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Effect of Wastewater Discharge From Coffee Processing Plant on River Water Quality, Sidama Region, South Ethiopia

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ABSTRACT: In Ethiopia, most of the coffee processing plants are generating large amounts of wastewater with high pollutant concentrations and discharge directly into the water bodies untreated or partially treated. The main objective of this study was to assess the effects of coffee wastewater discharged to river water quality using physicochemical parameters and macro-invertebrate indices. This study was conducted from November to the end of December 2019. Ten wastewater and river water samples were taken from coffee the processing plant and river. The macro-invertebrate samples were collected by kick sampling technique using a standard hand net. Shannon and Simpson diversity indices were examined at 3 sampling stations. The Pielou evenness index was also determined. It was found that except for TDS all the parameters of the raw wastewater and river water did not comply with the international discharge limit. The mean concentration of Faro coffee processing plant wastewater were BOD_5 (2409.6 ± 173.1 mg/L), COD (4302 ± 437 mg/L), TSS (2824.6 ± 428.4 mg/L), TDS (3226 ± 623.6 mg/L), and TS (4183.3 ± 432.9 mg/L). Whereas from Bokaso coffee processing plant were BOD_5 (3770 ± 604.4 mg/L), COD (4082.6 ± 921.9 mg/L), TSS (2766 ± 501.7 mg/L), TDS (3017 ± 747.6 mg/L), and TS (3874 ± 471.1 mg/L). A total of 392 macroinvertebrates belonging to 24 families and 7 orders were collected. The benthos assemblage communities in this river were 40, 56, and 296 at downstream 1, downstream 2, and upstream respectively. The value of the Simpson diversity index varies from 0.4 to 0.75. In the same manner, the value of the Shannon diversity index also varied from 0.5 to 1.36. Most of the physicochemical parameters of the raw wastewater were beyond the national and international discharge limits. The quality of Orsha river water downstream was more adversely affected compared to upstream.

KEYWORDS: Coffee wastewater, macro-invertebrate, physicochemical characteristics, river water quality

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Background

Coffee beans can be processed in 2 methods either dry or wet. The dry method (also called the natural one) is used to process coffee beans and that the coffee berries are both sun-dried and by using machines. Coffee husk (coffee processing by-products) is obtained when harvested coffee is processed by the dry method. The whole process is done by hand. This is very common in small or medium plantations in regions where the temperature is warmer and supplies of clean, freshwater are not plentiful.[1]

Coffee waste is generated in large quantities using the wet method of coffee cherry processing, which is known to contain 23% to 27% fermentable sugars on a wet basis. Most of the coffee pulp remains underutilized in many countries and a need exists for its treatment by appropriate waste treatment processes to overcome severe environmental pollution.[2] Several studies reported that untreated wastewater from traditional and modern industries is threatening surface waters worldwide, and it is severe in developing countries. Based on the type of industry, various levels, and quantities of pollutants can be discharged into the environment directly or indirectly.[3]

The wet coffee processing industries use a large quantity of water (an average of 147 m^3/day) for pulping, fermentation, and washing of the coffee cherry with no recirculation. Consequently, the wet coffee processing sections are generating large amounts of high-strength wastewater and discharge directly into the water bodies or partially treated before discharging to the environment.[4] The wastewater generated from coffee processing is characterized as high a concentration of Biological Oxygen Demand (BOD) up to 20 000 mg/L and a Chemical Oxygen Demand (COD) of up to 50 000 mg/L as well as the acidity of below pH 4.[5]

The study area, Sidama region, southern Ethiopia is famous for high-quality, washed coffee production. Sidama farmers deliver their coffee to the collection center at their base group (local coffee farmers association) where about 60% of the coffee is washed and wet-processed.[6]

Coffee wastewater is acidic, pH is 3.6 to 4.75, and also it causes pungent smell and odor to the receiving water body.[7] The problems are widespread which affects people downstream and causes the river ecosystem imbalance. This study tried to assess the effect of coffee processing plant wastewater on the

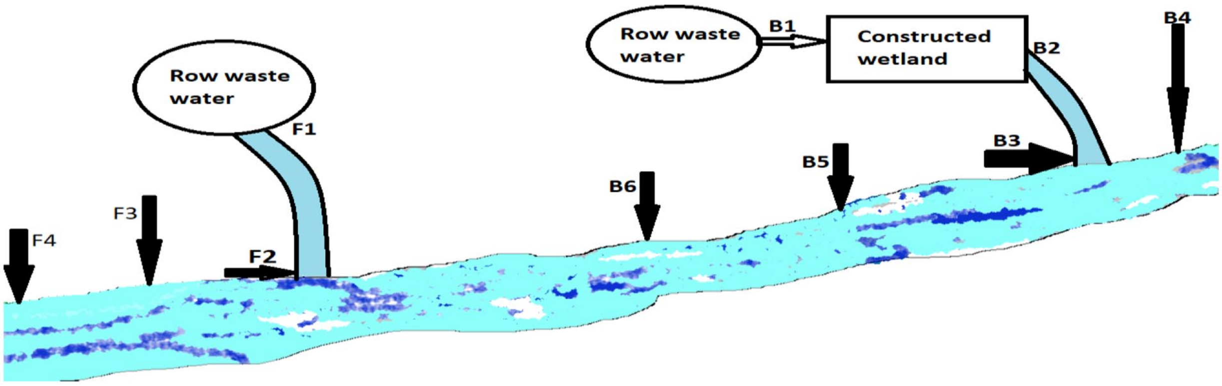

Figure 1. A sketch of sampling points in the Bokaso and Faro coffee processing plants and Orsha River.

quality of river water in the Sidama region Ethiopia as evidence for further action to tackle the problem.

