Influence of automobile industrial wastewater on soil quality

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Abstract: Reuse of industrial wastewater (effluent) for irrigation purpose is a common practice. However, lack of adequate treatment of the effluent can cause soil deterioration, vegetation destruction and contamination of the aquatic environment. These adverse effects necessitated the study of wastewater irrigation in Emene Industrial Layout, Enugu State, Nigeria. Wastewater and soil samples were collected, analyzed and subjected to Analysis of Variance (ANOVA) for Completely Randomized Design (CRD) at 5% probability level using GENSTAT software. The results obtained from the study were compared with FAO soil and water standards. The wastewater analysis suggested that contamination at the untreated stage was very high and results at the treatment level were within the FAO reuse range. The study also found wide variation in chemical status of industrial wastewater treated soil. Almost all the values for the wastewater treated soil were not within the FAO irrigated soil chemical properties standards. This suggests high re-contamination along the open channel (from non-point sources) before reuse. This calls for proper monitoring and treatment of the industrial effluent prior to irrigation application.

Keywords: irrigation, soil quality, contamination, wastewater, automobile industry

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1 Introduction

Rapid population growth in many municipalities continues to place increasing demands on limited tap water supplies. Many cities and districts are struggling to balance water use among municipal, industrial, agricultural, and recreational users. The population increase has not only increased the fresh water demand but also increased the volume of wastewater generated. In order to solve the problem of limited fresh water supply, wastewater is reused especially for agricultural purpose. Treated or recycled wastewater appears to be the only water resource that is increasing as other sources are dwindling[2,3]. According to the report of the US Directory of Industrial Establishment in 1988, about 215 billion gallons of industrial wastewater is being produced daily from industrial sectors in most countries. Some of the water is used in agriculture.

Worldwide, it is estimated that 18% of cropland is irrigated, producing 40% of all food[4]. A significant portion of the irrigation water is wastewater. It was reported that at least 20 million hm^2 cropland in 50 countries is irrigated with raw or partially treated wastewater[5]. Similarly a report shows that one tenth or more of the world's population consumes foods produced on land irrigated with wastewater[6]. Wastewater and excreta is also used in urban agriculture. A high proportion of the fresh vegetables sold in many cities, particularly in less-developed countries are grown in

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urban and semi-urban areas. For example, in Dakar, Senegal, more than 60% of the vegetables consumed in the city are grown in urban areas using a mixture of groundwater and untreated wastewater[1]. It is generally accepted that wastewater use in agriculture is justified on agronomic and economic grounds but care must be taken to minimize adverse environmental impacts. However, very few industries employ primary treatment and chemical neutralization of effluent[7,8]. Hence, the possibilities of soil and water contamination in the area are not ruled out, since recycled wastewater contains different levels of dissolved solids, metals, nutrients (N and P), and other elements[9,10].

In Enugu State Nigeria, wastewater effluent by Anambra Motor Manufacturing Company (ANAMMCO) an automobile maker serves as a major source of water for irrigation of farm lands. The effects of the wastewater on the local soil are important. Therefore, the objective of the paper was to study the quality of effluent wastewater from the industry and to determine their effects on the immediate environment (soil) where it was reused for irrigation of farm lands.

2 Materials and methods

2.1 Experimental site

Nkpologu area in Emene Enugu, Enugu State Nigeria is an industrial layout with scattered settlement; it is located on the latitude 6′25″N and longitude 7′30″E. The Emene area has a population of above 100 000 persons. Most of the population is involved in dry season vegetable farming[11] .

2.2 Design of experiment

The field layout was a Completely Randomized Design (CRD) with two treatments and four replications. The two treatments are (i) wastewater irrigation(WWI) and (ii) Tap Water Irrigation(TWI). The irrigation period was two months. Vegetable was grown in all the blocks. Irrigation water was applied to the blocks using watering cans. Responses are the concentrations of the chemical constituents of the soil in each block when sampled and analyzed.

2.3 Soil sampling and analysis

Soil samples were collected from these plots at 25 cm depth using a soil auger. Parameters such as pH, extractable salt content including calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), iron (Fe), manganese (Mn), and boron (B), base saturation percent of Ca, Mg, K, and Na, soil organic matter (SOM) content and cation exchange capacity (CEC) were analyzed according to the analytical methods from Australian Laboratory Handbook of Soil and Water chemical methods[12] and the Bouycos hydrometer method of soil analysis.

