

Wastewater Quality Characteristics as Affected by Industrial Discharges, Its Extent for Environmental Pollution and Implication on Food Security in Ethiopia: A Case Study from at Akaki and Debre Zeit

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Abstract
In Ethiopia, there is a growing concern with regard to the adverse effect of industrial discharge on the environment where soil and water qualities are the main pillar of it. The majority of the people who lived in agriculture are highly affected by this consequence. Therefore, this study was conducted on wastewater discharged from industries in the central part of Ethiopia with the objective of studying its quality as affected by these industries, the extend for environmental pollution and their implication on food security efforts in Ethiopia. For these, several wastewater samples were collected at the point of impact and every 100 m from the point of discharges, and characterized for their chemical composition, concentration and proportion of elements in them. The analytical results indicated that the reaction (pH) ranged from slightly alkaline (7.86- textile) to heavily alkaline (9.27- Agro-stone) at Akaki while at Debre Zeit t varies from 7.99 (flower) to 9.23 (East Africa food processing) and heavily saturated with basic cations except Ca^{2+} raising the electrical conductivity to 2.2dS m^{-1}. Available P, chlorides, sulfate and carbonates and bicarbonates were found to be too high to use for agricultural purposes while micronutrients are too low to affect the wastewater quality. Sodium Adsorption Ratio (SAR) vary from 2.01 (low) to 16.41 (medium) at Akaki while it ranges from 11.19 (medium) to 46.13 (high) at Debre Zeit implying that the high potential of these wastewater to contaminate or pollute the soil. Accordingly, it might significantly affect the soil physico-chemical properties as well as plant growth. Positive Relative Pollution Potential (RPP) and positive ad more than 1 contamination/pollution index (C/P) implying that these wastewater do have a potential to pollute the environment and significantly affecting the food security efforts in the region.
Keywords: Discharges, environmental pollution, food security, soil quality, water quality

Introduction

The life and livelihood of millions of people, more than 83 % of the total population in Ethiopia, entirely depend on agriculture which is now severely affected by the expansion of industries through their wastewater discharges. Following this, the natural resources base gets degraded and the severities of the problems are increasing mainly due to lack of appropriate management of industrial wastes (Getu, 2009; Malefia, 2009; Sisay, 2007).Low external input agricultural practices are also contributing to soil degradation, whereas damping industrial wastes to the nearby water sources highly contributing to the pollution of water bodies thereby affecting the environment (Mesfin*et al.,* 2012a; Mesfin and Sheleme, 2012b; Malefia, 2009; Sisay, 2007). The central part of the country is under high pressure in this glimpse.

Wastewatersare used by farmers for irrigation in many regions around the globe where freshwater is scarce and agricultural land is located near cities such as Addis Ababa, Ethiopia; Haroonabad, Pakistan; Dakar, Senegal; Cochabamba, Bolivia; and Irapuato and Guanajuato, Mexico (Buechler and Devi, 2005). There is an association between the quality of these wastewater and the soil qualities after and during irrigation. Generally, the quality of wastewater should be measured in terms of pH, EC, Total Dissolved Solids (TDS), nutrient status such as cations (Na, K, Ca, Mg) and anions (nitrate, phosphate, sulphate, chloride), metal ions (Cu, Zn, Mn, Fe, Al), biochemical oxygen demand (BOD), Total Solids (TS) and Total Suspended Solids (TSS). If the wastewaer having a pH of different or far from 7 and EC above 1 dS m^{-1} (1000 uS cm^{-1}) should be investigated further (Patterson, 1999). According to the same author, for any agricultural purposes, the influence of any effluents should be seen from the point current nutrient status, cation exchange capacity-nutrient storage, and sodium adsorption ratio (SAR).

Therefore, this study was conducted on wastewater generated from industries around Akaki (3) and Debre Zeit (4) to study its quality and dynamics as affected by the discharge and its implication on food security efforts in the region.