Materials and Methods

Description of study area and period

This study was conducted at Wonsho District Sidama region, South Ethiopia, from November 5 to the end of December (peak for wet coffee processing time), 2019. There are 2 coffee processing plants in the study area (Faro and Bokaso coffee processing plants).

Faro coffee processing plant

Faro coffee processing plant is a privately owned entity that was established 7 years ago. Faro coffee processing plant uses 15 000 L of water per day for pulping and washing coffee beans. This large amount of water consumption generates a significant amount of wastewater, which is directly discharged into the Orsha river without any prior treatment.

Bokaso coffee processing plant

Bokaso coffee processing plant consumes 20 000 L of water per day for the coffee process. This processing plant has a constructed wetland for its wastewater treatment.

Sample Collection and Laboratory Analysis

A total of 10 place composite wastewater and river water samples were collected from both coffee processing plants and the river Orsha at different stations. The sampling points were fixed (Figure 1).

Sampling History

Coffee processing plant wastewater sampling

Composite samples of raw wastewater were collected from both sampling sites designated as F1 and B1 from Faro and Bokaso coffee processing plants, respectively. In addition to this, in the case of Bokaso coffee processing plant a treated wastewater sample. Wastewater leaving the constructed wetland (B2) was also collected, but not from the Faro coffee processing plant since it does not have any treatment facilities. Samples were collected from both sites during production time. The samples from each period 2-L representative place composite samples were taken in each sampling date.

River water sampling: Water samples from the river Orsha were collected at the discharge points (mixing points), upstream, and downstream of the discharge points in the river during the sampling periods November and December that is the peak time for wet coffee processing. Seven samples were collected from the rivers that is, F2, F3, and F4 River along the side of Faro plant and River course of Bokaso coffee processing plant samples were collected from B3, B4, B5, and B6 (Figure 1).

F2 and B3 samples were coffee processing plant effluent mixing points (discharge points) into Orsha River and from Faro and Bokaso processing plant respectively, which were designated as 0-m distance. B4 were collected at a distance of 50 m upstream of B3 and F2 respectively, while B5 and F3 were taken at a distance of 50 to 100 m downstream of the corresponding discharge point. The upstream and downstream sampling points were carefully placed based on the rivers flow and checking any entrance of sources of pollution like a sewer line.

At each sampling point (in the river water and wastewater) samples were collected using polyethylene bottles. The polyethylene bottles are used for the physicochemical parameters. All the bottles were previously washed with detergent and further rinsed with deionized water before usage. Finally, before sampling was done, the bottles were rinsed with the water sample at the point of collection. All samples were transported to Hawassa University laboratory and analyzed immediately.

In general, Sample collection and handling procedures were performed according to the standard methods for the examination of water and wastewater.[8]

Reference condition provides a baseline for assessing the contemporary status of rivers. As Stoddard et al[9] indicated that, some of the approaches to defining reference conditions include the use of minimally disturbed sites (unpolluted) and historical datasets. The "reference condition" is commonly characterized by first stratifying natural variation using classifications like stations or sites. Sites reference state based on the absence of anthropogenic stressors. The reference condition is then quantified for biotic or water quality measures based on surveys of the chosen reference sites. In this case, the uppermost section of the river (B4) was considered as a reference.

Physicochemical Analysis of Wastewater and River Water Samples

The parameters such as pH, turbidity, and dissolved oxygen (DO) of the wastewater and river water were measured immediately on the sampling sites. It was done using a portable DO meter (Hach P/N HQ30d, Loveland. CO, USA) to measure the dissolved oxygen, a portable pH meter (Wagtech International N374, M128/03IM, and USA) was used to determine pH and Jackson Candle Turbidimeter to measure turbidity. These types of equipment were calibrated properly for each sampling period.

The Chemical oxygen demand (COD), nitrate (NO_3-N), ammonium (NH_4-N), and phosphate (PO_4-P) were measured by using a spectrophotometer (Hach model DR/2400 portable spectrophotometer, Loveland, USA) according to Hach (2002) instructions/procedures. Biochemical oxygen demand (BOD_5), total solids (TS), total suspended solids (TSS), and total dissolved solids (TDS) were determined using the standard methods.[8] All the parameters analyses were done in the Hawassa University Chemistry, Environmental Health, and Engineering Department. TS and TSS (Gravimetric method), COD (Reactor Digestion Method HR), BOD_5 (Membrane Electrode Method).[8]

Evaluation of wastewater treatment: Evaluation of wastewater treatment was done from the characteristics of wastewater influent and effluent of the constructed wetland, that is, its removal efficiency was obtained by calculating the difference in each parameter concentrations between the influent and effluent of the wetland.

$$\text{Removal efficiency} = \left(\text{Ci} - \text{Cf} / \text{Ci}\right) \times 100$$

Where, Ci = the concentration of the raw wastewater, Cf = the concentration of the treated wastewater by the constructed wetland.

