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Original Research Article

Assessment of the effluent quality of wet coffee processing wastewater and its influence on downstream water quality

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A B S T R A C T

The objective of this study was to evaluate the impact of effluents from traditional wet coffee processing plants on the downstream water quality in Ethiopia. Composite water samples were collected from 11 rivers/streams associated with wet coffee processing plants at the peak hours of coffee processing, and water quality parameters were measured for the wastewater discharged as well as for the river water upstream and downstream of the discharge point. Acidic pH values were recorded for all plant effluents. The organic content of the effluents varied from one plant to another but was considerably high overall, with maximum values of 7200 mg/L and 871 mg/L for COD and BOD_5, respectively. This high level of organic content in the effluents depleted the oxygen content to the level of 0.25 mg/L. The organic load and the presence of nutrients invoke a large risk of eutrophication. We found that variations in coffee bean soaking time, pulp fermentation, and the absence of appropriate treatment facilities were the major factors affecting the water pollutant parameters. In general, the measured values of effluent parameters significantly deviated from both the Ethiopian-EPA and US-EPA guidelines. Thus, water bodies and ecosystems located downstream of the traditional wet coffee processing plants are at an alarming risk of ecological disruption, and there may also be severe health consequences for the nearby residents. These findings raise the need for further research into the design and implementation of coffee waste valorization and treatment in view of sustainable coffee production.

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1. Introduction

Coffee is one of the most popular beverages in the world and second largest traded commodity after petroleum (Murthy and Naidu, 2012). It is cultivated in about 80 countries across the globe and gives rise to a huge business worldwide (Murthy and Naidu, 2012). According to United States Department of Agriculture data (USDA, 2011), global coffee production in 2010/2011 is estimated to be above 8.2 million tons. Over 2.25 billion cups of coffee are consumed every day globally. Over 90% of coffee production takes place in developing countries, whereas consumption is mainly in the industrialized economies (Ponte, 2002).

Ethiopia is the origin of highland coffee (*Coffea arabica* Linnaeus), a plant earlier known as *Jasminum arabicum laurifolia* Jussieu. This coffee tree species, the only native coffee in the world, has traditionally been tended and harvested as a wild tree in the highland forests of southwestern Ethiopia (Schmitt, 2006), mostly in the former Kaffa Province. In Ethiopia, coffee plays a central role in the incomes of more than one million coffee-growing households and the livelihood of over 15 million people directly or indirectly depends on this commodity crop (LMC, 2000). According to data from the Ministry of Agriculture and Rural Development (MoARD) of Ethiopia for 2013, there were 1722 coffee processing (wet and dry) plants in Ethiopia, owned by private individuals, cooperatives and the government. Furthermore, according to data from the Ethiopian coffee and tea development and marketing authority for 2016/17, the total number of coffee processing plants in Ethiopia has now surged to 2156 (ECTA, 2017) (Table 1).

Almost all wet coffee processing plants in Ethiopia are located close to water bodies. This is because a lot of water is needed for washing the beans, removing the pulp and the mucilage, but also in order to use the water bodies for direct disposal of the wastewater released from the wet coffee processing plants. While there are some wet coffee processing plants that use disposal pits to stabilize the generated wastewater, these disposal pits are constructed without following the correct design and dimensions. In addition, they lack the proper linings (HDPE or cemented floor, for example) to protect against leakage of the effluents into the underground water and the holding capacity of the disposal pits is not taken into consideration during construction. Thus, the coffee processing water and its wastewater are routinely discharged into nearby streams and rivers. Fig. 1 illustrates disposal pits used by wet coffee processing plants. In this regard, proclamation number 602/2008 (FDRE, 2008b) and the Council of Ministers Regulation number 159/2008 (FDRE, 2008a) of Ethiopia proclaimed that coffee processors shall dispose waste without causing harm to the environment, the public or individuals. However, in most cases there is a lack of continuous follow up and implementation.

Industrial processing of coffee cherries for both dry and wet processes is outlined in Fig. 2. The wet coffee processing procedure requires mechanical removal of pulp with the help of water, as a result of which it produces a considerable volume of wastewater. In wet industrial processes a large amount (about 29% dry-weight of the whole coffee berry) of coffee-pulp is produced as the first byproduct (Corro et al., 2013). It is obtained during wet processing of coffee and for every 2 tons of coffee processed, 1 ton of coffee pulp is generated, whereas in the dry process 0.18 ton coffee husk is generated for every ton of fresh coffee cherries (Adams and Dougan, 1981). Most of the coffee processing plants in Ethiopia prefer to follow the wet processing method because wet processed coffee is considered superior in quality to dry processed coffee. In addition, it obtains higher prices and has a better aroma/flavor than the coffee obtained by the dry processing method. However, wet coffee processing plants discharge untreated effluents into the nearby water bodies and open land. In addition, water consumption is high for this method. In this regard, Kivaisi et al. (2010) estimated that coffee processing is generating about 9 million m^3 of wastewater, and 600,000 tons of husks annually in the East Africa region.