Materials and Methods

Site description:

Akaki is geographically located at $8^0$33'-$8^0$57' N latitude and $38^0$43'-$38^0$50' E longitude. The average annual range of maximum temperature lies between 15 ^{0}C and 20 ^{0}C, whereas, low temperature lies between 10 ^{0}C and 15 ^{0}C. The average annual range of rainfall is from 800-1200 mm. The District lies between the altitudinal ranges of 1500 and 2300 m a.s.l (Damitew*et al.,* 2012). According to WRB (2006) and FAO (2006), Vertisols are the most dominant soil types.

Debre Zeit is located at coordinates of $8^0$45'52''N to $8^0$48'45''N latitude and $38^0$58'53''E to $39^0$01'00''E longitude with altitude of 1950 masl. It is characterized by a humid tropical climate and heavy precipitations from June to August having annual mean rainfall of 801.3 mm (NMA, 2007). The mean annual maximum temperature is about 25.5 ^{0}C and monthly values range between 23.7 ^{0}C in July and 27.7 ^{0}C in May. The mean annual minimum temperature is 10.5^{0}C and monthly values range between 7.4^{0}C in December and 12.1 ^{0}C in July and August. According to FAO soil classification (WRB, 2006) Vertisols are the dominant soil types of the area. Geologically, these soils consist of alkaline basalt and trachyte belonging to the Bishoftu Formation of the Cenozoic volcanic eruptions (Tefera*et al.,* 1996).

Wastewater sampling and preparation

Wastewater samples were collected from three industries at Akaki (agro-stone, steel and textile) and four at Debre Zeit (ELSE, Flower, steel and East Africa food and packaging processing) at the point of impact and every 100 meters to the point where it was not able to access it. At each location and sampling site, the wastewater samples were taken from three different points along the same equi-distance and bulked to make a representative composite sample. Then, each sample collected from the impact site as well as from every 100 m were passed through Whatman No.42 and prepared following the standard procedures for the analysis of their chemical composition, concentrations and proportion of the elements.

Wastewater analysis and characterization

The pH, EC and Na were directly measured with the respective pH, EC and flame photometer, respectively while available P, carbonate, chloride and sulfate by turbidity test, all micronutrients and bases were extracted with EDTA and each element is directly read from the respective instrument (FAO, 2008). These wastewaters were also characterized in terms of Sodium Adsorption Ratio (SAR), Relative Pollution Potential (RPP) and contamination/pollution (C/P) index parameter respectively.

Results and Discussion

pH

The wastewater pH ranges from 7.86 - 9.27 and 7.99 - 9.23 with the mean value of 8.50 and 8.58 at Akaki and Debre Zeit, respectively, and hence classified as moderately to highly pollutants according to Patterson (1999). Generally, it followed the trends of decreasing its value as the distance increased at every 100 m implying that the dilution factor with other sources contributes to the low levels of soluble salts (Table 1).

$$\mathrm{DF} = \frac{(B - A)}{A} * 100$$

Where DF = Dilution Factor
A = At impact point
B = After every 100 m

The average dilution factor for Akaki and Debre Zeit were found to be positive and stood at 0.07 and 0.02 implying that there is sufficient water sources with relatively good quality at Akaki than Debre Zeit. The dilution factor at Akaki decreased from textile, steel and agro-stone factory with 0.09, 0.06 and 0.056 while at Debre Zeit except flower which has a dilution factor of 0.01, all the three industries have got 0.02. East Africa (food processing, packaging…), ELSE and Steel factories contributes to the highest level of pH for the water bodies and their pollution capacity differs in decreasing order. Therefore, this figures are implying that agro-stone and flower industries at Akaki and Debre Zeit contributes to the highest level of pollutants to the nearby water bodies that can affect the capacity of the water sources to limit the dilution effect for the same. These results confirm the previous study made by Mesfin *et al.,* 2012a; Mesfin and Sheleme, 2012b and Malefia, 2009.