Macroinvertebrate sample collection and examination

The macroinvertebrate samples were collected by kick sample using a standard hand net consisting of a 20 × 30 cm metal frame with a 300 μm mesh net for 10 minutes. Sampling was done by vigorously disturbing the bottom sediment by footing and collect the macroinvertebrates in the net. All microhabitats present at the sample site were covered thoroughly during the sampling period.[10] Collected invertebrates were sorted in the field and stored in Labelle bottles with 80% ethanol. Finally, the invertebrates were transported to the laboratory and then examine with a stereomicroscope (×10 magnifications). Family level identification was carried out using the identification key.[11,12]

Statistical Data Analysis

The data analysis for all parameters was made by using SPSS version 16.0 software and an excel spreadsheet. Bivariate Spearman correlation test was applied to test the relationship between various physicochemical and macroinvertebrate indices along the different sampling sites at .05 and .01 significant levels and results were presented in tables and graphs.

Shannon diversity and Simpson diversity index were examined to determine the diversity of benthic macroinvertebrates (BMI) in 3 sampling points of river sampling points. Furthermore, the Pielou evenness index (J) will be determined in each sampling point to assess the evenness of their distribution among the different sampling points. The Shannon-Wiener Diversity Index (H′) is a diversity index that incorporates evenness and richness. A high H indicates good water quality.

It was calculated by using the following formula.

$$\mathbf{H' = -\Sigma\left[\left(ni / N\right) x \left(ln\ ni / N\right)\right]}$$

H′ = Shannon Diversity Index
Ni = number of individuals belonging to "I" species
N = Total number of individuals
H is ranging from 0 for a community with a single-family to over 7 for a very diverse community.

Simpson Diversity Index (D): It is a diversity index derived by Simpson in 1949 which varies from 0 to 1. But while calculating, the final result is subtracted from 1 to correct the inverse proportion.

$$\mathbf{1 - D = \left[\Sigma ni\left(ni - 1\right)\right] / N\left(N - 1\right)}$$

D = Simpson Diversity Index
ni = Number of individuals belonging to i species
N = Total number of individuals

Pielou evenness index (Shannon evenness index) (J)

The index was derived from the Shannon index by Pielou in 1966. The ratio of the observed value of the Shannon index to the maximum value gives the Pielou Evenness Index result. The values are between 0 and 1. When the value is getting closer to 1, it means that the individuals are distributed equally.[13]

$$\mathbf{J' = H' / H'\ max}$$

J′ = Pielou evenness index
H′ = The observed value of Shannon index
H′ max = lnS
S = Total number of species

Family biotic index (FBI)

It is a biotic index that was calculated by multiplying the number of individuals of each family by an assigned tolerance value for the specified family. The assigned tolerance values range from 0 to 10 for families that increase as water quality decreases. It was calculated by using the following equation.[14]

$$\text{HFBI} = \Sigma\left[(\text{TVi})\ (\text{ni})\right] / \text{N}$$

Where TVi is the tolerance value of family i and ni is the total number of individuals of the family i and N is the total number of individuals in the sample collection. High HFBI community values are an indication of organic pollution, while low values indicate good water quality.

Biological monitoring working party (BMWP)

The Biological Monitoring Working Party score (BMWP) provides single values, at the family level, representative of the organisms' tolerance to pollution. The greater Tolerance toward pollution, the lower the values of the BMWP score. BMWP is calculated by adding the individual scores of all families.

The average score per taxon (ASPT)

The Average Score per Taxon (ASPT) represents the average tolerance score of all taxa within the community and was calculated by dividing the BMWP by the number of families represented in the sample.

Taxa richness (TR)

TR indicates the health of the community through its diversity and increases with increasing habitat diversity, suitability, and water quality.TR equals the total number of taxa represented within the sample. The healthier the communities, the greater the number of taxa found within that community. Furthermore different macroinvertebrate metrics like % Ephemeroptera Plecoptera and Trichoptera (EPT) index, % Diptera, % dominant taxa, and % Chiromidae were determined at downstream sampling point as an indicator to assess the river health condition.

Result and Discussion

Physicochemical characteristics of wastewater discharge from coffee processing plant

Wastewater characteristics based on the analysis of the composite sample from raw (untreated) wastewater of both coffee processing plants are shown in Table 2.

