectively. The standard of Iran for Fe and Mn was 3 and 1 mg/L, respectively meeting Iranian guidelines.

Microorganism: Total coliforms, fecal coliforms and nematode eggs are the biological indicator that commonly used in wastewater treatment and reuse. For restricted irrigation (The used of treated wastewater to grow crops that are not eaten raw by humans) WHOguideline [31] is = 10^5Fecal coliform/100ml and for unrestricted irrigation. The use of treated wastewater to grow crops that are normally eaten raw is = 10^3 fecal coliform /100ml (Table 7).

Table 7: Revised WHO guidelines for wastewater reuse in agriculture [36]

	Reuse condition	Exposed group	Irrigation Method	Helminth eggs/L	Fecal Cloi/100ml
A	Unrestricted:				
	Crops eaten uncooked, sport fields, public parks	Workers, consumers, public	any	≤ 0.1	≤ 10^3
B	Restricted:				
	Cereal crops, industrial crops, fodder crops,	B1 workers > 15 years	Spray/sprinkler	≤ 1	≤ 10^5
	pasture and tree	B2 workers > 15 years	Flood/furrow	≤ 1	≤ 10^3
		B3 workers including children, nearby communities	any	≤ 0.1	≤10^3
C	Localized irrigation of crops in category B if exposure of workers and public does not occur	None	Trickle, drip or bubbler	Not applicable	Notapplicable

Table 8: Some crop water requirements and growing period [24]

Crop	Total water requirement (mm)	Approximate growing period (day)	Land that can be irrigated with reuse in Isfahan (hectare) *
Wheat	375	90	4316
Barley	360	90	4500
Cotton	1070	200	3364
Rice	1060	105	1783
Sun flower	875	120	2468

* 375mm/90 day= 4.17 mm/Day. If this loading is applied over 1 hectare of land, it equals to 0.00417m/day × 10000 m^2 = 41.7 m^3/ha. Day and for growing period equal to 41.7 × 90 = 3753 m^3/ha. Isfahan's North WWTP effluent is 180000 m^3/day. For growing period equal to 180000 m^3/day×90=16200000 m^3. At last 16200000/3753= 4316 hectare.

WHO guideline for nematode egg is = 1 eggs/L and is = 0.1 egg/L for restricted and unrestricted irrigations, respectively. In Iran national standards for total and fecal coliforms are 1000 and 400 per 100 mL. Standard for nematode eggs is = 1 eggs/L. Other study has shown that in Isfahan only A. lumbricoides, Trichostriogylus and H. nana were isolated. Also after treatment, the number of eggs/l fell to < or = 1 egg/l. By this quality, Isfahan north wastewater treatment plant effluent can be used without any roughing filters [32, 33].

Unfortunately, Isfahan north wastewater treatment plant didn't meet the total coliform and fecal coliform standards. Both Total coliforms and fecal coliforms were present in high levels so effluent have problem to both restricted and unrestricted irrigation. This effluent didn't have any nematode eggs. Table 6 shows the WHO guidelines for wastewater reuse in agriculture. The presence of pathogens in contaminated water has a serious concern in view of irrigating fresh produce. Many of these organisms can cause gastro-enteric illnesses via the consumption of raw produce irrigated with contaminated water [34]. The long-term farming activities represent a potential source that can increase the load of salt in the area [35] so, it is very important to use treated wastewater alternatively.

Biochemical and Chemical Oxygen Demand (BOD_5 and COD): Biochemical oxygen demand (BOD_5) express the amount of dissolved oxygen needed by aerobicbiological organisms in a body of water to break down organic matter in a given water sample at certain temperature over a specific time period. Chemical oxygen demand (COD) test commonly used to indirectly measure the amount of organic compounds in water.In this study BOD and COD for Isfahan north wastewater treatment planteffluent were 80 and 240 mg/L, respectively. BOD concentration meets the Iranian guidelines and values below 100 mg/L pose no restriction to irrigation use. Unfortunately COD concentration exceeded from Iranian guidelines so it is necessary to do some act for reducing COD concentration. COD typically ranges from 50 mg/L for most municipal wastewaters. Values below 200 mg/L didn't pose any restriction to irrigation use (adopted for Iran).

The Amount Irrigation: Table 8 show some crops water requirement, growing period and amount of farm land that can be irrigated with treated wastewater in Isfahan (hectare). It can be seen that with application of treated wastewater in Isfahan for irrigation proposes, about 4316 hectare of farmland could be cultivated forWheat production. So, by using wastewater reuse, high amount of freshwater consumption for agricultural purposescan be saved.

CONCLUSION

Among environmentally important factors, heavy metals and pathogenic microorganisms have very important concern for public health. Isfahan north wastewater treatment planteffluent was in normal concentration of heavy metals. Therefore, this source of water can be used for irrigation purposes without any hazardous effect on soil and plants. This effluent didn't have any nematode eggs but number of total coliforms and fecal coliforms in studied effluent was very high and exceeded the Iranian and WHO guidelines, so at present use of this effluent for agricultural purposes may pose risk to worker and consumers. Nevertheless, upgrading and improving the existing wastewater treatment plant of Isfahan for coliform quality of effluent to reach national and international standard is necessary. By this practices use of this effluent is permissible and can be used for various purposes.

- BOD concentration meets the Iranian guidelines and its value was below 100 mg/L so application of it doesn't pose any restriction to irrigation. Unfortunately COD concentration exceeded from Iranian guidelines so it is necessary to do some act for reducing COD concentration.
- Nitrite and Phosphate concentrations in Isfahan north wastewater treatment planteffluent were acceptable by Iranian guidelines. These nutrients don't have any adverse effect on plants. On the other hand they can be act as a fertilizer to plants.
- Boron concentration in Isfahan north wastewater treatment planteffluent was 0.02 mg/L so its quality was excellent for irrigation usage. Boron is necessary in small quantities for plant growth and 0.3 mg/L in irrigation is tolerable for most plants.
- The quality of effluent was good for agriculture purposes according to Na content (%) and SAR index. Isfahan north wastewater treatment planteffluent (SAR=2.62) didn't have sodic effect on soil and have low sodium hazard effect to Soil.
- By using Isfahan north wastewater treatment planteffluent for agricultural irrigation purposes high amount of freshwater can be saved.
- By using Isfahan north wastewater treatment planteffluent, about 4300 hectare and 4500 hectare of Isfahan farmland can be cultivated for Wheat and Barley products, respectively.

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