Similarly, Devi et al. (2008) indicated that the wastewater generated from coffee processing has high concentrations of organic pollutants like pectin, proteins and sugars. Due to high pollutant content, its disposal without treatment in water bodies has become undesirable due to the danger this poses for the water bodies and to human health. The few existing case studies (Haddis and Devi, 2008; Beyene et al., 2012; Endris et al., 2008) indicate that disposing untreated coffee wastewater into local water bodies results in the pollution of downstream water sources and people residing in the vicinity of the wet coffee processing plants suffer from different types of diseases. However, there have been no detailed studies evaluating the impact of coffee wastewater effluents on the organic load, nutrient enrichment and eutrophication of the nearby water bodies. Therefore, this paper presents an assessment of effluent quality and the magnitude of impact on the downstream water quality.

Table 1
National wet and dry coffee processing industries (June, 2017).

S. No.	Region	Wet coffee processing				Dry coffee processing				Grand total
		Privately owned	Association	State farm	Sub-total	Privately owned	Association	State farm	Sub-total	
1	Oromia	367	165	15	547	604	58	6	668	1215
2	SNNP	520	175	–	695	181	44	–	225	920
3	Gambela	7	–	–	7	14	–	–	14	21
Total		894	340	15	1249	799	102	6	907	2156

Source: Ethiopian Coffee and Tea Development and Marketing Authority, Addis Ababa, 2017.

Fig. 1. Disposal pits used by wet coffee processing plants: D and F.

2. Materials and methods

2.1. Study area

The study was conducted in the Jimma zone, Oromiya region, Ethiopia. From the 18 districts of the Jimma zone, the Limmu Kossa, Manna and Gomma districts were selected because these are the three leading districts in terms of wet coffee processing. For the data collection, 2, 3 and 6 wet coffee processing plants were selected from the Limmu Kossa, Manna and Gomma districts, respectively, because of their proximity to water sources. For simplicity alphabetic letters ranging from A to K are used as codes throughout this paper. Of these 11 wet coffee processing plants, only plants D and F have temporary disposal pits to stabilize the effluent, whereas all the other plants discharge their effluent without any form of treatment. Fig. 3 shows the area of study and the sampling points.

2.2. Sampling

Since wet coffee processing is a seasonal activity, the study was conducted during the harvesting period for ripe coffee cherries, which varies from year to year and usually falls between October and January. To study the impact of these coffee processing industries on downstream water bodies, water samples were taken from the upstream inlet water (water used for washing, depulping, fermenting), from the effluent wastewater after the depulping of the coffee beans (removing the pulp and mucilage), and from the nearest downstream water bodies, that is, after the effluent is discharged into the nearby river water. However, samples could not be taken in the downstream water bodies in two coffee plants (downstream site of plants G and I) due to road inaccessibility. As a result, a total of 31 sites were sampled (all 3 sampling sites for 9 plants, plus two sites for a further two plants).

To ensure that the sampling was representative, composite samples of the wastewater released by the plants were collected at the peak hours of coffee processing. In addition, composite water samples were also taken from upstream and downstream rivers/streams. All samples were collected using clean polyethylene plastic bottles that were thoroughly washed with deionized water. The water samples were filtered onsite before the analysis of NO_3-N, NH_4^+-N, TN, and phosphorous as ortho-phosphate. Then, the samples were properly and carefully labeled, sealed and transported to the laboratory of the Department of Environmental Health Sciences and Technology, Jimma University, Ethiopia. Cold storage was maintained throughout the process until analysis was performed. Every sample was taken in triplicate and the average results were reported.

2.3. Water and wastewater analyses

On-site measurements of samples from the upstream and downstream river water and samples from wastewater for electrical conductivity (EC), pH, temperature and dissolved oxygen (DO) were carried out using a Hach