A total of 11 parameters were characterized from the raw wastewater of both coffee processing plants. The pH of both coffee processing plant raw wastewater samples was more or less similar. However, the mean pH level of both coffee processing plant wastewater was acidic with values of 2.38 for Faro and 2.68 for the Bokaso (Table 2). This may be due to the fermentation process in the effluent from pulpers, fermentation tanks, and mechanical mucilage removers, sugars will ferment in the presence of yeasts to alcohol, and CO_2. However, in this situation, the alcohol is quickly converted to acetic acid in the fermented pulping water.[15] This result indicates that the pH values of both wastewaters were below the EEPA standards (6.0-9.0)[16] (WHO, 2011).[17]

The mean TS, TSS, and turbidity levels of both coffee processing plants were also found high enough to cause pollution (Table 2). Both TS and TSS Values were found similar to previous studies obtained by Mosissa et al[18] such elevated value of TS, TSS, and turbidity in both plant coffee wastewater could be attributed to various solid by-products such as coffee pulp, skin, parchment, and bean can contribute to turbidity. Discharge of solids increases the turbidity of water and causes a long-term demand for oxygen because of the slow hydrolysis rate of the organic fraction of the material. This organic material may consist of sugar, proteins, and carbohydrates. The natural biodegradation of proteins will eventually leading to the discharge of ammonium, which ammonium oxidation into nitrite and nitrate by nitrifying bacteria, leading to extra consumption of oxygen on its oxidation by bacteria.[19]

DO standard for sustaining aquatic life is stipulated at 5 mg/L a concentration below this value adversely affects aquatic life.[19] However, the mean DO values of raw wastewater in both coffee processing plants were obtained less than 5 mg/L (Table 1). So that discharging of those effluents to rivers would be harmful to sustaining aquatic life. This study is in agreement with the study done previously.[3]

The mean BOD_5 and COD values in this study were found extremely high (Table 2) and these values were found much higher than EEPA[16] standard limits of 80 mg/L (BOD_5) and 250 mg/L (COD) for the discharge of coffee processing plant wastewater into surface water. However, the COD value in this study is comparable with the value found by Haddis and Devi[20] with the range of 15 780 to 25 600 mg/L. Obtaining high BOD_5 and COD results in this study is expected since coffee wastewater quality depends on the degree of separation of mucilage, pulp juice, and other solid by-products. However, coffee pulping and washing were practiced in both plants it was the main component of the wastewater, and is reported that mucilage and a high contributor of organic load with 19 810 mg/L BOD_5 and 33 600 mg/L COD.[2] Therefore, the high BOD_5 and COD values obtained in this study could be mainly attributed to mucilage generated due to fermentation and point out that high organic materials present in both coffee processing plant wastewater.

The nutrient concentrations of Faro coffee processing plant wastewater were found higher than Bokaso (Table 2). Discharge of such wastewater with high nutrients (Table 2) may cause eutrophication of the receiving water bodies and excessive algae growth and subsequent dying off and mineralization of these algae, may lead to the death of aquatic life because of oxygen depletion. The phosphate and ammonia value obtained in this study was in parallel with the value obtained[3,20] which were

Table 1. Description of sampling point's location of the 2 plants and the river.

SOURCE	STATION	TYPES OF WASTEWATER SAMPLE
Bokaso coffee processing plant	B1	Raw wastewater before entering the constructed wetland (influent)
	B2	Treated wastewater by constructed wetland
	B3	Treated wastewater at the entry point of Orsha River
	B4	Upstream (above the entry point)
	B5	Downstream 1 of Orsha River (below the entry point)
	B6	Downstream 2 of Orsha River
Faro coffee processing plant	F1	Raw wastewater (without treatment) discharged from the plant
	F2	The entry point of wastewater to Orsha River
	F3	Downstream 1 of the river Orsha
	F4	Downstream 2 of the river Orsha

Table 2. Physiochemical characteristics of raw wastewater from the coffee processing plant.

PARAMETERS	MEAN ± SD	MEAN ± SD
	FARO COFFEE PROCESSING PLANT	BOKASO COFFEE PROCESSING PLANT
PH	2.38 ± 0.37	2.68 ± 0.62
DO (mg/L)	0.11 ± 0.07	0.49 ± 0.03
BOD_5 (mg/L)	2409.6 ± 173.1	3770 ± 604.4
COD (mg/L)	4302 ± 437.0	4082.6 ± 921.9
NH_4-N (mg/L)	21.8 ± 5.57	21.5 ± 7.1
NO_3-N (mg/L)	68.3 ± 2.74	74.2 ± 54.33
PO_4-P (mg/L)	29.6 ± 1.52	28.67 ± 5.5
TSS (mg/L)	2824.6 ± 428.4	2766 ± 501.7
TDS (mg/L)	3226 ± 623.6	3017 ± 747.6
TS (mg/L)	4183.3 ± 432.9	3874 ± 471.1
TURB (NTU)	457 ± 64	443 ± 124.5

ranging 4.6 to 7.3 mg/L of phosphate and 5.0 to 30.0 mg/L ammonium.

The lowest values were recorded in the Bokaso coffee processing plant outlet (Table 3, Figure 2) and the highest values in the Faro coffee processing plant outlet (Table 4, Figure 2). It is because of the treatment by the constructed wetland.

Impact of coffee processing wastewater on the quality of river water

The data obtained can be believed to provide enough information regarding the effect of the coffee processing plant effluent on the hydrosphere to which the effluent is released. Human beings and other animals that might use the water polluted with coffee processing effluent are susceptible to various types of health problems. The results of the assessment of physico-chemical parameter of the rivers are discussed below.