Electrical Conductivity (EC)

Similar trends were also observed for EC whereby their values range from 507-1744 μScm^{-1} at Akaki while at Debre Zeit 707 to 2220 μScm^{-1} with the mean values of 971.86 and 1141.39 μScm^{-1} (Table 1) and still seems that the problem is aggravated at the latter and both are classified as slightly to moderately pollutant (FAO, 1985). At Akaki, Textile, Agro-stone and steel, and at Debre Zeit Flower, steel, ELSE, and East Africa contribute highly soluble salts in relatively decreasing order. This results is also has been confirmed by the dilution factor presented earlier.

Available P (ppm)
Significant variations in the available P were observed among the different industries at both Akaki and Debre Zeit with values ranging from 15 to 285 and 15 to 425 ppm, respectively (Table 1). According to FAO (1985) these wastewaters are of poor quality and were found to be good enough to pollute the soil.

Chlorides, Sulfates and Carbonates (mgL^{-1})
Chloride concentration in the wastewater generated by these industries ranges from 209 to 2605.6 and 407.7 to 2481.5 mg L^{-1} while sulfates vary from 3200 to 12180 and 5060 to 38000 mg L^{-1} with average values of 1043.63 and 5848.57 for Akaki and 1131.45 and 15330.67 for Debre Zeit, respectively (Table 1). Thus, chlorides and sulfate concentration were found to be too high for all sampling points irrespective of the type of industries while carbonates are ranges from low to medium and bicarbonates falls in sever category by having more than 10 ppm (FAO, 1985).

Basic Cations (Na^+, K^+, $Ca^{2+}$and Mg^{2+}) and SAR
Generally, these wastewaters were classified as slightly to severely pollutant in most parameters (FAO, 1985). Accordingly, the concentrations of basic cations considerably vary from none to sever. For example, the concentration of Na was 2.78 which is classified as none (<3) to 23.72 which is sever (>9) at Akaki. Unlike to Akaki, at Debre Zeit, the concentration of Na in wastewater falls in the sever category by having values more than 9 (Table 2). This has been also proved by the previous parameters like pH ad EC.
Besides, the SAR, which is calculated as the concentration of sodium divided by the average square root of the concentration of Ca and Mg, values considerably varies at these two locations owing to the fact that the industries along with the inputs and process do vary. Accordingly, the SAR value ranges from 2.01 to 16.41 at Akaki and from 11.19 to 46.13 at Debre Zeit characterize the wastewaters (Table 2). They are classified as low to medium for Akaki while medium to high at Debre Zeit (FAO, 1985). Therefore, using these wastewaters for agricultural purposes is not recommended as it might cause soil salinity according to Mohammed *et al.,* 2010; Mesfin and Yifru, 2012b and Mesfin *et al.,* 2012a

Micronutrients (Cu^{2+}, Fe^{2+}, $Mn^{2+}$and Zn^{2+})
The concentrations of metals considerably vary from none to moderately pollutant (FAO, 1985). Accordingly, the concentration of Fe (<5.0), and Zn (<2.0) classified as none while Mn (0.2-0.5) is slightly and Cu (0.01-0.2) ranges from slightly to moderately pollutants for both locations (Table 2). The application of these wastewaters might not have causing pollution according to Mohammed *et al.,* 2010; Mesfin and Yifru, 2012b and and Mesfin *et al.,* 2012a

Table 1 Characterization of wastewaters in terms of pH, EC, Available P, carbonates, chloride and sulfates

