THE INTERNATIONAL JOURNAL OF SCIENCE & TECHNOLEDGE

Impact of Soap Factory Wastewater on Soil Physicochemical Properties: a Study of Cape Coast Industrial Area in Ghana

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Abstract:
Analysis of physicochemical properties of soil samples from Cape Coast Industrial area, Ghana influenced by discharge of soap factory effluent for 43 years was conducted. A control profile excavated 1 km away provided the basis for comparison of results from the contaminated site. A two-way data comparison was done. Changes within the same soil profile were compared. Analogous profile levels of the contaminated and control profiles were also compared. Sixteen (16) soil properties were evaluated in this experiment. Results of the study showed that the cation exchange capacity of soil and concentrations of nitrogen, phosphorus and potassium in the soil increased significantly following 43 years of effluent discharge. Organic matter content was also significantly higher in the contaminated soil than in the control soil, especially in the top 30 cm depth. The soil can be considered as a sodic soil as the exchangeable sodium percentage (ESP) in the contaminated soil exceeded the established minimum of 15 % for sodic soils while the electrical conductivity (EC) in the same soil was less than 4 dS m^{-1}*). The impact of the sodic condition on soil structure (dispersion and slacking of clay soil particle) resulted in the development of compact soil of high bulk density throughout the soil profile.*

1. Introduction

The need to produce food crops all year round has made it necessary to explore alternative sources of water to irrigate farm lands. One potential alternative sources of irrigation water are industrial effluent. Industrial effluent is a common by-product of most industrial processes whose containment, treatment and disposal adds to production cost of industries. The composition of industrial effluent may vary from one industry to the other due to the differences in raw materials processed and chemical substances involved in different industrial activities. Depending on the chemical composition of an effluent, its application to farm lands could either enhance soil fertility or render it infertile. On the one hand, wastewater irrigation has been reported to increase crop yield compared to irrigation with fresh water due to the supply of nutrients such as nitrogen, phosphorus and potassium contained in the effluents [1, 2]. On the other hand, physico-chemical analysis of soil irrigated with wastewater usually indicate sodium and bicarbonates accumulation and pH increase to alkaline values especially in the top soil horizons of farmlands irrigated with wastewater [3, 4]. Shrinkage analysis has shown that the structural pore network of such soils collapses dramatically, resulting in compact layers with poor water storage capacity [5]. Besides, alkanization induces organic matter dissolution, which leads to the formation of black alkali on top of the soil [6]. The build-up of soil micro nutrients such as iron, copper, chlorine, boron, zinc among others to toxic levels and the subsequent detrimental effects on seed germination and plant growth were also reported [7, 8]. The study site for this research is a land situated opposite Cape Coast industrial area, Ghana, onto which wastewater from soap factory was discharged for 43-years. The industry extracted palm oil from palm fruits and thereafter, used the palm oil as a raw material to manufacture soap, with sodium hydroxide (NaOH) as alkali. Over the years, all other plant species died, leaving only one grass specie (guinea grass – *Magathysus maximus*). All farming activities also ceased on the land as farmers harvested no crop to compensate for their toils. The objective of the study therefore was to conduct profile analysis of physicochemical properties of the soil as influenced by soap factory wastewater for 43 years.

2. Materials and Methods

The soil samples used in this experiment were collected from an area about 50 m around the premises of a Soap Industry in Cape Coast, Ghana where effluent from the factory was discharged for 43-year. Two different soil profiles were excavated, one at the contaminated site and a control profile at 1- km distance from the contaminated site. A soil profile measured 150 X 100 X 210 cm for length, breadth and depth, respectively. Each profile was sampled at every 30-cm depth from the surface to the bottom, giving seven soil samples per profile (designated PL1 – PL7). The basis for the 210-cm depth was to evaluate a universal rooting depth of soil for a wide range of crop plants, after receiving industrial discharge for such a long period. Each soil sample was pulverized, thoroughly mixed, air- dried for 7 days, sieved through a 2-mm sieve and used for the soil analyses. Sixteen (16) physicochemical parameters of soil were investigated. These are soil, pH, electrical conductivity, sodium and exchangeable sodium percentage, calcium, magnesium and potassium, ammonium and nitrate nitrogen, available phosphorus, organic carbon, iron, zinc, and gypsum requirement, bulk density and textural class. These parameters were informed by an earlier study of the physicochemical properties of the effluent from the industry. The experiment was conducted at the Soil Science Laboratory, School of Agriculture, College of Agriculture and Natural Resources, University of Cape Coast.