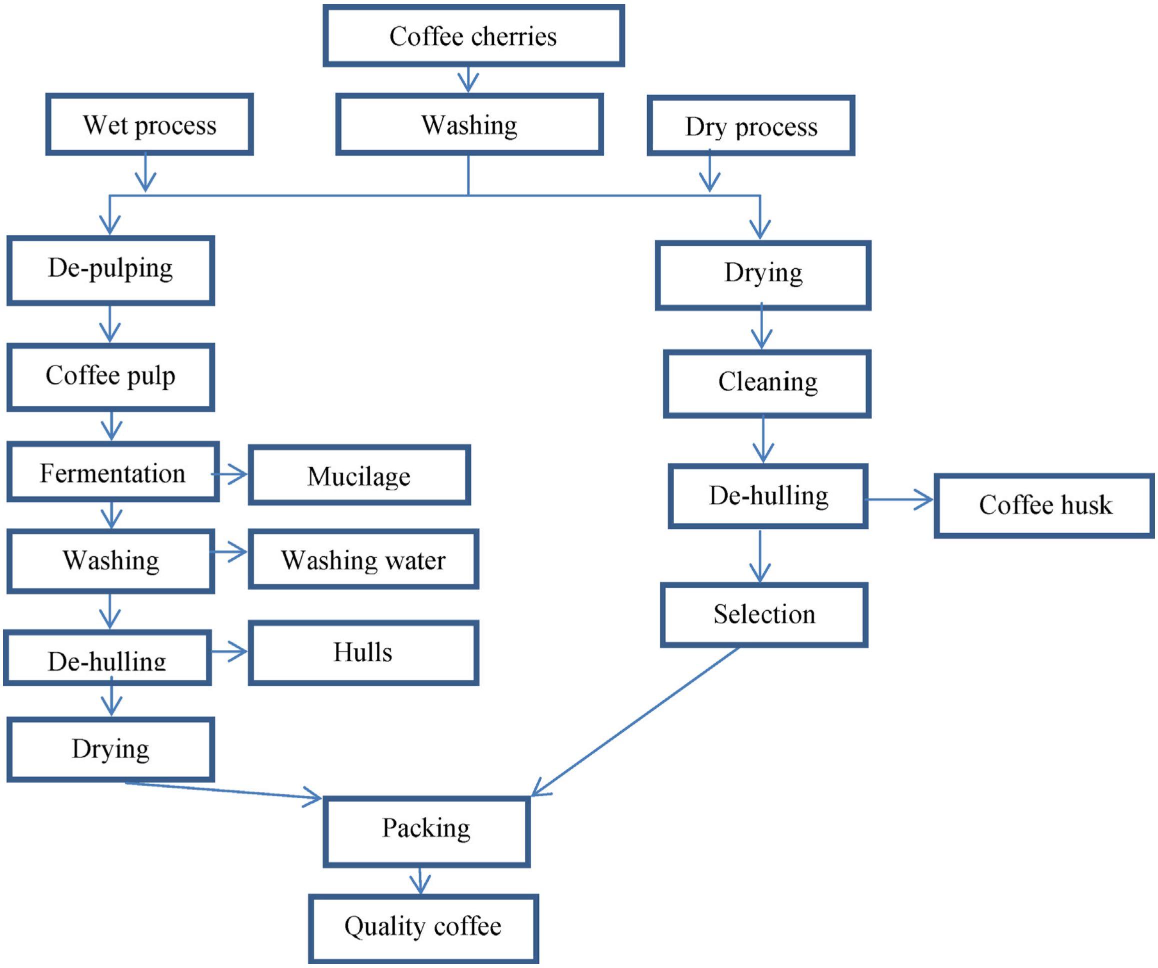

Fig. 2. Industrial processing of coffee cherries.
Modified from Pandey et al. (2000).

multi-meter probe (P/N HQ40d multi meter). To measure total suspended solids (TSS) and BOD_5, a gravimetric method (by using glass microfiber GF/A Whatman filter paper having 4.7 cm diameter and with pore size of 1.6 μm) and the Azide modification of the Winkler method (by using aerator TRITON 2000cc, China) were used, respectively. For the remaining parameters (COD, NO_3-N, NH_4^+-N, TN, and phosphorous as ortho-phosphate), LCK test kits (Hach Lange, Germany) were used.

3. Discussion of results

3.1. General physico-chemical characteristics of the upstream water and downstream

The values of pH, EC, temperature and TSS measured at the selected sampling points are presented in Table 2. In fact, since a correctional measurement of temperature at river sites is often misleading, it is not the appropriate way to measure water temperature in river water. The pH is generally lower in the effluent. In all cases the pH is below 7, which indicates that all the effluents from wet coffee depulping processes lead to acidic conditions, which can be toxic to the downstream ecosystem. It was also observed that the pH of effluents from D, F, I and K plants/factories were measured to be below 5 (Table 2). This may be due to the nature of the coffee bean itself, the harvesting time of the bean, the soaking duration of the depulped coffee bean, the fermentation time to remove the mucilage and differences in processing the coffee bean (for example the amount of water used for washing). However, at plant sites A, B, D and F the downstream pH value is higher than the corresponding upstream value. This might be due to the self-buffering capacity of the receiving water. From the results, it is evident that the pH in the effluent drops to 3.56 (K), indicating the active decomposition of organic matter. This shows that there was fermentation of sugars in the mucilage in the presence of yeasts to alcohol and CO_2. As the organic waste oxidizes, CO_2 is released and increases the acidic characteristics of the water, decreasing the pH value below the range of 6–9 (which is the surface water quality standard for ambient environment in Ethiopia) and 5.5–9 (which is the US-EPA Standards for Discharge of Environmental Pollutants to Inland Surface Waters) (Table A1 in appendix).

The sugars contained in the mucilage ferment and the organic and acetic acids from the fermentation of the