Site	Industry	Distance [a](100m)	pH (1:2.5)	Dilution Factor	EC (µS cm^{-1})	Av. P (ppm)	CO_3^{2-} (ppm)	HCO_3^- (ppm)	Cl^- (ppm)	SO_4^{2-} (ppm)
Akaki	Agro-stone	1	9.27		1192	15	9.2	49.8	2605.6	3200
		2	8.85	0.05	590	15	18.4	24.9	209	3380
		3	8.36	0.06	507	35	6.1	62.2	372.2	2980
	Steel	1	8.56		695	40	6.1	68.4	289.9	4460
		2	8.06	0.06	773	35	18.4	62.2	425.4	2620
	Textile	1	8.56		1744	285	6.1	155.6	1878.9	12120
		2	7.86	0.09	1302	170	5.8	68.4	1524.4	12180
Debre Zeit	ELSE	1	8.78		1350	330	6.1	112.2	1745.9	13700
		2	8.69	0.01	1285	350	9.2	112.2	1276.2	13200
		3	8.42	0.03	1620	35	6.1	113	1134.4	21240
		4	8.37	0.01	684	55	9.2	74.6	957.2	24340
	Flower	1A	8.04		2220	335	8.5	31.1	478.6	23500
		1B	7.99	0.01	2200	370	9.2	31.1	301.3	22660
	Steel	1	8.96		1410	45	7.9	47.4	1550.0	5538
		2	8.84	0.01	1122	15	6.1	74.7	1763.6	5060
		3	8.58	0.03	1345	60	12.2	93.3	2481.5	4980
	East Africa	1A	8.49		670	215	6.1	93.3	478.6	5340
		2A	8.39	0.01	740	210	6.1	68.4	1418	5900
		3A	8.26	0.02	707	220	6.1	68.4	797.6	5800
		1B	9.23		2060	425	15.3	205.3	1834.5	38000
		1C	8.92	0.03	1183	225	9.2	136.9	407.7	17360
		2C	8.81	0.01	1060	90	6.1	113	372.2	16700

NB: *Figures in* [a] *refers to the distance at every 100m while the letter is to meant different factories of the same industry*

Table 2 Characterization of wastewaters in terms of basic cations and micronutrients

Site	Industry	Distance[a](100m)	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cu^{2+}	Fe^{2+}	Mn^{2+}	Zn^{2+}	SAR
Akaki	Agro-stone	1	3.77	1.68	0.36	6.65	0.07	0.01	0.29	0.07	2.01
		2	2.78	0.94	0.82	2.29	0.07	0.35	0.26	0.10	2.23
		3	2.93	1.01	1.56	1.76	0.11	0.06	0.26	0.07	2.27
	Steel	1	3.92	1.94	1.65	2.15	0.15	0.28	1.35	0.03	2.84
		2	3.53	0.50	1.76	3.60	0.06	0.33	0.46	0.06	2.16
	Textile	1	15.15	15.80	1.77	2.11	0.13	0.36	0.32	0.02	10.88
		2	23.72	0.70	2.35	1.83	0.17	0.10	0.31	0.04	16.41
Debre Zeit	ELSE	1	15.76	21.90	0.40	0.48	0.09	0.14	0.26	0.09	23.76
		2	17.16	20.89	0.43	0.51	0.11	0.35	0.44	0.06	25.03
		3	25.09	12.49	0.61	1.14	0.11	1.08	0.87	0.10	26.82
		4	24.55	19.16	0.62	1.10	0.07	0.77	0.61	0.10	26.47
	Flower	1A	12.58	49.49	4.45	3.88	0.08	0.72	0.38	0.00	6.16
		1B	9.51	54.81	5.91	3.33	0.09	0.62	0.30	0.10	4.42
	Steel	1	18.55	10.22	0.99	2.58	0.07	0.27	0.52	0.11	12.97
		2	13.75	8.32	0.81	2.21	0.08	0.20	0.43	0.09	11.19
		3	20.86	9.06	0.86	2.54	0.11	0.36	0.28	0.09	16.00
	East Africa	1A	9.34	11.26	0.70	0.59	0.10	0.39	0.57	0.05	11.63
		2A	10.28	9.87	0.37	0.58	0.14	0.47	0.98	0.06	14.92
		3A	9.98	9.86	0.62	0.60	0.10	0.42	0.72	0.05	12.78
		1B	27.29	9.37	0.36	0.34	0.13	0.50	0.54	0.20	46.13
		1C	22.17	10.79	0.30	0.55	0.06	0.13	0.35	0.11	34.01
		2C	20.78	7.41	0.20	0.37	0.16	0.45	0.43	0.10	38.92