pH determination was done using the pH meter and soil to water ratio of 1:2.5, electrical conductivity by use of conductivity meter and sample to water ratio of 1:2. Ca^{+2} was determined by titrating aliquot of ammonium acetate extract against 0.005 *M* Na$_2$ – EDTA, using Erichrome Black T as indicator whilst Mg^{+2} determination followed a similar process but with calgon indicator. Potassium and sodium were determined by use of the flame photometer [9] and available nitrogen forms determined by Kjeldahl distillation method. For exchange acidity, soil was extracted with 1*M* KCl (soil to extractant ratio of 1:2.5) and titrated against 0.1 *M* NaOH with phenolphthalein as indicator. Organic carbon determination followed the potassium dichromate digestion method. The digest was then titrated against 0.5 M ammonium ferrous sulphate solution, using diphenylamine as indicator. Available phosphorus determination was by the use of spectrophotometer at a wavelength of 882 nm whilst the micro nutrients were determined using the Atomic Absorption Spectrophotometer (AAS) after 10 g of soil was extracted with 20 ml of diethylene triamine pentaacetic acid (DTPA). Textural class determination was by the hydrometer method described by [10] and soil bulk density was by the use of sampling cylinder. Using the Genstart software [11], analysis of variance (ANOVA) was used to determine the effects of industrial wastewater on soil properties. This enabled the determination of the level of differences for measured parameters of soil samples.

3. Results and Discussion

3.1. Soil pH

Table 1 presents the results of the physicochemical properties of the effluent contaminated soil profile as against the control profile.

PL	**Soil pH**		**EC (dS m^{-1})**		**Na$^+$ (cmol kg^{-1})**		**Ca^{+2} (cmol kg^{-1})**		**Mg^{+2} (cmol kg^{-1})**		**K$^+$ (cmol kg^{-1})**		**CEC (cmol kg^{-1})**		**ESP**	
	C	S	C	S	C	S	C	S	C	S	C	S	C	S	C	S
PL 1	6.5	8.7	0.0	3.7	0.1	3.1	2.2	9.3	0.6	6.5	0.3	0.8	3.1	19.6	1.5	18.0
PL 2	6.4	8.0	0.0	4.5	0.0	1.3	0.7	2.1	0.4	3.9	0.1	0.2	1.1	7.4	1.7	18.2
PL 3	6.4	7.3	0.0	5.0	0.0	1.3	0.4	2.1	0.4	3.3	0.1	0.1	0.8	6.7	1.6	18.5
PL 4	6.4	7.2	0.0	5.2	0.0	1.3	0.3	1.9	0.4	3.7	0.1	0.1	0.7	7.0	1.2	18.4
PL 5	6.1	6.6	0.0	4.6	0.0	1.1	0.3	1.9	0.4	2.9	0.1	0.1	0.8	6.0	2.0	18.3
PL 6	5.4	6.5	0.0	3.8	0.0	1.0	0.2	1.9	0.4	3.1	0.1	0.1	0.7	6.2	3.1	16.8
PL 7	5.2	6.1	0.0	3.8	0.0	0.8	0.2	2.1	0.4	3.3	0.1	0.1	0.7	6.3	3.5	15.4
LSD (0.05)		0.20		0.06		0.06		0.01		0.18		0.01		0.69		0.99

Table 1: Physiocochemical properties of effluent contaminated soil and control site
PL = Profile level, C = Control, S = Sample

Values of soil pH exhibited significant ($p < 0.05$) differences inter and intra soil profiles. pH values of both contaminated and control sites were relatively high in PL1 but steadily declined with soil depth. The contaminated soil exhibited a general alkaline soil pH up the profile, which gradually declined to slightly acidic pH in lower profile samples. These were however different from the control profile whose pH was slightly acidic in PL1 but declined to acidic pH values in lower profiles. This difference could be as a result of the impact of the industrial effluent (of pH 11.2) on the contaminated soil. The relatively lower soil pH (≤ 8.7) as compared to that of the effluent could be attributed to the acidifying effect of decomposing oil and grease of effluent and also, soil acidity. pH is a good measure of acidity and alkalinity of soil-water suspension and provides a good identification of the soil chemical nature [12]. Similar observations were made by [3, 13, 6] where the application of industrial wastewater to land resulted in increased soil pH. Contrary situations were however reported by [1] where the application of industrial wastewater to farmlands increased soil acidity. The impact of industrial wastewater on soil fertility therefore depends largely on the source and composition.