As explained in the above discussion pH is the indicator of acidity and alkalinity status of water. The mean values upstream of the Orsha river were normal with a pH value of 6.9. This value was within the EEPA standard limit. However, the mean pH value was 3.0 at discharge points and 4.0 at the downstream was observed. This could be attributed to the addition of the coffee processing plant effluents to the river. Therefore these change is serious and the pH values of the river on the 2 site indicated that below the EEPA standard limit and may harm the survival of aquatic organisms.

Table 3. Mean concentration of selected physicochemical characteristics of upstream, entry point, and downstream 2 of Orsha River with Faro discharge.

PARAMETER	UPSTREAM (F3) (MEAN ± SD)	ENTRY POINT (F2) (MEAN ± SD)	DOWNSTREAM 1 (F4) (MEAN ± SD)	DOWNSTREAM 2 (F5) (MEAN ± SD)
pH	6.9 ± 0.24	3 ± 0.5	3.56 ± 0.35	4 ± 0.30
DO (mg/L)	10 ± 1.94	0.63 ± 0.49	0.96 ± 0.41	1.33 ± 0.15
BOD (mg/L)	28.1 ± 10.4	2091.6 ± 131.6	1869 ± 220.4	1456.3 ± 206.1
COD (mg/L)	105.6 ± 13.6	3600 ± 458.2	3300 ± 200	2652 ± 434
NH_4-N (mg/L)	1 ± 0.31	21.1 ± 4.28	17.6 ± 2	15.6 ± 3
NO_3-N (mg/L)	9.53 ± 2.73	62 ± 5.1	56 ± 3.6	37.3 ± 5.38
PO_4-P (mg/L)	12.3 ± 3.21	23.1 ± 2.5	19.9 ± 1.85	15.1 ± 2.15
TSS (mg/L)	69.5 ± 10	2365.3 ± 486.2	1675.6 ± 26.9	1269.6 ± 306.2
TDS (mg/L)	129.3 ± 35.8	2624.3 ± 150.3	2201 ± 230.1	1851 ± 223.3
TS (mg/L)	184 ± 5.29	3961.3 ± 264.6	3296.3 ± 449.9	2372 ± 382.3
TURB (NTU)	17.1 ± 2.1	405.3 ± 39.5	316 ± 57.2	289 ± 61.5

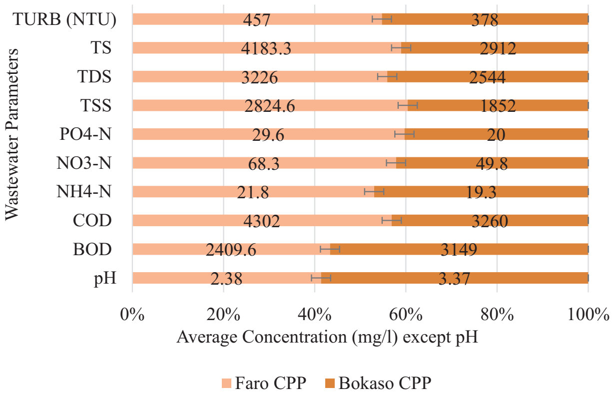

Figure 2. Average concentrations of physicochemical parameters from both coffee processing plants discharged to the river.

As regards the means of total solids (TS), total suspended solids (TSS), and turbidity values of both coffee processing plant outlets were tremendously high as present in Table 5. Upon introduction of these effluents into the river, the values had been changed from 184 to 2372 mg/L of TS in Orsha River; again from 69.5 to 1269.6 mg/L of TSS in the River. Similarly, turbidity values had been changed from 17 to 289 NTU respectively. The increment in the magnitude of these parameters downstream compared to the values upstream is due to the influence of the coffee wastewater on the receiving water bodies. The presence of such a high concentration of TS, TSS, and turbidity reduces the esthetic value of the receiving water bodies and also reduces the DO of the river further causing for suffocation of aquatic organisms.

Dissolved oxygen is a very important parameter for the survival of the aquatic organism and is also used to evaluate the degree of freshness of a river. However, the DO concentration of the river examined was found below the value that can support the survival of aquatic organisms (5 mg/L) as well as at a concentration that can lead to death for most fish, below 2 mg/L.[19]

Since BOD and COD directly affect the amount of DO in the river. Both BOD and COD are used to determine whether a water body is polluted or not.[19] A COD lowest value was recorded in the Bokaso coffee processing plant and the highest value in Faro coffee processing plant wastewater. But in the BOD the lowest values were recorded in the Faro coffee processing plant and the highest values in Bokaso coffee processing plant. It might be due to the decomposition of the wetland plant. The magnitude of the pollution due to these parameters was much higher downstream than upstream. This is attributed to the difference in the concentration of effluent discharged from both coffee processing industries to the corresponding river.

The observed BOD and COD levels were also noticed to be above the EEPA[16] limit value for the undisturbed river which is less than 80 and 250 mg/L respectively. These high levels of BOD and COD could deplete the DO in the river water ecosystem. The result indicated that the water bodies sampled were deteriorated due to continuous discharge of untreated and partially treated coffee processing plant effluents.