Base saturation percentages of Ca, Mg, K, and Na were calculated by dividing the extracted Ca, Mg, K, and Na by the calculated CEC, respectively. Base saturation percent of Na was considered the exchangeable sodium percentage (ESP). Soil organic matter was determined by reaction with chromate ($Cr_2O_7^{2-}$) and sulfuric acid. The remaining un-reacted $Cr_2O_7^{2-}$ was titrated with $FeSO_4$ using ortho-phenanthroline as an indicator, and oxidizable organic matter was calculated by the difference in $Cr_2O_7^{2-}$ before and after reaction[13].

Additional soil samples from each site were also collected to measure soil electrical conductivity (EC) and sodium absorption ratio (SAR) of saturation. Electrical conductivity of soil saturation paste extract was determined with a conductivity meter. Cation (Ca^{2+}, Mg^{2+}, and Na^{+}) concentrations of saturation paste extracts were analyzed by inductively coupled plasma–emission spectrophotometry instrumentation and then SAR was calculated.

2.4 Wastewater sampling and analysis

Industrial wastewater samples were also collected at three different points for analysis (i) before treatment, (ii) as point source effluent, and (iii) nonpoint source effluent (reuse point). Wastewater sample source from open canal was also collected. All wastewater was analyzed for total soluble salts, pH, soluble Ca^{2+}, Mg^{2+}, carbonate (CO_3^{2-}), bicarbonate (HCO_3^{-}) and heavy metals such as Cu^{2+}, Zn^{2+}, Mn and Fe^{2+}. The samples were also analyzed for the concentrations of the following chemical constituents: Na^{+}, sulfate (SO_4^{2-}), K^{+}, chloride (Cl^{-}), ammonia (NH_3), B, EC, coliform, BOD_5, SAR and Residual Sodium Carbonate (RSC) where calculated with equations (1) and (2) respectively.

$$SAR = \frac{Na^{+}}{\sqrt{(Ca^{2+} + Mg^{2+})/2}} \qquad (1)$$

$$RSC(meq/L) = (CO_3^{2-} + HCO_3^{-}) + Ca^{2+} + Mg^{2+} \qquad (2)$$

The data obtained were subjected to Analysis of

Variance (ANOVA) for CRD at 5% probability level using GENSTAT software.

3 Results and discussion

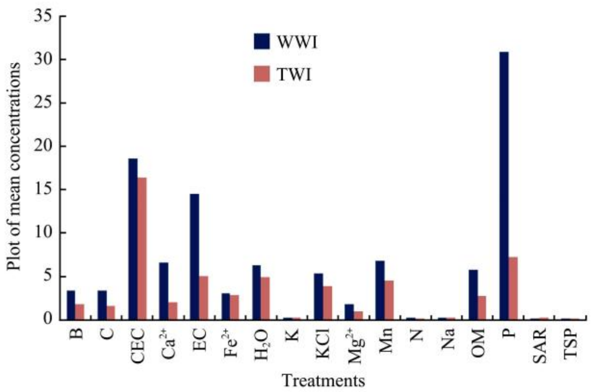
3.1 Soil chemical properties

The mean concentration of chemicals and soil chemical properties for the treatments are presented in Table 1 and on Figure 1 and Figure 2. Tables 2a, 2b and 2c present the ANOVA results for the measured soil properties after irrigation using CRD. The summary of the comparison of means to ascertain significance of difference of means based on the ANOVA results of Tables 2-4 at 5% level using their respective Least Significant Difference (LSD) are shown on Table 5.

Table 1 Mean concentration of chemical properties of soils by wastewater irrigation (WWI) and tap water irrigation (TWI)

Treatments	pH	KCL	C /%	OM /mg.L^{-1}	N /%	Na^+ /mg.L^{-1}	K^+ /mg.L^{-1}	Ca^{2+} /mg.L^{-1}	Mg^{2+} /mg.L^{-1}	Fe^{2+} /10^{-6}	CEC /me·100g^{-1}	B /10^{-6}	EC /dS^w/m	Mn /mg·L^{-1}	P /10^{-6}	SAR /mg·L^{-1}	TSP /mg.L^{-1}
WWI 1	6.1	5.3	3.17	5.47	0.238	0.27	0.31	4	1.4	3.92	17.2	5.94	12	6.2	37.31	0.104	0.0157
WWI 2	6.4	5.5	3.52	6.07	0.266	0.29	0.14	9.2	2.2	1.68	20	1.19	17	7.2	24.25	0.122	0.0145
WWI 3	6.2	5.3	3.2	5.98	0.264	0.29	0.29	5.5	1.6	3.48	17.8	1.19	12	7.4	30.45	0.154	0.0163
WWI 4	6.3	5.3	3.52	5.56	0.24	0.27	0.15	7.7	2	2.92	19.4	4.97	17	6.4	31.31	0.123	0.0137
TWI 1	4.8	3.7	1.87	3.22	0.112	0.29	0.16	1.6	1.4	2.8	18.4	1.19	5	5.2	5.6	0.2367	0.0158
TWI 2	5.1	4	1.35	2.32	0.098	0.27	0.26	2.4	0.2	2.8	14.4	2.38	5	4	9.33	0.2368	0.0188
TWI 3	4.9	3.8	1.42	2.68	0.11	0.27	0.26	1.8	0.8	2.9	18	1.19	5	3.8	6.53	0.2368	0.0147
TWI 4	5	3.9	1.61	2.86	0.1	0.29	0.15	2.2	1.4	2.7	14.8	2.38	5	5	7.4	0.2162	0.0196