Relative pollution potential (RPP) of these wastewaters

RPP of a pollutant is a measure of the level of chemical interaction between the point of impact, pollutant, and every 100 m apart, the recipient. This was computed using the following scheme (Eghareveba and Odjada, 2002)

$$Y = \frac{A - B}{B}$$

Where Y= Relative Pollution Potential (RPP)
A= Concentration at impacted point
B= Concentration at point away from impacted point

At Akaki, RRP for all sampling points were found to be positive except for textile industry in Na, textile and steel in Ca and negative for steel in Mg implying that these wastewaters relatively possess high pollution potential in terms of soluble salts (Table 3). Similarly, only negative values for textile in Cu, agro-stone and steel in Fe and for all industries in Zn explains little effect on the pollution potential in terms of these metals (Table 4). The highest RPP were found for agro-stone at Akaki in terms of K, Ca, Mg and Na with a significant impact on the concentration of K.

At Debre Zeit, RRP for all sampling points were negative except for flower on Na and Mg, East Africa on Na and Ca, and ELSE on Na and Ca. It is not surprising that ELSE (metal industry) produces a positive RPP on metals like Fe, Mn and Zn while East Africa join ELSE in Zn (Table 5 and 6).

Table 3 Lateral distribution of salts in wastewaters at impact point and a point far away from at Akaki

Salts	Industry	Point of impact	Far away	RPP
Na^{+}	Agro-stone	3.16	2.78	0.14
	Steel	3.73	3.53	0.06
	Textile	19.44	23.72	-0.18
K^{+}	Agro-stone	1.21	0.94	0.29
	Steel	1.22	1.05	0.14
	Textile	8.25	7.70	0.07
Ca^{2+}	Agro-stone	0.91	0.82	0.11
	Steel	1.71	1.76	-0.03
	Textile	2.06	2.35	-0.12
Mg^{2+}	Agro-stone	3.57	2.29	0.56
	Steel	2.88	3.60	-0.20
	Textile	1.97	1.83	0.08

Table 4 Lateral distribution of metals at impact point and a point far away from at Akaki

Metals	Industry	Point of impact	Far away	RPP
Cu^{2+}	Agro-stone	0.08	0.07	0.19
	Steel	0.11	0.06	0.75
	Textile	0.15	0.17	-0.12
Fe^{2+}	Agro-stone	0.14	0.35	-0.60
	Steel	0.31	0.33	-0.08
	Textile	0.23	0.10	1.30
Mn^{2+}	Agro-stone	0.27	0.26	0.04
	Steel	0.91	0.46	0.97
	Textile	0.32	0.31	0.02
Zn^{2+}	Agro-stone	0.08	0.10	-0.20
	Steel	0.05	0.06	-0.25
	Textile	0.03	0.04	-0.25

Table 5 Lateral distribution of salts at impact point and a point far away from at Debre Zeit

Salts	Industry	Point of impact	Far away	RPP
Na^{+}	ELSE	20.64	17.16	0.20
	Flower	11.05	9.51	0.16
	Steel	17.31	20.86	-0.17
	East Africa	16.64	10.28	0.62
K^{+}	ELSE	18.61	20.89	-0.11
	Flower	52.15	54.81	-0.05
	Steel	8.69	9.06	-0.04
	East Africa	9.76	9.87	-0.01
Ca^{2+}	ELSE	0.52	0.43	0.20
	Flower	5.18	5.91	-0.12
	Steel	0.84	0.86	-0.03
	East Africa	0.43	0.37	0.15
Mg^{2+}	ELSE	0.81	0.51	0.58
	Flower	3.61	3.33	0.08
	Steel	2.38	2.54	-0.06
	East Africa	0.51	0.58	-0.13

