Evaluation of suitability of Windhoek's wastewater effluent for re–use in vegetable irrigation: Case study of Gammams effluent

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Abstract. Reuse of wastewater for vegetable irrigation may provide the nutrients required for crop growth while reducing potential degradation of receiving water bodies. Evaluation of the suitability of Windhoek's treated effluent for use in vegetable irrigation was done by measuring the physical, chemical and bacteriological quality of the effluent. The concentrations of the measured and calculated effluent parameters were compared with the World Health Organisation (WHO) and Food, Agriculture Organisation (FAO) and South African guidelines for irrigation water quality. The effluent had very low heavy metal content, and generally was suitable for use in irrigation except for one abstraction point where the E.Coli levels were too high, and potassium levels were higher than minimum vegetable requirements.

Keywords: E.coli, Irrigation, Nutrients, Soil salinity, Treated wastewater effluent, Vegetable.

[1] Introduction

The world is experiencing growing water stress due to increasing demand because of population growth, erratic precipitation and pollution from agricultural and urban surface runoff, and increasing volumes of wastewater discharged untreated or partially treated. The pressure for the available limited fresh water resources has grown to the extent that other unconventional sources of water are being exploited for various uses. Since 1968, the city of Windhoek, located in the central area of Namibia, has been successfully reclaiming treated domestic effluent to portable standards[1] to cater for increasing demand for fresh water for its 325 000 population[2]. Some farmers opted to reuse Windhoek's partially treated effluent for vegetable irrigation purposes since Windhoek is located in a semi-arid area which is not conducive to crop production that receives an average of rainfall of 370 mm /annum with 3 300 mm potential annual evapotranspiration[3]. Treated effluent is now widely used for agricultural irrigation particularly in arid regions of the world[4], but there are environmental impacts and health risks from pathogens and chemical constituencies[5]. These sewage effluents are considered a rich source of organic matter and other nutrients, but irrigation with wastewater is known to contribute significantly to the level of heavy metals like Fe, Mn, Cu, Zn, Pb, Cr, Ni, Cd and Co in receiving soils[6]. The quality of Windhoek's partially treated wastewater effluent has not been evaluated for vegetable irrigation suitability, hence the environmental impact and health risks of consuming fresh vegetables irrigated with Windhoek's effluent were unknown. Therefore the main objective of the study was to determine the suitability of the semi- treated effluent for use in vegetable irrigation by evaluating its biological, nutrients, soluble salts and heavy metal quality, as well as some physical parameters.

Study Area

The city of Windhoek has almost all the formal settlements connected to the sewerage network while some sections of informal settlements are still to be connected to the sewage system. There are separate sewerage treatment plants for industrial wastewater and domestic wastewater which is treated at Gammams Water Care Works, and the domestic effluent is either released into the Goerangab Reservoir or treated to potable quality by the WINGOG wastewater reclamation plant. The volume of domestic wastewater currently being produced from the city of Windhoek is estimated to be about 33 000 m^3/day, while the design capacity of the treatment plant is 27 000 m^3/day [7]. The map in Figure 1 shows some residential areas of Windhoek, the wastewater treatment plant, wastewater reclamation plants, Goerangab Reservoir and the river system that receives treated wastewater and untreated urban surface runoff. The reservoir was decommissioned as a source of water for treatment by the WINGOG wastewater reclamation plant due to its poor quality, but the water released from the polluted reservoir is used for vegetable irrigation.