3.2. Electrical Conductivity (EC) and Exchangeable Cation

Values obtained for electrical conductivity (EC) of the soils are reported in Table 1. EC of soil is a measure of the total concentration of ionized substances in soil solution. It affects crop yield, crop sustainability, plant nutrients availability, activity of soil microorganisms and also provides the basis for diagnoses of soil sodicity and salinity [12, 14]. Analysis of variance indicated significant ($p < 0.05$) difference in EC values obtained for contaminated site as against that of the control. Even though EC of the control were below detection limit, EC of contaminated soil increased with depth and values ranged between 3.67 and 5.2 dS m^{-1}. These values predict a sodic top soil and slightly saline soils from PL2.

Values obtained for exchangeable sodium (Na$^+$) exhibited significant ($p < 0.05$) difference from each other. PL1 of contaminated soil accumulated showed a high amount of Na$^+$, but the Na concentration reduced 3-fold throughout the other depths. Samples from the control site did show any significant sodium concentration. The accumulation of exchangeable sodium in soil of farm lands is of a particular interest because it is not required in high concentration by most crops [15]. Besides sodium has a dispersive influence on the clay component of soil. By processes of slaking and swelling, soil clay particles disperse in a process that affect aggregate stability, break down soil structure, seal soil pores and reduce water infiltration [16]. [3] observed sodium accumulation in the top soil of plots irrigated with recycled wastewater Did you measure any of the parameters mentioned above? This resulted in a dramatic collapse of structural pore network of soil and lead to the formation of compact soil layers with poor water storage ability. Similar observations were made by [8] and [4].

Calcium (Ca^{+2}), magnesium (Mg^{+2}) and potassium (K^{+}) are all important plant nutrients whose build up in soil through the application of wastewater is desirable. Ca^{+2} exhibited moderately high concentration in PL1 of the contaminated soil and followed by fourfold decrease in PL2, but remained constant hereafter. A similar trend was observed in the cases of Mg^{+2} and K^{+}, all of which were significantly different ($p < 0.05$) higher or lower. [14] observed accumulation of Ca^{+2}, Mg^{+2} and K^{+}, in soil after the continuous discharge of industrial wastewater onto soil at Kurkumbh Industrial area in India. A similar observation was made by [17] after they studied the physico-chemical properties of soil as influenced by the discharge of palm oil mill effluent onto farmlands at Anyigba, Kogi State of Nigeria. After five years of irrigating farm land with industrial wastewater from tyre factory, however, [17] did not observe any significant change in the value of soil K^{+}. [1] stated that land application of wastewater can increase the level of soluble and exchangeable forms of potassium in soil more rapidly than with conventional inorganic fertilizers and that, most of the potassium in wastewater is immediately available. They added that, elements such as Ca^{+2} and Mg^{+2} needed for plant growth can accumulate in soil and improve soil pH especially in acidic soils

Cation exchange capacity (CEC) of soil is a measure of the quantity of readily exchangeable cations neutralizing negative charges in the soil. It therefore serves as the buffer against the development of extreme acidic soil conditions which are detrimental to microbial activity and availability of soil-plant nutrients. CEC of soil was moderate in the PL1 of contaminated soil but generally low in all sub layers examined in this. Analysis of variance showed significant ($p < 0.05$) differences in values for CEC within sampling levels of contaminated soil and also with the control.

3.3. Exchangeable Sodium Percentage

Exchangeable sodium percentage of soil is often used as a measure of the amount of sodium which can cause soil structure deterioration [19, 20]. The exchangeable sodium percentage (ESP) of soil exceeded the minimum 15 % through the entire sampled depth of contaminated soil. With a corresponding EC of < 4 dS m^{-1}, the top 30 cm layer of the profile is classified as sodic. Sodicity increased with increased soil depth with values which were significantly ($p < 0.05$) different from values of the control. Soil permeability has been shown to decrease with increasing ESP and decreasing soil solution electrolyte concentration as a result of swelling and or dispersion of clay [12]. Blockade of soil pores as a result of clay dispersion and movement has been identified as the main mechanism controlling soil permeability when soils of low ESP values are leached with dilute salt solutions whereas swelling is recognized as the dominant mechanism at high ESP values [16]. The impact of the industrial effluent on the soil was thus significant. It is however worth to indicate that the widely accepted ESP 15 % as the critical level beyond which soil structure could be deleteriously affected has also been considered too high by some authors. Nearly 40 years back, [21] proposed an ESP of 5 % as more appropriate for identifying sodic soil in Australia. [22] also reported dispersion with resulting decrease in hydraulic conductivity at ESP close to zero in a soil medium of low electrolyte concentration. [23, 24] also observed that swelling of clay is not generally appreciable unless ESP exceeds 25 or 30 %. Besides, climatic variability and soil factors such as texture and mineralogy, bulk density, aggregate binding agents such as iron and aluminum oxide, organic matter and mechanical stress to which soil is subject to have also been identified as variables which could affect the ESP at which soil structure deterioration could arise. These arguments therefore bring afore a new dawn of soil research in order to establish a universal ESP which is applicable in our day.

