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Research Article
Impact of Effluents from Wet Coffee Processing Plants on the Walleme River of Southern Ethiopia

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Abstract
Background and Objective: Ethiopia is one of the well-known coffee producing countries in the world. Coffee processing industries in Ethiopia are generating very high amount of pollution in the water resources because they are disposing its effluent to the nearby water course without any treatment. Therefore, the present study was conducted to evaluate the impact of effluents from wet coffee processing plants discharged into Walleme river. **Materials and Methods:** Water samples from 4 sampling stations were analyzed for pH, conductivity, total dissolved solids (TDS), total suspended solids (TSS), chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), total nitrogen, ammonium nitrogen (NH_4^+-N) and phosphate (PO_4^{3-}). Sampling stations were designated as S1 (upstream station above effluent discharge point) and three downstream stations (S2, S3 and S4). One-way ANOVA was used for analysis of data. **Results:** The mean values for all analyzed parameters, except phosphates were significantly ($p<0.05$) higher at the stations found below the coffee effluent discharge points than the upstream one. TSS, total ammonia, total nitrogen, COD, BOD_5 and pH were found to exceed the maximum permissible limit (MPL) set both by Ethiopian Environmental Protection Agency and World Health Organization (WHO). **Conclusion:** The study has clearly indicated that the water quality of the river was significantly affected by the discharge of un-treated effluents and by-product from coffee washed plants. Therefore, urgent interference should be taken for effluent management options to avoid further needless damage to the environment.

Key words: Coffee effluent, wet coffee, water pollution, waste management and ecosystem

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Water is one of the most essential natural resource for all living creatures on earth. It covers around 71% of our Earth's surface[1]. Out of this amount, 97% is salt water in oceans which is not healthy for humans and animals to drink. About 2.14% of water is in the form of ice caps and glaciers that are not available for humans as well. The available freshwater for human use is less than 1% and this small amount of water supports more than 7 billion people and other forms of life in the world. As the world human population is increasing, the amount of available fresh water is decreasing and in danger[2].

Water as a resource is getting more and more affected by various kinds of chemicals and other hazardous materials generated by humans[3]. These pollutants are getting into water system or being released directly into the water. Earlier, the released wastes were naturally diluted and purified by the aquatic ecosystem itself[4]. However, nowadays due to urbanization, rapid growth in population, industry and other socio-economic activities, the quantity and complexity of wastes generated have been increased and the aquatic ecosystems are adversely affected.

Coffee processing plants are among the major agro-based industries which are responsible for water pollution. Ethiopia is one of a well-known coffee (Arabica) producing, processing and exporting country. Coffee is produced and processed in many regions of Ethiopia. It is a valuable trading goods and the backbone of Ethiopian economy that earns foreign exchange for the country. This major agro-based coffee processing industry is expanding in the country. The two famous coffees in Ethiopia are Kocheree and Yirgachefee that are produced and processed around Dilla, Southern regions of Ethiopia. These two coffees are known and receive higher prices for their natural flavors and taste. Dilla is one of the leading coffee producing regions in Ethiopia[5].

The most commonly used coffee processing method in Ethiopia is wet processing one. It demands high amount of water to separate the outer red coffee skin and pulp and also for the removal of the mucilage in fermentation tank. According to Selvamurugan *et al.*[6] the conventional wet coffee processing plants need about 80-93 m^3 water in order to process 1 t of fresh cherry coffee. Due to this water demanding nature, wet coffee processing plants are usually constructed very near to river or other water streams. Based on my personal observation some of wet coffee washing plants uses Walleme river as a destination point for their effluent[6].

The effluent consists of different sugars, crude protein, crude fiber, different nutrients and chemicals which are generated from both pulping and mucilage fermentation processes[7]. The organic compounds in coffee wastewater create high BOD and COD. Fermentation of sugars in fermentation tank also generates high acidity[8,9]. The effluent also consists of different toxic chemicals such as tannins, alkaloids (caffeine) and polyphenolic compounds and nutrients like nitrate and phosphate[10]. Discharge of such kinds of untreated coffee washed effluent into open environment and the river can bring various environmental and public health problems[6]. It can also cause socio-economic impacts mainly due to human health problems and loss of biodiversity.

The downstream community of Ethiopia is using the river water for washing clothes, bathing, swimming, irrigation as well as drinking. Additionally, the river is serving as a home for various aquatic plants, animals and other organisms[11]. The advent of untreated coffee effluent to the river is causing a severe threat to the aquatic ecosystem and the downstream users. To tackle this problem, understanding the nature of the coffee processing wastewater is fundamental for the design and operation of appropriate and effective treatment technologies. The physico-chemical properties of the receiving aquatic ecosystems have been serving as effective methods in assessing the impacts of pollutants on the water ecosystem[12]. Thus, the main objective of this study was to assess the effect of coffee processing plant effluent on the downstream of Walleme river using some selected physico-chemical parameters.