Table 6 Lateral distribution of metals at impact point and a point far away from at Debre Zeit

Metals	Industry	Point of impact	Far away	RPP
Cu^{2+}	ELSE	0.10	0.11	-0.14
	Flower	0.09	0.09	-0.06
	Steel	0.10	0.11	-0.14
	East Africa	0.12	0.14	-0.18
Fe^{2+}	ELSE	0.59	0.35	0.67
	Flower	0.67	0.62	0.08
	Steel	0.28	0.36	-0.22
	East Africa	0.39	0.47	-0.16
Mn^{2+}	ELSE	0.55	0.44	0.24
	Flower	0.34	0.3	0.13
	Steel	0.36	0.28	0.27
	East Africa	0.60	0.98	-0.39
Zn^{2+}	ELSE	0.09	0.06	0.46
	Flower	0.05	0.10	-0.50
	Steel	0.09	0.09	0.00
	East Africa	0.10	0.06	0.58

Contamination/pollution index (C/P) of wastes

The contamination/pollution index (C/P) in the wastewater was calculated using the scheme formulated by Lacatusu (2000)

$$\mathrm{C/P} = \frac{\textit{concentration in the waste}}{\text{targetted value}}$$

If C/P > 1, pollution ranges
If 0.1 < C/P < 1, contamination ranges
If C/P < 0.1, slight contamination ranges

Based on the detailed analytical results three selected parameters (Mg, Cu and Zn) were taken to see the possible contamination or pollution index of these wastewaters from short and long term perspectives.

Table 7 Contamination/Pollution (C/P) Index of the Metals in the wastewater sample

Site	Industry	Mg	Cu	Zn
		Short term		
Akaki	Agro-stone	0.36	0.02	0.01
	Steel	0.29	0.02	0.00
	Textile	0.20	0.03	0.00
Debre Zeit	ELSE	0.08	0.02	0.01
	Flower	0.36	0.02	0.01
	Steel	0.16	0.01	0.01
	East Africa	0.05	0.02	0.01
		Long term		
Akaki	Agro-stone	17.83	0.42	0.04
	Steel	14.38	0.53	0.02
	Textile	9.85	0.75	0.02
Debre Zeit	ELSE	4.04	0.48	0.04
	Flower	18.03	0.43	0.03
	Steel	2.38	0.1	0.09
	East Africa	0.51	0.12	0.10

Accordingly, the concentration of these elements should not exceed 0.2, 0.2 and 2 for short term while 10, 5 and 10 mg L^{-1} long term perspectives for safe use of these wastewater for agricultural purposes, respectively. Therefore, these wastewaters can be used for short term without significantly affecting its quality as the ratio is less than critical values for all the respective elements as they fall to meet slightly contamination stage while for long term use, however, these ratios could split in to three and ranging from slightly contamination to pollution ranges. Accordingly, it was found to be slightly contamination ranges, contamination ranges and pollution ranges for Zn, Cu and Mg respectively.

Conclusion and recommendations

All these industries were found to either contaminate or pollute with different magnitudes. Overall, agro-stone from Akaki and flower industries from Debre Zeit were found to press their influence on the soils. The analytical results indicated that the reaction (pH) and the electrical conductivity is too high to produce negative influences on the wastewater quality. Available P, chlorides, sulfate and carbonates and bicarbonates were found to be too high to use for agricultural purposes. Calculations on SAR, RPP and C/P values indicating that these wastewaters do have a potential to pollute the environment and significantly threatening the food security efforts in the region. Therefore, it is recommended that careless disposal of industrial wastes to the nearby water bodies or to the soil without pretreatment should be discouraged and the regulatory body should develop ways to monitor how these industrial wastes are managed by the respective industries in order to ensure the protection of soil and water resources from further degradation.

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