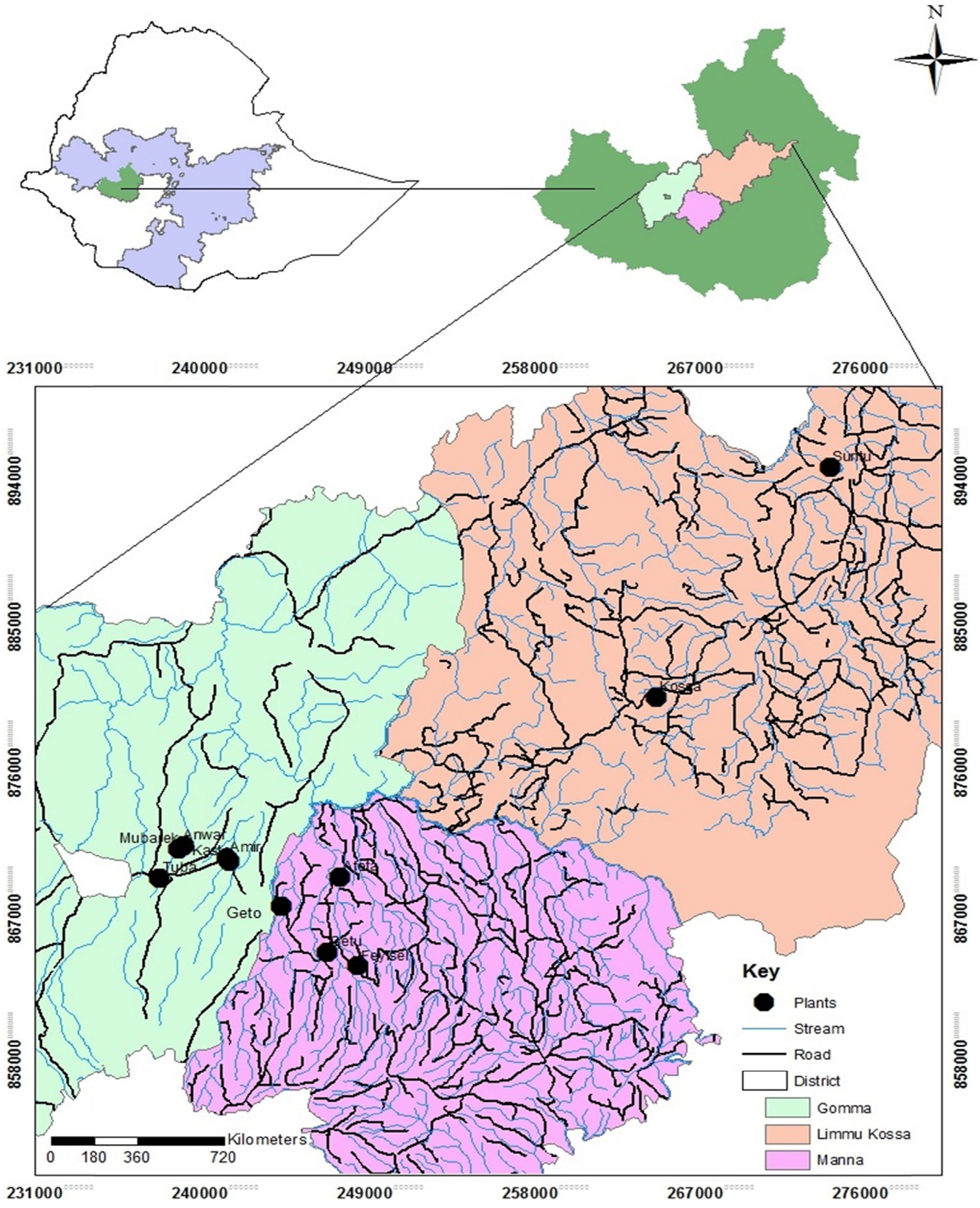

Fig. 3. Study area and sampling points.

sugars make the wastewater acidic, a condition in which higher plants and animals can hardly survive (Enden and Calvert, 2002). The acidic nature of wet coffee processing industry wastewater has also been reported elsewhere (Kefale et al., 2012; Beyene et al., 2012; Beyene et al., 2014). The direct effects of pH changes involve alterations in the ionic and osmotic balance of individual organisms, in particular changes in the rate and type of ion exchange across body surfaces. This requires greater energy expenditure, with subsequent effects such as slow growth and reduced fecundity becoming apparent (EFEPA, 2003). The relative increment of pH in downstream water bodies may be due to the buffering capacity of the receiving water. However, if this situation increases from time to time, the

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Table 2
General physico-chemical parameters (pH, EC, temperature and TSS) measured from upstream, the influent and the downstream water bodies of wet coffee processing plants.

Wet coffee processing plant	Sampling site	Physico-chemical parameters			
		pH	EC (μS/cm)	Temp (°C)	TSS (mg/L)
A	Upstream	6.6	105.3	21.7	84
	Effluent	5.24	102.1	20.7	66
	Downstream	6.9	104.6	19.3	96
B	Upstream	6.0	86.8	19.3	38
	Effluent	6.0	98	18.8	38
	Downstream	6.31	85.6	17.8	46
C	Upstream	5.12	121.7	17.4	8
	Effluent	5.14	200.8	21	92
	Downstream	5.11	142.8	17.2	22
D	Upstream	6.3	69.4	19.5	48
	Effluent	4.48	3270	19.1	780
	Downstream	6.6	134.8	19.9	10
E	Upstream	6.04	63.2	19	36
	Effluent	5.55	103.6	20.3	44
	Downstream	6.03	91.8	18.7	60
F	Upstream	5.67	71.9	21.2	38
	Effluent	4.2	777	21.6	2260
	Downstream	5.93	125.1	19.1	48
G	Upstream	7.39	101.2	20.5	18
	Effluent	6.8	112.2	20.9	50
	Downstream	ND	ND	ND	ND
H	Upstream	6.6	134.8	19.7	4
	Effluent	5.35	292	18.9	88
	Downstream	5.46	172.3	20.8	40
I	Upstream	6.77	104.8	22.3	158
	Effluent	4.83	3700	23.9	1440
	Downstream	ND	ND	ND	ND
J	Upstream	7.15	80.7	20.4	68
	Effluent	5.4	295	21.8	84
	Downstream	4.27	600	24.1	62
K	Upstream	6.65	92.6	19.3	6
	Effluent	3.56	1134	18.7	1240
	Downstream	4.43	871	21.7	72

ND, not detected.

self-purification capacity of these water bodies will decline. In general, the wastewater of wet coffee processing plants has impacted the pH of downstream water bodies. For example, comparison of the upstream and downstream pH values clearly shows that the pH values were measured to be much lower at the downstream sites for plants H, I, J and K.