MATERIALS AND METHODS

Study area: The study was conducted in Walleme river found in Dilla town, Gedeo Zone, SNNPR. It is located 360 km South of Addis Ababa, capital city of Ethiopia and 85 km South of Hawassa (the regional capital city). Dilla town is located at 6°24 30″N longitude and 38°18 30″E latitude and lies at an altitude of 1800 m above sea level. The mean annual temperature of the area is 30.2 °C and the mean annual rainfall is 1333 mm. The study area was mapped using Geographical Information System using information obtained by GPS.

Sampling methods: Four sampling stations were selected along the river for physico-chemical analysis. The sampling stations were designated as S1, S2, S3 and S4. S1 is the upstream station used as a reference point or a pristine habitat. It is located 500 m above wet coffee processing effluent discharge points. The other three (S_2, S_3 and S_4) were downstream stations located with different intervals. Station 2 is located approximately 500 m below the two wet coffee processing plants discharge points. Station 3 is found 500 m away from station 2 and station 4 is also found 500 m below the third effluent discharge point. All the 4 sampling stations were selected according to the method stated in Klemm *et al.*[13] as a result all have almost similar flow velocity, vegetation type, pools and muddy bottom.

Physico-chemical analysis: Samples for physico-chemical analysis were taken monthly (two wet season months, October and November and two dry season months, January and February) from the same sampling area and at the same time. All the standard methods and instrumentations followed during sample collection were based on APHA[14]. Surface water sample from all stations were collected in 1000 mL polyethylene bottles after cleaned with nitric acid (10% v/v) and then rinsed with distilled water. The sample bottles were tightly closed without agitation and aeration, kept in the ice-box and taken immediately to laboratory for analysis. The pH, conductivity and total dissolved solids (TDS) were measured at the stations of sampling using combined pH/TDS and conductivity meter. In the laboratory, COD, total nitrogen, ammonium nitrogen (NH_4^+-N) and phosphate (PO_4^{3-}) were measured calorimetrically using a spectrophotometer (DR/2010 HACH, Loveland, USA) according to HACH instructions[15]. BOD was measured following standard methods[14]. Total suspended solid (TSS) was determined photometrically.

Statistical analysis: The physico-chemical data were analyzed using descriptive statistics. One-way ANOVA was used to see the deviations in physico-chemical data among the sampling stations ($p<0.05$)[16]. Means were separated using Tukey HSD.

RESULTS AND DISCUSSION

The water samples from 4 stations of southern Ethiopia were analysed for the selected physico-chemical parameters that showed significant spatial variations among the sampling stations. Table 1 shows the results of physico-chemical characteristics of water samples from 4 stations of Southern Ethiopia with maximum permissible limit (MPL) for discharges to water set out by Ethiopian Environmental Protection Authority[17]. The physico-chemical characteristics of water samples showed the spatial variations across the 4 sampling stations. The mean concentrations of all other selected and analyzed physico-chemical parameters were significantly higher at the downstream stations ($p<0.05$) except reactive phosphorous and pH. In addition, the spatial variations

Table 1: Physico-chemical characteristics of water samples from the Walleme river of Southern Ethiopia

	Station 1		Station 2		Station 3		Station 4				EEPA (2003)
Parameters	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range	SEM	p-value	limit
pH	7.27 ± 0.13^x	7.09-7.40	5.55 ± 0.19^y	5.35-5.73	5.59 ± 0.45^y	5.13-6.21	5.65 ± 0.79^y	4.82-6.72	0.19	0.001	6-9
EC	68.13 ± 10.51^x	51.80-81.40	238.70 ± 96.75^y	163.40-367	212.80 ± 47.58^y	158.8-264.8	221.23 ± 57.67^y	165.2-272.9	26.60	0.007	
TDS	57.68 ± 30.68^x	28.40-94	211.33 ± 103.91^y	131.90-351	218.38 ± 103.76^y	129.2-367.30	302.50 ± 101.19^z	198.2-411.5	42.40	0.017	1000
TSS	68.25 ± 34.79^x	24-106	354.00 ± 112.33^y	227-497	333.50 ± 76.97^y	231-414	295.00 ± 68.23^y	237-369	36.60	0.001	50
T-NH_3	0.39 ± 0.44^x	0.02-1.03	30.60 ± 6.23^y	23.60-36.60	16.56 ± 6.22^z	11.09-24.20	24.87 ± 12.53^z	17.16-43.50	3.18	0.001	20
T-N	3.00 ± 2.26^x	1.01-5.74	54.83 ± 12.60^y	42.61-72.50	39.08 ± 5.70^y	31.21-44.70	43.93 ± 7.17^y	36.54-51.41	3.46	0.00	40
PO_4^{3-}	3.93 ± 1.25	2.70-5.13	3.77 ± 0.94	2.90-5.10	3.71 ± 1.43	2-5.40	3.16 ± 0.75	2.12-3.80	0.55	0.783	5
BOD	4.88 ± 2.16^x	2.47-7.50	51.31 ± 12.20^y	36.0-62.03	34.87 ± 13.95^y	23.18-54.51	44.73 ± 17.92^y	27.80-63.07	5.78	0.001	60
COD	27.73 ± 12.82^x	13.02-42	333.68 ± 72.73^y	235.60-401	300.53 ± 99.32^y	161.30-395	336.88 ± 81.64^y	253.40-417	33.30	0.00	250