The phosphate (PO_4-P) concentration ranged from 12.33 to 29.7 mg/L in the entire sampling point. Possible sources of phosphate might be from the phosphorus-rich liquid and solid by-products of coffee processing activities such as extensive uses of phosphate-based detergents for washing coffee beans. Total phosphate levels in undisturbed rivers are generally less

Table 4. Mean concentration of selected physicochemical characteristics of upstream, entry point, and downstream of Orsha River with Bokaso discharge.

PARAMETER	UPSTREAM (B4) (MEAN ± SD)	ENTRY POINT (B3) (MEAN ± SD)	DOWNSTREAM 1 (B5) (MEAN ± SD)	DOWNSTREAM 2 (B6) (MEAN ± SD)
pH	6.9 ± 0.24	3.77 ± 0.25	4.5 ± 0.35	5 ± 0.05
DO (mg/L)	10 ± 1.5	1.28 ± 0.08	1.65 ± 0.20	2.2 ± 0.05
BOD (mg/L)	28.1 ± 10.4	2887 ± 98.4	2757.6 ± 332.7	2422.3 ± 184.5
COD (mg/L)	105.6 ± 13.6	2840 ± 680	2487 ± 671.1	2129 ± 776
NH_4-N (mg/L)	1 ± 0.31	17.3 ± 3.0	14.5 ± 1.5	10 ± 2
NO_3-N (mg/L)	9.53 ± 2.73	33.9 ± 10.4	28.6 ± 11.3	24.2 ± 13.3
PO_4^3 (mg/L)	12.33 ± 3.2	18.6 ± 7.3	15.6 ± 2.5	14.6 ± 3
TSS (mg/L)	69.5 ± 10	1514.6 ± 882.2	1367 ± 826.7	913.3 ± 476
TDS (mg/L)	129.3 ± 35.8	2010 ± 523.5	1694 ± 445.4	1196 ± 323.3
TS (mg/L)	184 ± 5.2	2567 ± 976.8	2262 ± 626.7	1936 ± 421.9
TURB (NTU)	17.1 ± 2.5	345 ± 78.7	300 ± 127	204.3 ± 147.8

Table 5. The value of Orsha River water quality and the standard of wastewater discharge to the environment from an industry.

PARAMETERS	ORSHA RIVER							DISCHARGE PERMIT LIMIT
	F2	F3	F4	F5	B3	B4	B5	EEPA
pH	3	6.9	3.56	4	3.7	4.5	5	6-9
DO	0.63	10	0.96	1.33	1.28	1.65	2.23	—
BOD	2091.6	28.5	1869	1456.3	2887	2757.6	2422.3	80
COD	3600	105.6	3300	2652	2840	2487	2129	250
NH_4-N	21.1	1	17.6	15.6	17.3	14.5	10	5
NO_3-N	62	9.5	56	37.3	33.9	28.6	24.2	20
PO_4-P	23.1	12.3	19.9	15.1	18.6	15.6	14.6	5
TSS	2365.33	69.5	1675.6	1269.6	1514.6	1367	9133.3	100
TDS	2624.3	129.3	2201	1851	2010	1694	1196	3000
TS	3961	184	3296.3	2372	2567	2262	1936	—
TURB	405.3	17	316	289	345	300	204.3	

than 5 mg/L, phosphate concentration greater than 5 mg/L, are attributed to human activities and contamination rise to excessive growth of algae.[16] So that the effluent discharged from both coffee processing plants was plentiful to cause eutrophication on receiving river.

The other nutrients like ammonium and nitrite follow a similar trend as phosphate in all sites. In the case of the Faro site higher nitrate concentration was observed at the discharged point of the River than upstream and downstream during the sampling periods. It suggested that due to coffee effluent entering into the receiving water body. Its presence in high concentration in drinking water has a health risk for young children causing methemoglobinemia (blue babies syndrome) if the community uses this river water for drinking purposes.[21]

The relative concentrations of pollutants in the discharge point, upstream, and downstream of the river were illustrated in Table 6. It was observed that the concentration of most of pollutants were highest at the discharge points due to the increased discharges of both coffee processing plant wastewater and fall at the down streams due to the assimilation and

Table 6. Average concentrations of selected physicochemical characteristics in Bokaso coffee processing plant influent, effluent, and its treatment efficiency.

PARAMETERS	INFLUENT VALUE (MEAN ± SD)	EFFLUENT VALUE (AFTER TREATING) (MEAN ± SD)	% REMOVAL EFFICIENCY	EEPA[16]
PH	2.6 ± 0.6	3.37 ± 0.2		6-9
DO (mg/L)	0.49 ± 0.03	0.9 ± 0.46		—
BOD (mg/L)	3770 ± 604.4	3149 ± 103.0	16.4	80
COD (mg/L)	4082.6 ± 922.9	3260 ± 620.0	20.1	250
NH_4-N (mg/L)	21.5 ± 7.1	19.3 ± 3.5	10	5
NO_3-N (mg/L)	74.2 ± 54.3	49.8 ± 12.4	32.8	20
PO_4-P (mg/L)	28.6 ± 5.5	20 ± 3.2	30	5
TSS (mg/L)	2766 ± 501.7	1852.3 ± 875.5	33	100
TDS (mg/L)	3017 ± 747.6	2544 ± 377.9	15.6	3000
TS (mg/L)	3874 ± 471.1	2912 ± 1100	24.8	—
TURB (NTU)	443 ± 124.5	378 ± 102.8	14.6	—

dilution effects of the river water. The lowest concentration was recorded upstream of the river. This clearly showed that both coffee processing plant wastewaters play a substantial role in the deterioration of the water quality of the river. Regardless of the sampling point, all of the parameters examined except TDS, were found much higher than the national and international wastewater discharge recommended standards limit (Table 5).