Note: WWI = Wastewater irrigated soil; TWI = Tap water irrigated soil. The same below.



Note: WWI = wastewater irrigated soil; TWI = tap water irrigated soil.

Figure 1 Bar chart showing mean concentrations of soil chemical constituents for wastewater and fresh-water irrigated soils

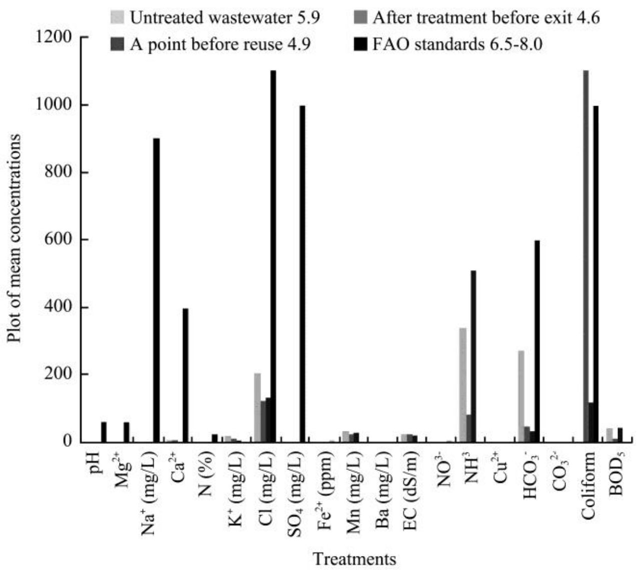


Figure 2 Bar chart showing mean concentrations of chemical properties of wastewater at different points in relation to standards[1]

Table 2 Analysis of variance for soil C, CEC, Ca^{2+}, EC, Fe^{2+}, pH and K

ANOVA					
Variate: Organic carbon, c (%)					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	1	6.4082	6.4082	139.84*	<.001
Residual	6	0.27495	0.04583		
Total	7	6.68315			
Variate: cation exchange capacity, CEC (meq/100 g)					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	1	9.68	9.68	3.17*	0.125
Residual	6	18.32	3.053		
Total	7	28			
Variate: Calcium, Ca^{2+} (mg/l)					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	1	42.32	42.32	15.54*	0.008
Residual	6	16.34	2.723		
Total	7	58.66			
Variate: EC (ds/m)					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	1	180.5	180.5	43.32*	<.001
Residual	6	25	4.167		
Total	7	205.5			
Variate: Fe^{2+} (ppm)					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	1	0.08	0.08	0.17^{NS}	0.696
Residual	6	2.8456	0.4743		
Total	7	2.9256			
Variate: pH					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	1	3.38	3.38	202.8*	<.001
Residual	6	0.1	0.01667		
Total	7	3.48			
Variate: K (mg/l)					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	1	0.00045	0.00045	0.08^{NS}	0.792
Residual	6	0.03535	0.005892		
Total	7	0.0358			

Note: * = Significant (5% level); NS = Non-significant (5% level). d.f. = degree of freedom s.s. = sum of squares m.s.= mean square variates.. F pr.= F- value .