Similar letters with mean values in a row show means that are not significantly different and the reverse is true for different letters at different stations based on Tukey HSD at $p<0.05$. All the parameters are given in mg L^{-1}, except for pH and EC which is given in $\mu S\ m^{-1}$

in means of total ammonia, total nitrogen, BOD, COD and conductivity were also higher in stations 2 and 4 than in station 3 (Table 1).

The neutral pH mean value within the range of MPL (7.27±0.13) was measured in the upstream station, where as acidic pH mean value, which were significantly lower than MPL also measured in the S2, S3 and S4, respectively. Mean pH value in S1 was significantly higher ($p<0.05$) than S2, S3 and S4. The increase in pH might be due to the addition of coffee effluent and the presence of free ammonia, which is likely to pose problems when the water is used by downstream users for drinking and fishing. Ammonia is much more toxic in alkaline waters than in acidic ones because free ammonia at high pH values is more toxic to aquatic biota than when it is in the oxidized form. There was no significant variation in pH among the downstream stations. The results (Table 1) showed that the mean pH values are significantly lowered (acidic) in the downstream stations as compared to the MPL[17]. This might be due to fermentations of mucilage sugars in the fermentation tank that generates different weak organic acids. When these organic acids in coffee washed water released to river significantly lower the pH of water to acidic. A study by Von Enden and Calvert[8] and Campos *et al.*[9] displayed that the sugar fermentation during wet coffee processing can lower pH of the effluent as low as 4. Additionally, lower pH also indicates the existence of active decompositions of coffee organic substances discharged together with washed water.

Decomposition of organic matter in the river water body can produces more CO_2. The CO_2 from microbial decompositions and other sources readily dissolves into river water to produce a weak acid called carbonic acid. NO_x generated during microbial oxidations of nitrogenous waste are also responsible for acidification of fresh water body[17]. As a result, the acidic coffee washed effluent, carbonic acid and nitric acids lowered the neutral pH of the river water. Acidic water body will create a condition where aquatic plants, animals and microbes are hardly survived[8].

The electrical conductivity is a valuable indicator of the amount of material dissolved in water. The electrical conductivity of S1 was significantly lower than the downstream sites ($p<0.05$). But there was no significant variation among the downstream stations (Table 1). The electrical conductivity in the downstream samples showed the presence of a relatively large amount of ions, which may cause eutrophication in the water bodies[18]. The upstream water quality is strongly degraded and results in low dissolved oxygen and high conductivity.

The total dissolved solids (TDS) is an important parameter in evaluating the suitability of water for irrigation since the solids might clog both pores and components of water distribution system. The TDS present in the water affects its aesthetic value as well as its physico-chemical properties. The average total soluble solids (TSS) concentration in upstream station was 68.25 mg L^{-1}. However, high mean concentrations of 354, 333.50 and 295 mg L^{-1} were recorded in S2, S3 and S4, respectively. The upstream station had significantly higher mean TSS value than the downstream stations ($p<0.05$), but no significant variation among the downstream stations. The suspended solids in the water bodies cause turbidity in the receiving water and may alter the habitat of aquatic microorganisms[19]. The high TSS might also be attributed to coffee pulp released from coffee processing plants.

The mean values of total dissolved solids in S1 was significantly lower than the downstream stations ($p<0.05$). The last downstream station also had significantly higher TDS mean than the two downstream stations. But there was no significant variation between S2 and S3 sample (Table 1). Although the mean total dissolved solids value was within the range of MPL for drinking water, but relatively higher TDS was recorded at stations 2, 3 and at 4 than station 1. This indicated the existence of high levels of dissolved ions in the coffee washed effluent.

The high TDS and EC might also be due to microbial degradation of organic components found in the effluents as well as other dissolved solids and ions (both cations and anions) originated from river basins[19]. The existence of TDS and EC in excess amount can increase salinity of the River water that might not be potable for using the water for drinking, irrigation and other similar purpose by downstream users. High concentration of TSS and TDS might also lower photosynthetic processes and water quality by lowering light penetration potential[20, 21].