Electrical conductivity (EC) can be regarded as a crude indicator of water quality for many purposes, since it is related to the sum of all ionized solutes or total dissolved solid (TDS) content. The electrical conductivity of the water depends on the water temperature: the higher the temperature, the higher the electrical conductivity would be. The trend of EC is not uniform, but generally the EC values in the effluent are higher than for the upstream and downstream river sites. The values are in the range from 63.2 μS/cm to 871 μS/cm (Table 2). The EC concentration of the effluent from plant/factory I (3700 μS/cm), D (3270 μS/cm), and K (1134 μS/cm) plants were observed to be higher than the other facilities. This value is above the Ethiopian surface water quality standard, which is 1000 μS/cm (Table A1 in appendix). This increment in EC may be due to the solubility/decomposition of compounds during depulping and fermentation of the coffee pulp. Differences in the capacity of the coffee pulping mills may explain the differences between plants. EC values downstream in the water bodies are lower due to dilution with water; however, this dilution may not always be sufficient. This finding is consistent with similar studies done by Endris et al. (2008) and Tekle et al. (2015). Generally, we found that wet coffee processing wastewater has impacted the EC of downstream water bodies. For example, comparison of the EC values in the upstream and downstream clearly shows that the EC values were measured to be much higher at the downstream sites of the plants: C, D, E, F, H, J and K.

Total suspended solids (TSS) give a measure of the turbidity of the water. It is a fact that EC is related to the ionic content of the sample, which is in turn a function of the dissolved (ionizable) solids concentration. TSS values were indeed observed to follow approximately the trend of EC. This increment in EC might be due to presence of inorganic compounds and floating particles having larger sizes. The TSS values ranged from 4 to 158 mg/L in upstream and 10 to 96 mg/L in downstream water bodies. Coffee mills F, I, K and D were found to have the maximum TSS values of 2260 mg/L, 1440 mg/L, 1240 mg/L and 780 mg/L in their effluents, respectively (Table 2). This may be due to the difference in soaking time, washing frequency, depulping and duration of fermentation of coffee beans. In addition, this may be due to the difference in the type of pulping machine used by the plants. It is obvious that these values surpass by far the Ethiopian surface water quality standards (50 mg/L), and also the US-EPA standards for discharge of pollutants to inland surface waters (100 mg/L) (Table A1 in appendix).

TSS levels of 38 mg/L, 2260 mg/L and 48 mg/L were measured in the upstream, effluent and downstream site of plant F, respectively. The difference in upstream and downstream is only 10 mg/L, which is not that high, perhaps due to the functioning of the temporary disposal pit used by the plant. The maximum value of TSS in this study is larger (2260 mg/L) than the maximum values reported by Beyene et al. (2012), which was 970 mg/L for the impacted sites, and by Devi et al. (2008), which was 700 mg/L. However, it is consistent with values found in similar studies done by Haddis and Devi (2008) and Tekle et al. (2015), who reported 2080 mg/L in the effluent of coffee processing mills and 2504 mg/L in downstream waters, respectively. This high concentration of solids in suspension may lead to negative impacts in the ecosystem. In turbid waters, light penetration is reduced, leading to a decrease in photosynthesis. The resultant decrease in primary production reduces food availability for aquatic organisms higher up the food chain. Suspended solids may interfere with the feeding mechanisms of filter-feeding organisms and the gill functioning, foraging efficiency (due to visual disturbances) and growth of fish.

Suspended solids that settle out may smother or abrade benthic plants and animals, and may result in changes to the nature of the substratum. This may then lead to changes in the structure of the biotic community, through the decline of these organisms and their replacement with organisms which burrow in soft sediments. Sensitive species may be permanently eliminated if the source of the suspended solids is not removed (EFEPA, 2003). In addition, as mentioned by Tekle et al. (2015), suspended solids may affect the use of water for various purposes by exacerbating the dissolved oxygen problem by sedimentation and forming oxygen demanding sludge deposits, which may alter the habitat of aquatic microorganisms. Similarly, as described by Enden and Calvert (2002), the suspended material (especially the digested mucilage) builds a crust on the surface, clogging up waterways and further contributing to anaerobic conditions. These TSS concentrations automatically influence the quality of the receiving water bodies. The elevated TSS levels can be toxic to freshwater animals by causing osmotic stress and affecting the osmo-regulatory capability of the organisms and can give rise to obnoxious odors from the decomposition of organic matter (Tekle et al., 2015).

In general, we found that wet coffee processing plant wastewater impacted the TSS of downstream water bodies. For example, comparison of the TSS values for upstream and downstream clearly shows that the TSS values were measured to increase in the downstream sites of plants A, B, C, E, F, H and K.