Figure 1: Map and a photograph of one of the irrigated gardens

[2] METHODOLOGY

The effluent water samples were collected along the streams at positions 1, 2 & 3, as shown in Figure 1 whereby position 1&2 were irrigation water abstraction points. Measurements of the following parameters in the effluent were done in a laboratory; E.Coli and BOD_5, total phosphorus, total nitrogen, potassium, heavy metals (Pb, Cd, Cu, Fe, Cr) total suspended solids, sodium, calcium and magnesium cations. Electrical conductivity (EC), turbidity, temperature, pH and total dissolved solids where measured in situ. Effluent effect on soil salinity was evaluated using EC and standard equations of Sodium Adsorption Ratio (SAR), Soluble Sodium Percentage (SSP) and Exchangeable Sodium Percentage (ESP). The concentrations of the measured and calculated effluent parameters were compared with the World Health Organisation (WHO) and Food and Agriculture Organisation (FAO) guidelines for irrigation water quality.

[3] RESULTS AND DISCUSSIONS

The farmers using the untreated and treated wastewater effluent mainly grow spinach, spring onions and carrots under surface irrigation. The fresh vegetables are sold in Windhoek, and there may be health risks to consumers who eat raw vegetables from the gardens. Spinach is moderately sensitive while spring onions and carrots are sensitive to soil salinity[8], hence monitoring of effluent water quality and soil salinization are important for a sustainable tong term effluent irrigation of the vegetables.

3.1 Biological Quality

E.Coli levels ranged from 36 to > 11 000 most probable number (MPN)/100ml, but sampling positions 1 and 2 had E.Coli levels less than 1000 MPN/100mL during the study period. The FAO guideline indicates a level of less than 1MPN/100mL as completely safe for use for irrigation of vegetables eaten raw or uncooked. An E.Coli level of 1-1000MPN/100mL is recommended for use on vegetables which are consumed after cooking. Position 3 had high E.Coli levels ranging from 4600 to 11 000 MPN/100mL. The high level was attributed to the lack of conventional sanitation facilities in the informal settlement located on the right banks of the river and downstream of irrigation water abstraction points. Use of the water for irrigation may cause health risks to farm workers who are likely to be exposed to pathogens as they use the effluent for irrigation[9] . The biological oxygen demand (BOD_5) of the effluent had averages of 9.3, 8.8 and 8.3 mg/L for positions 1, 2 and 3 respectively. The FAO guideline recommends a maximum level of 10 mg/L for the BOD, hence with respect to BOD; the effluent quality was acceptable for irrigation.

3.2 Chemical Quality and Nutrients

Total nitrogen (TN) which referred to all the forms of nitrogen which could be found in effluent as ammonia, nitrate, organic nitrogen and nitrite, ranged from 4.5 to 19 mg/L with an average of 10 mg/L. Total nitrogen concentration of less than 5mg/L does not affect most crops while TN concentrations > 30mg/L is severe, however nitrogen requirements depends on the crop level of development. With respect to TN the effluent was suitable for irrigation since it was found to be less than 30 mg/L. Nitrates maybe leached down to the groundwater sources where they can contaminate the drinking water and pose health threats to consumers[10]. The relatively higher levels of nitrogen in the effluent may result in overstimulation of growth of algae and aquatic plants which may affect operation of some irrigation systems. The total phosphate in the effluent ranged from 1.0 to 5.5 mg/L. Availability of phosphorus in the effluent could be beneficial for the vegetables. The treated effluent had phosphorus levels above the maximum recommended level of 2 mg/L[11]; hence the effluent may cause environmental damage. The use of the effluent for irrigation may help in recycling the phosphorus and minimize environmental damage thereby reducing chances of eutrophication of water bodies receiving Windhoek's effluent. The levels were well above the recommended FAO limit for irrigation water effluent of 2 mg/L, hence careful management of irrigation systems is required in order to prevent possible negative impact on the level of eutrophication that can occur in water bodies receiving leachate and surface runoff from the gardens[10]. Water allocation and utilization for irrigation in Namibia is estimated at 15000m^3/ha/year [12]. The average NPK macro nutrient contribution of wastewater to the irrigated garden soil was estimated at 93 kg N, 41 kg P and 292 kg K per hectare. The acidic effluent provided more potassium (K) nutrients in kg/ha than required by the vegetables which meant that there was a strong possibility of leaching of the K into deeper layers of the soil, and hence the gardens were possible polluters of ground water with potassium.