3.4. Organic Carbon, Nitrogen and Phosphorus

Values obtained for organic carbon (OC), nitrate nitrogen (NO_3^--N) and ammonium (NH_4^+-N) nitrogen and also available phosphorus (P) are presented in Table 2.

PL	**OC (%)**		**NH_4^+(mgN kg^{-1})**		**NO_3^- (mgN kg^{-1})**		**P ($mgkg^{-1}$)**		**BD (gcm^3)**		**Texture**	
	C	S	C	S	C	S	C	S	C	S	C	S
PL 1	0.4	1.2	1.5	26.8	2.5	18.2	10.3	42.5	1.1	1.4	SL	CL
PL 2	0.3	0.3	1.3	16.7	1.4	16.7	5.7	5.7	1.1	1.6	SL	SCL
PL 3	0.1	0.2	0.8	19.6	1.2	17.0	2.8	3.9	1.1	1.6	SL	CL
PL 4	0.3	0.2	1.1	19.5	1.4	17.0	4.9	1.4	1.1	1.6	SL	CL
PL 5	0.1	0.2	0.8	23.3	2.2	24.9	1.6	2.3	1.1	1.7	SCL	CL
PL 6	0.2	0.2	0.9	25.7	1.7	23.7	1.8	4.8	1.1	1.6	SCL	CL
PL 7	0.1	0.2	0.9	25.6	1.2	21.4	12.8	1.5	1.1	1.6	SCL	CL
LSD (0.05)	0.05		2.16		2.78		0.68		0.06			

Table 2: Some macro plant nutrients and physical properties of effluent affected soil
PL = Profile level, C = Control, S = Sample, SL = Sandy loam, CL = Clay loam, SCL = Sandy clay loam

Values for OC were significantly ($p < 0.05$) different within the contaminated soil profile and also, with the control. OC value for PL1 translates to a moderate level of soil organic matter. A fourfold decreased value was however observed from PL2 which remain virtually constant down the profile. Contrary to this trend, NO_3^-N and NH_4^+-N of the contaminated soil registered generally high values throughout the soil profile, relative to the control. Probably for its immobility in soil, available phosphorus (P) accumulated to a very high level in PL1 of contaminated site, followed by six times decrease in the P value of the next sampling level. Organic matter content strongly affects soil fertility by increasing the availability of plant nutrients, improving soil structure and water holding capacity and also acting as the accumulation phase for toxic heavy metals in the soil environment. For this reason, the recycling of organic wastewater through their application to the soil can be an important promising activity for agriculture activities [12, 25, 26]. The application of palm oil mill effluent to farm land over time resulted in the build-up of soil organic matter, nitrogen and phosphorus [17]. The assessment of the physicochemical properties of soil at Kurkumbh Industrial Area of india also revealed a similar trend of high accumulation of OC, N and P in soils onto which industrial effluent was dumped over time [14]. The contrary situation was however reported by [18] whereby the application of effluent from tyre factory at Yazd, Iran, resulted in decreases in soil OC, N and P as compared to the use of ground water for irrigation. It therefore holds that the use of industrial wastewater for farmland irrigation would always require a thorough assessment of the source.

The contaminated soil exhibited generally high bulk density throughout the profile when compared to the control. This corresponded with a textural class of clay loam, as against a constant textural class of sandy loam throughout the control profile. A clayey soil with such a high bulk density is characterized by compact layers, poor porosity, low rate of water infiltration and poor hydraulic conductivity [1]. Such a soil would inhibit seeds emergence and root penetration [12]. The best management option for such a soil may be an organic based amendment which has the tendency of reducing soil bulk density, improving aeration, hydraulic conductivity among other things.

3.5. Micro Nutrients

Figures 1 and 2 display the results for iron (Fe) and Zinc (Zn) in contaminated soil as against the control.