Table 3 Analysis of Variance tables for soil KCl, Mg^{2+}, Mn^{2+}, Na^+, OM and P

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
(1) Variate: KCl					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	1	4.5	4.5	337.5*	<.001
Residual	6	0.08	0.01333		
Total	7	4.58			
(2) Variate: Mg^{2+} (mg/L)					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	1	1.445	1.445	6.24*	0.047
Residual	6	1.39	0.2317		
Total	7	2.835			
(3) Variate: Mn^{2+} (mg/L)					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	1	10.58	10.58	25.19*	0.002
Residual	6	2.52	0.42		
Total	7	13.1			
(4) Variate: N (%)					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	1	0.043218	0.043218	313.17*	<.001
Residual	6	0.000828	0.000138		
Total	7	0.044046			
(5) Variate: Na^+ (mg/L)					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	1	0	0	0^{NS}	1
Residual	6	0.0008	0.000133		
Total	7	0.0008			
(6) Variate: OM (mg/L)					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	1	18	18	156.66*	<.001
Residual	6	0.6894	0.1149		
Total	7	18.6894			
(7) Variate: P (ppm)					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	1	1115.34	1115.34	71.77*	<.001
Residual	6	93.25	15.54		
Total	7	1208.58			

Table 4 Analysis of Variance table for soil SAR, TSP, and B

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variate: SAR (mg/L)					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	1	0.022419	0.022419	83.55*	<.001
Residual	6	0.00161	0.000268		
Total	7	0.024029			
Variate: TSP (mg/L)					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	1	9.46E-06	9.46E-06	2.75*	0.148
Residual	6	2.06E-05	3.44E-06		
Total	7	3.01E-05			
Variate: B (ppm)					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	1	4.728	4.728	1.41*	0.279
Residual	6	20.077	3.346		
Total	7	24.805			

Table 5 Comparison of difference of means using LSD (Least Significant Difference)

Difference of means table					
Response	Treatment means		Difference	LSD	Remark
Variate	WWI	TWI			
B(ppm)	3.32	1.78	1.54	3.165	NS
C(%)	3.353	1.562	1.791	0.3704	*
CEC (meq/100 g)	18.6	16.4	2.2	3.023	NS
Ca^{2+} (mg/L)	6.6	2	4.6	2.855	*
EC (ds/m)	14.5	5	9.5	3.532	*
Fe^{2+} (ppm)	3	2.8	0.2	1.192	NS
pH	6.25	4.95	1.3	0.2234	*
K (mg/L)	0.223	0.208	0.015	0.1328	NS
KCl	5.35	3.85	1.5	0.1998	*
Mg^{2+} (mg/L)	1.8	0.95	0.85	0.833	*
Mn (mg/L)	6.8	4.5	2.3	1.121	*
N (mg/L)	0.252	0.105	0.147	0.02033	*
Na (mg/L)	0.28	0.28	0	0.01998	NS
OM (mg/L)	5.77	2.77	3	0.586	*
P (mg/L)	30.8	7.2	23.6	6.82	*
SAR (mg/L)	0.1258	0.2316	0.1058	0.02834	*
TSP (mg/L)	0.01505	0.01723	0.00218	0.003209	NS

Table 6 Comparison of difference between wastewater irrigated soil, tap water irrigated soil and FAO 1985 Standards

Variate	WWI	TWI	FAO 1985 Standards
B (ppm)	3.32	1.78	0.7-3.0
C (%)	3.353	1.562	1.0
CEC (meq/100 g)	18.6	16.4	-
Ca^{2+} (mg/L)	6.6	2	400
EC (ds/m)	14.5	5	3.0
Fe^{2+} (ppm)	3	2.8	5.0
pH	6.25	4.95	6.5 – 8.5
K (mg/L)	0.223	0.208	2.20
KCl	5.35	3.85	-
Mg^{2+} (mg/L)	1.8	0.95	60
Mn (mg/L)	6.8	4.5	2.0
N(%)	0.252	0.105	2.1
Na (mg/L)	0.28	0.28	900
OM (mg/L)	5.77	2.77	6.34
P (ppm)	30.8	7.2	>2.0
SAR (mg/L)	0.1258	0.2316	15
TSP (mg/L)	0.01505	0.01723	-

The mean pH value for wastewater treated soil was above 6.2, which agrees with earlier literature that stated the tolerable range of pH value for soil to be 5.0-8.2[1]. This shows a recommendable irrigation using wastewater from the automobile company. However, potassium chloride (KCl), with a treatment mean of about 5.4 for wastewater treated and 3.9 for clean water suggests liming of the soil.

In analyzing the organic matter (OM) content of the soil, consideration was given to the presence of carbon (C) and OM percentages. The ANOVA analysis shows a significant difference between the organic matter content and percentage carbon content in soil irrigated with wastewater and fresh water (Table 6). The percentages of carbon and OM were 3.3 and 5.8, respectively and these values are within the recommended standards for agricultural soils[1].