Pearson correlation matrix (r) among selected physicochemical parameters and benthos assemblages as biological indicators of river water quality. pH (r = .93, P-value <.05) and Dissolved Oxygen (DO) (r = .82, P-value <.05) exhibited that they were positively and significantly correlated with benthos assemblages, while BOD (r = −.91, P-value <.05) and COD (r = −.96, P-value <.05) are negatively correlated with benthos. The results of the analyses for most parameters showed that the expected trends in water quality. DO has a negative correlation with almost all parameters such as turbidity (r = −.926), TS (r = −.914), TSS (r = −.826), PO_4^3 (r = −.630), NH_3 (r = −.922), COD (r = −.934), BOD (r = −.980), and positive correlation with pH (r = .909). This implies that presence in a high value of turbidity, TS, TSS, NH_3, COD, BOD had caused directly or indirectly depletion of DO in the sampled wastewater. Since upon. A by-product in the wastewater that can bring change in the amount of TS, TSS, COD, and BOD parameters may also cause a change in the value of pH and DO in addition to the oxidation of the pollutants that consumed oxygen.

TS and TSS have a significant positive correlation with each other as well as with COD and BOD and they have also a positive correlation with PO_4^3 and NH_3 and NO_3. However, negative correlation with DO. This is pointed out that an increase in TS and TSS led to an increment of COD, BOD, and decrement in DO. Since degradation of both TS and TSS reduce the DO of the wastewater which led to increased BOD and COD in the wastewater. This suggests that wastewater characterized by high TS and TSS also be characterized by high BOD, and COD.

The temperature has a negative correlation with DO (r = −.697) but it has a positive correlation with COD and BOD. Indicates as the wastewater temperature increase, DO decreases which means the COD and BOD of the water is high. Similarly, COD and BOD are correlated to each other (r = .985) since both measure the oxygen demand of the organic substance in the wastewater.

Performance of constructed wetland in treating coffee wastewater at Bokaso coffee processing plant. The wastewater sample was taken before and after it had passed through the constructed wetland bed in Bokaso coffee processing plant and analyzed for physicochemical characteristics. A total of 2 samples were taken before and after treatment as B1 and B2.

The influent COD, BOD, turbidity, TS, TSS, phosphate, ammonium, and nitrate concentrations were selected as operational variables in evaluating the constructed wetland wastewater treatment efficiency. The average influent and effluent physicochemical characteristics of the Bokaso coffee processing plant wastewater at each sampling point were presented in Table 6.

It was observed that before treatment the wastewater was turbid, high total solids and high total suspended solids. The influents were reduced their load after passing through the treatment wetland but it was noticed that the overall performance of the treatment system wasn't satisfactory for the removal of these pollutants. The overall removal efficiency of this constructed wetland was substantially low for most of the parameters (Table 6). This low performance might be due to different factors such as poor construction design, the plant and substrate type, hydraulic retention time and hydraulic and area loading rate, flow rate, and other factors.

From the information gathered from the company workers, we understand that this constructed wetland was not designed by professional experts. Most of the determinant factors for better performance were not considered. For example, the aspect ratio of horizontal subsurface constructed wetland should be a minimum of 2:1. But in this constructed wetland it was less than 1.5:1. The hydraulic retention time also was not sufficient for best performance because the volume of the constructed wetland was not maintained for the volume of wastewater discharged daily, in general, during our visit we recognize that the hydraulic retention time was less than a day, the effective depth of this constructed wetland was 0.53 m. However, the effective depth shall be more than 0.6 m to enhance the adsorption performance of the constructed wetland substrates as well as enough time for the plant uptake.[22]

Lack of such information, and an integrated approach, has led to the development of many constructed wetlands that are inappropriate, under-performing, or poorly designed or maintained. The reasons for these problems include lack of appreciation by many designers of the complex, physical, biological, and chemical processes within constructed wetlands; Lack of consistency in design, construction, and operation aimed at optimal performance; lack of appropriate design tools and methodologies suitable for local conditions; and changing nature of rapidly-developed technology. The performance of WSPs and constructed wetlands relies not only on good design but also on good construction and operation.[23]

Benthic macro invertebrate's characteristics of the Orsha River. Upstream, downstream1, and downstream2 benthos assemblages of fauna from 7 taxonomic orders were collected from the Orsha River. A total of 24 families and comprising 392 individuals were collected from the 3 sampling sites. The total number of individuals found in the (DS1) and (DS2) were 96 compared to 296 individuals were collected from the UPS. The pollution sensitive taxa of Ephemeroptera 67 (17%), Hemiptera 47 (12%), Trichoptera 68 (17.3%), Plecoptera 12 (3%), and Coleoptera 44 (11.2%) were present in greater number in the UPS. On the other hand, pollution tolerant species of families Chironomidae, Simuliidae (Diptera) 102 (26%) present in greater number in the DS sections throughout the experimental period reflected the coffee processing plant stresses of the ecological status of the river in downstream sections. These benthos assemblages would indicate the environmental effects of coffee processing activities on the Eco-hydrological river water quality and its vicinity. The analysis of the average species diversity of benthos assemblages as biological indicators (Shannon and Simpson) was much reduced in the DS as against UPS.