3.2. The state of organic load and dissolved oxygen

The results of organic load measured in terms of biochemical oxygen demand (BOD_5) and chemical oxygen demand (COD), and the level of dissolved oxygen (DO) from upstream, effluent and downstream sites are shown in Table 3. The minimum dissolved oxygen concentration measured in the upstream water sources was found to be 5.15 mg/L (plant H). The decrement in DO value might be due to the impact of different agricultural practices around the site. The dissolved oxygen showed a significant decrease in all the coffee processing plants from upstream to downstream, with values going down to 0.15 mg/L. The DO concentrations of the effluents from all the plants were found to be lower than the upstream water source, which indicates that the oxygen is consumed during the decomposition of organic matter. Besides, the DO concentration of all the downstream sites is lower than the upstream sites. This implies that the downstream water sources are compromised. In addition, plants J, K, H, and F were found to have a DO concentration of 0.15 mg/L, 0.27 mg/L, 1.5 mg/L and 1.75 mg/L, respectively, at the downstream water source. This value is much below the Ethiopian surface water quality standard, which is a minimum DO of 4–6 mg/L to support aquatic life (Table A1 in appendix), which indicates the severe level of pollution of the rivers at the downstream sites. Typically, it was observed that the DO value depleted up to 0.15 mg/L in the downstream (Table 3). Anoxic or hypoxic conditions may be lethal within short time scales (minutes to hours). The sensitivity of many species, especially fish and invertebrates, to changes in dissolved oxygen concentrations depends on the species and the life stages (eggs, larvae or adult) and behavioral changes (feeding and reproduction) (EFEPA, 2003).

The relative improvement of DO downstream of plants B, D, E, F and H might be due to the relative stabilization of the wastewater in the disposal pits, self-purification of aquatic systems and dilution of the effluents with downstream water sources. On the other hand, no improvements in DO values were observed downstream of plants A, C, J and K. Thus, self-purification is not sufficient for every plant. In this regard, Cox (2003) reported that self-purification of streams and rivers require both biological and chemical processes. Oxygen is removed from the river water as organic material is oxidized by chemical processes (COD) and the biological activities of aquatic organisms (BOD_5). Sediment or benthic oxygen demand (SOD), which results from organic matter being deposited and incorporated in the channel bed, is another major cause of DO deficiency in rivers (Cox, 2003; Lehman et al., 2004). Consequently, low levels of DO

Table 3
The state of organic load and dissolved oxygen.

Wet coffee processing plant	Sampling site	Chemical parameters		
		DO (mg/L)	COD (mg/L)	BOD_5 (mg/L)
A	Upstream	6.92	64	56
	Effluent	6.06	360	291
	Downstream	5.5	82.9	79
B	Upstream	7.65	126.2	108
	Effluent	7.01	254	185
	Downstream	7.32	124	84
C	Upstream	6.06	92.6	71
	Effluent	6.00	538	433
	Downstream	5.8	142	139
D	Upstream	7.16	91.1	67
	Effluent	0.48	6140	846
	Downstream	5.15	120.6	118
E	Upstream	7.11	129.1	126
	Effluent	6.09	142	110
	Downstream	6.8	82.5	66
F	Upstream	5.76	153.4	104
	Effluent	0.25	7180	869
	Downstream	1.75	148.9	100
G	Upstream	6.82	134	100
	Effluent	6.34	148.1	87
	Downstream	ND	ND	ND
H	Upstream	5.15	174	87
	Effluent	0.43	1253	819
	Downstream	1.5	318	269
I	Upstream	6.4	128	111
	Effluent	0.17	7200	871
	Downstream	ND	ND	ND
J	Upstream	6.91	154	149
	Effluent	5.52	455	370
	Downstream	0.15	636	503
K	Upstream	6.46	104	94
	Effluent	0.3	7200	828
	Downstream	0.27	616	505

ND, not detected.

reduce the self-purification capacity of rivers to recover from the waste impact during off season (Beyene et al., 2012). DO concentrations below 5 mg/L may also adversely affect the functioning and survival of biological communities (US-EPA, 1986). Oxygen depletion can cause death of fish and create dead zones (Lapointe et al., 2000).

Generally, we found that wet coffee processing plant wastewater impacted the DO content of downstream water bodies. Comparison of upstream and downstream DO values clearly shows that the DO values were measured to be much lower downstream of all the plants.

As can be expected, the chemical oxygen demand (COD) of the effluent is consistently larger than the upstream and downstream values for all mills except the effluent from plant J. This increment of COD downstream of plant (J) may be due to the impact of a polluted water source joining the effluent of the plant at the downstream side. The increment of COD value in the effluent of the plants is due to the degradation of soluble compounds during the fermentation of the pulp and mucilage. That is, the increment in COD values in the effluents indicated that there is an increment in chemical and biological oxygen demanding waste during fermentation of coffee pulp and mucilage. This indicates that the presence of organic matter consumes the oxygen, which in turn contributes to high COD and BOD_5. It is also evident that the downstream COD value is larger than the upstream value. The effluent COD values of plants I (7200 mg/L), K (7200 mg/L), F (7180 mg/L) and D (6140 mg/L) were found to be much higher than the other mills. This difference in COD value may occur because of differences in the pulping capacity of the mills, fermentation time to remove the mucilage, and amount of water used in the process (for washing the bean and for fermentation).