Similarly, the nitrogen (N) content of the soil analyzed for this experiment showed significant difference, since F-calculated was higher than the F-tabulated between the nitrogen content of soils that were treated with wastewater and with tap water. The percentage nitrogen was 0.252 and 0.105, respectively for wastewater and fresh-water irrigated soil. The treatment with fresh water was within tolerable limits for agricultural soils[1] while that of wastewater was above. This may be the reason for the massive vegetative growth around the experimental site.

In analyzing the exchangeable bases of the soil, Na^+, K^+, Ca^{2+}, and Mg^{2+} were considered. The ANOVA showed that Na^+ had no significant difference between the groups at $P<0.05$ while in K^+, Ca^{2+}, Mg^{2+}, the F-calculated was higher than the F-tabulated showing that they had significant differences. Other parameters like Fe^{2+}, CEC, B, EC, Mn, phosphorous (P), SAR, ESP, showed greater F-calculated than F-tabulated. This indicates significant difference within the groups of wastewater treated soil and the fresh water treated soil. Almost all the values for the wastewater treated soil were not within the irrigated soil chemical properties standards[1].

3.2 Wastewater chemical properties.

The results of wastewater analysis at three different points are shown in Table 7. The pH values of the three tested samples were not within the recommended range of 6.5-8.0[1]. It was also observed that from the plot of means, the treated wastewater at the reuse point had more tolerable value than others. Mg^{2+}, Ca^{2+} and Na^+ also had the highest value at the point before exit, followed by that at the reuse point; this suggests certain extent of recontamination after treatment, although all were within the reuse range of 60, 400, 900 mg/L respectively in accordance with the standards in FAO [1]. Cl^- showed the higher value at the reuse point and at the untreated stage than the point before exit, which is above the tolerable range for agricultural use. The relative high values of SO_4^{2-} and K^+ at the reuse point were above the other tested points. This suggests high re-contamination along the open channel before reuse. NH_3, Ba^{2+}, EC, Mn, and Coliform, all suggests abnormal high value at the reuse point and these were above the recommended tolerable limit of standards[1] of <20, 1.0, 3.0, 2.0 and 1,000 respectively as listed in Table 5. This situation may affect the plants in two ways: a) by creating salinity hazards and water deficiency; and b) by causing toxicity and other problems.

Table 7 The quality of automobile industrial wastewater at different points

Treatments	Untreated wastewater	After treatment before exit	A point before reuse	FAO Standards
pH value	5. 9	4.6	4.9	6.5-8.0
Mg^{2+} (mg/l)	1.6	2.2	1.4	60
Na^+ (mg/L)	0.29	0.29	0.27	900
Ca^{2+}	5.5	9.2	4	400
N (%)	0.238	0.266	0.264	30
K^+ (mg/L)	22.29	12.95	6.3	-
Cl^- (mg/L)	207	124.2	138	1 100
SO_4^{2-} (mg/L)	0.004	0.0026	0.0026	1 000
Fe^{2+}(10^{-6})	0.84	2.52	0.84	5
Mn^{2+} (mg/L)	35.11	27.47	32.96	0.2
Ba^{2+} (mg/L)	2.38	3.56	2.38	1
EC (dS/m)	26	27	22	3
NO^{3-} (mg/L)	0.7583	4.2286	0.4764	5
NH_3 (mg/L)	340.6	85.15	510.9	-
Cu^{2+} (mg/L)	0	0.0089	0.0178	0.1
HCO_3^- (mg/L)	275	50	35.2	600
CO_3^{2-} (mg/L)	0	0	0	0-1
Coliform (MPN/100 mL)	>24 000	1 100	120	1 000
BOD_5 (mg/L)	44	12	43	-

4 Conclusions and recommendations

The study found wide variations in chemical status of industrial wastewater treated soil. High values of Mn, OM, N, C, K, Ca, Mg, Fe, CEC, P, EC, B, SAR and EC of wastewater at the reuse point call for proper monitoring and treatment of the automobile industrial effluent prior to reuse. This may affect plants by creating salinity hazards, water deficiency and causing toxicity and other problems. This will prevent possible reductions in soil hydraulic conductivity and infiltration rate in soil with high clay content. Although these levels may not be high enough to result in short-term soil deterioration, however, salt leaching may become less effective when soil hydraulic conductivity and infiltration will be reduced. Furthermore, these chemical changes may in part contribute to stress symptoms and vegetation destruction. But with the management options such as determination and monitoring of crop yield potential, site conditions, methods and timing of irrigations, water uptake by crops and restriction on use, the adverse effects of wastewater can be prevented, corrected, or delayed from the onset. It is therefore recommended that long term effects of automobile wastewater on the irrigated sites be studied.

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