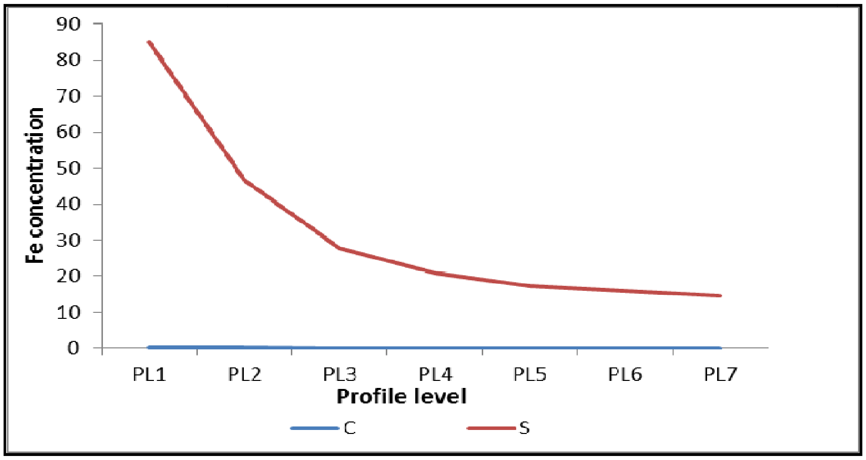

Figure 1: Iron (Fe) concentration across soil profile

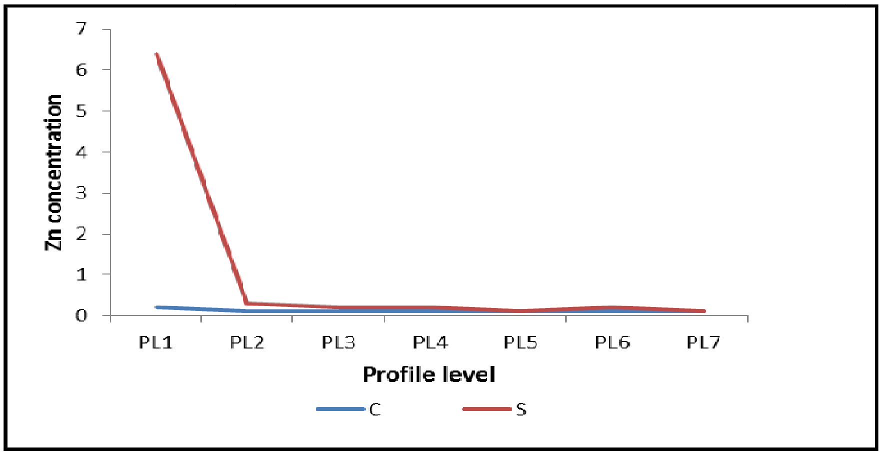

Figure 2: Zinc (Zn) concentration across soil profile

Even though Fe concentration in industrial wastewater was relatively negligible, the 43-years of continuous discharge onto the land have resulted in over 107 times increase in the contaminated soil with a linear decrease with soil depth. Zn build-up in contaminated soil was only 11 times that of the wastewater, but statistically significant (($p < 0.05$) from values of the control soil. Fe and Zn are essential plant micro nutrients whose tolerance level varies among plants. Their toxicity in plants is in the form of chlorosis, stunted growth, shorter root length and narrow leaves. Long term use of industrial wastewater on agricultural lands generally leads to the build-up of metals in soil [1]. Sewage irrigation for 20-years resulted in significant build-up of Fe (170 %) and Zn (208 %) in sewage irrigated soil in vicinity of Delhi relative to adjacent well water irrigated soil. Soils receiving sewage irrigation for 10-years exhibited significant increase in Fe and Zn whist only Fe in soils increased significantly by sewage irrigation in 5-years [1]. Adequate treatment of effluent would be required in order to avoid any of such metals build-up in soil to crop toxic levels.

4. Conclusion

The 43-year period of industrial effluent discharge onto the land has significantly influenced soil physicochemical properties. Cation exchange capacity of soil improved significantly as well as levels of major plant nutrients. Organic matter level far exceeded that of the control soil, especially in the top 30 cm depth. Exchangeable sodium percentage (ESP) has however exceeded the established minimum of 15 % for sodic soils. This, together with the electrical conductivity (EC) confers sodicity status on the contaminated soil. The related impact on soil structure (dispersion and slacking of clay soil particle) has resulted in the development of compact soil of high bulk density through the soil profile. Managing of such a soil would therefore require an approach which would not only remove excess sodium but also, improve soil physical properties.

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