Total ammonia and nitrogen are significantly higher in station 2 than S1 at $p<0.05$. The level of total ammonia in S1 and S4 was below the MPL, but it was beyond the MPL in S2 and S3. Even though S2 had the highest mean values of total ammonia and nitrogen as compared to S3 and S4, there were no significance variations in mean values of ammonia and nitrogen among the downstream stations 2, 3 and 4. Relatively, the total ammonia and nitrogen is low in S3 as compared to S2 and S4 (Table 1).

The result showed that the total ammonia and total nitrogen in the downstream sampling stations were significantly higher than the upstream station (Table 1). The discharge of effluent with high amounts of protein substances found in the coffee pulp and mucilage can increase ammonia and nitrogen concentrations in the river. Discharge of a large quantity of protein, carbohydrates and other organic matter also increase biological and chemical demand for oxygen. Oxygen serve as electron accepter during oxidation of these reduced organic chemical substances and can deplete the dissolved oxygen in the river water. Thus, it creates anaerobic aquatic environment where aquatic organisms are unable to get enough oxygen for further aerobic respiration and very difficult for their survival[18, 22].

In the study area, mean NH_3 concentration of up to 30.6 mg L^{-1} was measured (Table 1). This amount was also beyond the maximum permissible limit for domestic water[23]. It has been reported that ammonia is also toxic to most fresh water organisms at concentrations greater than 22.8 mg L^{-1} [24]. The ammonia could also be aerobically oxidized into nitrate that can harm human health when ingested with water[24]. Thus, such high concentrations of ammonia and nitrates in surface water can induce adverse effect on human health and economic problems when the water is to be used by downstream users for drinking and fishing[17].

Water samples from upstream station had lower mean values of BOD and COD as compared with the downstream stations. There was significant variation in the mean values of BOD and COD ($p<0.05$), the upstream station having significantly lower value. However, there was no significant variation in their mean values among the downstream stations.

In water body with less or any dissolved oxygen, anaerobic respiration is mandatory for anaerobes and/or facultative anaerobes in order to generate their metabolic energy. Anaerobically microbial degradation of protein and other nitrogenous organic substances also release much more ammonia in the river water. The levels of total ammonia (un-ionized ammonia, NH_3 and ionized ammonia, NH^+_4) and other inorganic nitrogenous substances are usually at their highest concentrations when the protein input into the water are greatest[25]. Therefore, at downstream stations, high total nitrogen, BOD, COD and high total ammonia were measured. The organic substances that are found in coffee washed water can create high BOD up to 20,000 mg L^{-1} and COD of upto 50,000 mg L^{-1} [8]. Aquatic ecosystem with high COD and BOD is toxic to aquatic animals[24].

Even though phosphorous is the other essential nutrient used for plant growth and cause eutrophication, its concentration along the river was minimal and within the range of MPL (below 5 mg L^{-1}). There was no significant variation among the sampling stations for mean values of phosphates. This might be due to the phosphorous in the effluent was insignificant to bring a change in concentration in the downstream stations. The other probability is that total phosphorous could be hydrolysed into other forms. Phosphorous is also a highly dynamic compound in the water that might be due to chemical transformation and storage by various aquatic organisms[26,27].

The findings are in line with similar study conducted in South West of Ethiopia[28,29]. However, the amount of BOD and TDS measured in the receiving river water differs probably due to the inherent differences in seasonal sampling results and annual variations. Moreover, several similar studies conducted on the effects of disposing coffee washed wastewater on nearby receiving rivers reported that complete deoxygenation and toxicity of the rivers which results longer-term threat to aquatic life and human health[19,28,30,31].

CONCLUSION

The high TSS and COD as well as relatively high BOD, TDS and nitrogenous wastes were recorded in the downstream stations where lots of people drink the river water and live very close to this potentially affected water body. The availability of high concentration of aforementioned parameters showed decline in water quality and also ecosystem functions of the river. These chemicals can harm the downstream community. The associated environmental pollution and ecological impacts of coffee washed effluents could also jeopardise national economic contributions and other societal benefits of wet coffee processing plants. Hence, to ensure sustainable production of processed coffee and its economic benefits, sound and cost effective coffee waste water treatment options are obligatory.

SIGNIFICANCE STATEMENTS

This study identifies the impact of effluents from wet coffee processing plants in the Walleme river. The different complex chemicals in the coffee effluents cause water pollution, bad odours and change in physical, chemical and biological properties of the receiving river ecosystem. It can also cause human health problems and loss of biodiversity. Therefore, the findings of this study will be used as a baseline data to know the pollution status of the river and to aware its potential harmful environmental consequences. The findings of this study will also help to develop an alternative and proper coffee waste management method by the wet coffee processing plants.

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