All heavy metals (Pb, Cd, Cu, Fe, Cr) tested were low, for example, cadmium and lead concentration of the effluent were found to be < 0.01 mg/L for all the three sampling points which meant effluent was suitable for vegetable irrigation. The FAO and South African guidelines both set the maximum allowable concentration of cadmium and lead in irrigation water at 0.01 mg/L and 5.0 mg/L respectively. The reason for low levels of cadmium and lead in the effluent was that the effluent was from domestic sources, since only domestic wastewater flow in the Gammams River system. The average concentrations of sodium was 174mg/L, calcium (30 mg/L), potassium (30mg/L) and magnesium was 30 mg/L. Table 1 shows the average SAR, SSP and ESP of the effluent.

Table 1: Calculated wastewater effluent salinity and salts cations characteristics

	Position 1		Position 2		Position 3	
Characteristic	Min	Max	Min	Max	Min	Max
SAR	4.39	5.64	4.39	5.48	4.31	5.50
SSP	55.85	58.14	55.85	59.11	54.56	59.25
ESP	4.95	6.59	4.95	6.38	4.85	6.41

The salt and salinity qualities of the effluent indicated a moderate degree of restriction for use in irrigation. SSP was close to 60%, and an SSP of more than 60% may result in sodium accumulation on soil colloids causing breakdown of the soil's physical properties. Therefore, agronomic and/or effluent treatment practices that increase calcium and/or magnesium ions in the soil or water may be appropriate for Windhoek's effluent. The SAR is below 15, the threshold where problems of water absorption by plants occur [11]. Therefore selection of appropriate irrigation systems, monitoring of effluent SAR quality and management of irrigation systems are required for mitigation of possible sodium problems in the reuse of Windhoek's effluent.

3.3 Physical Quality

The turbidity ranged from 6 to 15 NTU which was higher than 5 NTU recommended by FAO. High turbidity may result in the effluent harboring pathogens exposing effluent users to diseases[13].The pH range was 3.9 - 6.1 and the average was 4.5, but the FAO irrigation water guidelines and South African guidelines recommend a pH range of 6.5-8.4 for irrigation water. A pH of less than 6.5 promotes leaching through the soil[14]. Electrical conductivity (EC) which also measures the salinity hazard of the irrigation water ranged 120.4 - 151.2 mS/m for the three sampling positions. FAO guidelines recommend a maximum of 300 mS/m for irrigation water[11], and according to the US Salinity Laboratory, 1954 classification, an EC of 160 mS/m falls in the high category. Since EC was less than 160 mS/m, therefore the effluent had low potential on causing soil salinity problems. Total dissolved solids (TDS) in the effluent ranged from 637 - 985 mg/L. Effluent with TDS in the range 450 -2000 mg/L can be moderately used for irrigation. Excessive levels of TDS (>2000 mg/L) result in build-up of salts in the root zone altering the soil properties and reducing the yields[10]. Therefore Windhoek's effluent is suitable for irrigation reuse but monitoring for build-up of salts in the soil is required.

[4] CONCLUSIONS

The physical and chemical analysis of the Gammams effluent showed that apart from the acidic pH, the semi-treated effluent is generally suitable for use in vegetable irrigation. The high levels of macro nutrients N, P and K in the effluent may provide some essential nutrients required for plant growth. The low levels of < 0.01mg/L of cadmium and lead meant that the effluent had low risks of causing heavy metal accumulation in the vegetables and the soil, therefore with respect to heavy metals hazard; the effluent was safe for irrigation of the vegetables. With respect to pathogens the effluent was good for irrigation if the water was abstracted at positions 1 and 2. The effluent from position 3 and downstream reaches could cause a health risk to farm workers and vegetable consumers due to possible exposure to high levels of pathogens in the irrigation water.

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