Following the trend of COD values, the BOD_5 values are also larger for the effluent than the upstream and downstream values. In addition, as can be seen from Table 3, generally the BOD_5 value for downstream is greater than for upstream. In this regard, Enden and Calvert (2002) mentioned that the organic substances diluted in the wastewater break down very slowly by microbial processes, using up oxygen from the water. Due to the decrease in dissolved oxygen content, the demand for oxygen to breakdown organic material in the wastewater exceeds the supply, thus creating anoxic conditions.

According to Woldesenbet et al. (2014), the COD:BOD_5 ratio can be used as an indicator of biological degradability, with ratios below 5:1 indicating a high digestibility. In our case, the ratios of COD:BOD_5 values were below 5:1, which suggests the biological degradability of the coffee waste. Pulp and mucilage consume the oxygen in water, resulting in the death of plants and animals due to the lack of oxygen or the increased acidity (Pandey et al., 2000). This fact can later result in a proliferation of undesirable microorganisms, bringing foul odors, attracting flies and other insects, and rendering the water undrinkable and useless for many other uses (Navia et al., 2011).

The minimum value of BOD_5 in the effluent and downstream sites of the plants was found to be 87 mg/L and 66 mg/L, respectively, even after stabilization in a pit. Similarly, the minimum value of COD in the effluent and downstream site of the plants was found to be 142 mg/L and 82.9 mg/L, respectively, even after stabilization in a pit (Table 3). This indicates that large amounts of chemical and biological oxygen demanding substances in the effluent are released from the coffee processing wastewater into the rivers. If these values are compared with the Ethiopian surface water quality standards, in which the BOD_5 is less than or equal to 5 mg/L, and USEPA standards for surface waters, where the standard is 30 mg/L for BOD_5 and the maximum of 250 mg/L for COD (Table A1 in appendix), there is a clear indication that these coffee mills are substantially affecting the downstream water source, aquatic life and habitat.

The decrement in BOD_5 and COD values in the downstream water bodies may be due to a reduction of chemical and biological oxygen demanding wastes as the effluents pass through the disposal pits and due to the dilution of river water. For surface water, a BOD_5 greater than 10 mg/L usually indicates the presence of gross pollution (Nathanson, 2000). In this study, all the effluents and downstream water bodies show values exceeding this

Table 4
Nutrient enrichment and eutrophication status of wet coffee processing plants wastewater at different sites.

Wet coffee processing plant	Sampling site	Chemical parameters			
		NO_3-N (mg/L)	NH_4^+-N (mg/L)	TN (mg/L)	PO_4^{3-} (mg/L)
A	Upstream	0.362	0.041	0.72	0.75
	Effluent	1.31	0.594	3.22	0.5
	Downstream	0.235	0.369	0.96	0.65
B	Upstream	0.716	0.225	1.03	0.65
	Effluent	0.241	0.579	0.93	1.55
	Downstream	0.727	0.404	1.65	0.65
C	Upstream	0.408	0.742	1.46	0.6
	Effluent	0.723	0.727	1.94	1.3
	Downstream	UDL	0.076	0.63	1
D	Upstream	1.38	0.041	1.77	0.45
	Effluent	26.9	0.25	49.6	110.75
	Downstream	UDL	0.371	0.91	0.75
E	Upstream	0.685	0.433	1.89	1
	Effluent	0.494	0.932	2.79	0.65
	Downstream	0.828	0.747	2.21	0.85
F	Upstream	0.272	0.235	0.56	0.85
	Effluent	8.36	3.53	12.8	28.25
	Downstream	UDL	0.17	0.51	0.85
G	Upstream	0.317	0.426	1.01	1.1
	Effluent	0.09	0.042	1.19	0.55
	Downstream	ND	ND	ND	ND
H	Upstream	UDL	0.195	1.00	0.55
	Effluent	1.22	0.047	3.26	1.45
	Downstream	UDL	0.498	0.92	0.8
I	Upstream	UDL	0.087	1.93	1.4
	Effluent	8.3	0.5	12.2	21.75
	Downstream	ND	ND	ND	ND
J	Upstream	UDL	0.117	0.76	0.95
	Effluent	1.71	0.29	4.89	2.5
	Downstream	0.95	0.96	4.26	4.9
K	Upstream	UDL	0.088	0.50	1.45
	Effluent	2.84	0.4	10.5	24
	Downstream	1.25	0.62	5.2	5.3

ND, not detected; UDL, under detection limit.

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limit during the wet coffee processing season. Thus, it was evident that the downstream water bodies were substantially polluted with organic matter. This finding is consistent with other studies (Endris et al., 2008; Beyene et al., 2012; Beyene et al., 2014; Tekle et al., 2015). Haddis and Devi (2008) reported values even as high as 10,800 mg/L BOD_5 and 15,780 mg/L COD for coffee processing effluents.

Comparison of the BOD_5 and COD values we found for upstream and downstream clearly shows that both the BOD_5 and COD values increased in the downstream sites of plants A, C, D, H, J and K. Thus, it can be concluded that the wet coffee processing plants wastewater has impacted the BOD_5 and COD of downstream water bodies.

3.3. Nutrient enrichment and eutrophication

Eutrophication is one of the most serious threats to the natural environment resulting from human activity and impact (Chmiel et al., 2009). Table 4 shows the values of concentration of nutrients in terms of nitrogen as NO_3-N, NH_4^+-N and TN, and phosphorous as ortho-phosphate. Nitrogen and phosphorus content in the waters is a commonly used hydro chemical index for the assessment of the eutrophic potential of a river or lake (Chmiel et al., 2009). Normally, all the wet coffee processing plants we studied do not use any inorganic or organic chemicals during processing. As indicated in Table 4, at most of the sampling sites, the concentrations of NO_3-N, NH_4^+-N and TN increased from upstream of the coffee processing plant site to downstream of the effluent disposal site. The NO_3-N, NH_4^+-N, TN, and PO_4^{3-} concentration levels were found to be within the range of 0 mg/L to 2.84 mg/L, 0.041 mg/L to 0.96 mg/L, 0.50 mg/L to 4.89 mg/L and 0.45 mg/L to 5.3 mg/L, respectively (Table 4). The decline in the NO_3-N concentration to zero at the downstream sites of the plants (C, D, F and H) may be due to denitrification by microbial action. High nitrate concentrations in these effluents may occur as a result of the deamination of ammonium nitrogen from nitrogenous material that can be oxidized to nitrate by the action of microbiological agents (Morrison et al., 2001).

The PO_4^{3-} concentrations of the effluents were estimated to be huge. For instance, PO_4^{3-} concentrations of 110.75 mg/L, 28.25 mg/L, 24 mg/L and 21.75 mg/L were measured for plants D, F, K and I, respectively, which is higher than the other plants. This may be due to differences in pulping machines used by the plants, fermentation time and the amount of water used by these plants. The concentrations observed in this study are much greater than the findings of Endris et al. (2008) and Tekle et al. (2015), who reported a maximum PO_4^{3-} concentration of 9.9 mg/L and 18.5 mg/L, respectively. Thus, water bodies and ecosystems located downstream of the traditional wet coffee processing industries are at risk of eutrophication, which may have a huge impact on nearby residents and downstream aquatic organisms. Hence, urgent action should be taken, particularly in integrated coffee waste treatment and disposal as well as water resource management.

In general, comparison of the NO_3-N, NH_4^+-N and TN, and PO_4^{3-} values we found for upstream and downstream waters clearly shows that the NO_3-N, NH_4^+-N and TN, and PO_4^{3-} values increased in the downstream sites of certain plants. For example, NO_3^-N was found to increase in the downstream sites of plants B and E. NH_4^+-N was also measured to be higher in the downstream sites of plants A, B, D, E, H, J and K. Higher total nitrogen was measured at the downstream sites of plants A, B, E, J and K. Finally, higher PO_4^{3-} values were measured at the downstream sites of plants C, D, H, J and K than at the upstream sites. Thus, it can be concluded that wet coffee processing plant wastewater impacted the NO_3-N, NH_4^+-N and TN, and PO_4^{3-} concentration of downstream water bodies.

4. Conclusions

Overall, the coffee processing mills we studied were found to be polluting water streams with high acidity, organic load (BOD_5 and COD), nutrients (nitrate and phosphate) and suspended solids. Comparisons between upstream and downstream sites demonstrated deterioration in river water quality, which may have an adverse effect on the aquatic life as a result of being a dumping site for untreated coffee processing wastewater. From the present study, it can be concluded that the wastewater released from wet coffee processing industries is not in agreement with either US-EPA or Ethiopian EPA guidelines, involving higher than recommended concentrations of most of the measured physicochemical parameters. As a result, the polluting potential of the factories is enormous at locations below effluent discharge points, even after stabilization in a disposal pit. Thus, in order to comply with the environmental regulations and achieve a restoration of the environment, it is necessary to find an economical and easily adaptable technology for the treatment of coffee processing wastewater.

Conflict of interest

None declared.

Ethical statement

Authors state that the research was conducted according to ethical standards.

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Appendix

Table A1
Guidelines for Ambient Environmental Standards for Ethiopia and US-EPA Standards for Discharge of Environmental Pollutants.

Parameter	Ambient Environment Standards for Ethiopia: Water Quality Standards (Surface Waters)	US-EPA Standards for Discharge of Environmental Pollutants to Inland Surface Waters
BOD_5	$\leq$5 mg/L	30 mg/L, max (3 days at 27 °C)
COD, mg/L		Max 250
Conductivity	1000 µS/cm at 20°c	
DO	Min 4–6	
NO_3^-	50 mg/L	10 mg/L
NO_2^-	0.1 mg/L	
Nitrogen	1 mg/L (Kjeldahl Nitrogen)	100 mg/L, max (Total nitrogen as N)
Ammonical nitrogen		Max. 50 mg/L, (as N)
pH	6–9 (but no change of more than 0.2 units from natural level)	5.5–9.0
SO_4^{2-}	200 mg/L	
Dissolved phosphates (as P)		Max. 5.0 mg/L
Temperature	Discharge must not result in variation of more than 1.5 °C to 3 °C temp downstream of thermal discharge	Shall not exceed 5 °C above the receiving water temperature
TSS	$\leq$25 mg/L (annual mean) and 50 mg/L (max value)	100

Source: EFEPA (2003) and US-EPA (1989)

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