Table 7 shows different indices and metrics of macroinvertebrates in 3 sampling points of the study area. Simpson diversity index and Shannon Weiner diversity index were also assessed to examine the diversity of macroinvertebrates in 3 sampling stations. The value of the Simpson diversity index varies from 0.4 to 0.75. The maximum and minimum Simpson diversity was presented in the upstream sampling point (UPS) and the immediate downstream or (DS1) sampling point of the study site respectively. In the same manner, the value of the Shannon diversity index also varied from 0.5 to 1.36. The maximum value is present in the upstream sampling point (UPS) while its minimum value is presented in the immediate downstream (DS1) sampling point of the study area. The abundance of EPT (Ephemeroptera, Plecoptera, and Trichoptera) was almost dominated in the upper stream sites while in the case of downstream it was few. The abundance of Diptera was also high downstream compared to the upstream of the study site which can also be taken as an indication of the presence of pollution caused by the discharge of coffee processing industries effluent.

According to Burgess[24] Family level richness is a metric that is used to assess the diversity number of different families found in a sample. It reflects the health of the community as a measurement of the variety of families present. These metric increases with increasing water quality, habitat diversity, and habitat suitability. Based on this fact, the current finding showed that family richness varies from 6 to 12. The highest family richness was documented in the upper stream of the study site while points in the downstream of the study site exhibited taxa richness ranges from 6 to 10 which may indicate relatively decreased water quality, habitat diversity, and habitat stability compared to the upper stream sites of the study area. The lower level of dissolved oxygen in coffee waste receiving site provides a lower number of taxa while the free from the impact of the upper stream was able to support a higher number of taxa. A decrease in the number of taxa at sites may be due to experiencing depleted dissolved oxygen, nutrient enrichment, and sedimentation.

According to a study finding by Beyene et al[3] EPT was absent from impacted sites but present in the reference site (least impacted). It is considered as an indication of pollution that affects these organisms which are used as indicators of good water and habitat quality. The study conducted in Ethiopia evidenced that, the total disappearance of these taxa in highly polluted sites of Akaki River, Addis Ababa.[25] Therefore, these metrics can be used to know the impact of different activities which cause moderate perturbation on the water quality of streams, and rivers. The current finding was in line with the abovementioned finding. The possible justification may be due to the accumulation of nutrient enrichment,

Table 7. Cumulative number of individuals for macro-invertebrate taxa of Orsha River.

ORDER/FAMILY	UPSTREAM	DOWNSTREAM 1	DOWNSTREAM 2	TOTAL	% COVERAGE
Ephemeroptera					
Baetidae	12	0	4	16	4
Heptageniidae	18	1	0	19	4.8
Epemeridae	19	0	0	19	2
Caenidae	13	0	0	13	3.3
Plecoptera					
Perlidae	12	0	0	12	3
Trichoptera					
Hydropsychidae	16	0	2	18	4.6
Hydroptilidae	21	0	0	21	5.3
Leptoceridae	24	1	0	25	6.4
Polycentropodae	0	4	0	4	1
Odonata					
Coenagrionidae	10	2	2	14	3.6
Libellulidae	15	2	1	18	4.6
Gomphidae	12	0	0	12	3
Aeshnidae	8	0	0	8	2
Hemiptera					
Belostomatidae	13	1	1	15	3.8
Corixidae	11	3	0	14	3.6
Gerridae	18	0	0	18	4.6
Diptera					
Chironomidae	0	10	21	31	8
Ceratopogonidae	15	2	4	21	5.3
Simulidae	0	10	14	24	6.1
Syrphidae	0	3	7	10	2.5
Tibulidae	16	0	0	16	4
Coleoptera					
Gyrinidae	20	0	0	20	5.1
Elmidae	10	0	0	10	2.5
Dytiscidae	13	1	0	14	3.6
Total	296	40	56	392	

accumulation of organic matter and reduction of dissolved oxygen which is vital for the survival of living organisms.

The finding showed that the most sensitive macroinvertebrates were highly prevalent in the upper stream of the study site whereas highly tolerant macroinvertebrates highly occurred downstream of the study site. This might be due to their high tolerant capacity of disturbance the downstream of the study site indicates.

Hilsenhoff[14] investigated the classification of stream water quality based on the Family Biotic Index (FBI) range from 0.00 to 10.00. The values which are less than 3.75 are considered as excellent while 3.76 to 4.25, 4.26 to 5.00, and 5.01 to

5.75 are very good, good, and fair respectively. Values which ranges from 5.76 to 6.5, 6.51 to 7.25, and 7.26 to 10.00 were fairly poor, poor, and very poor respectively. Based on this fact, the current study showed that the 2 reference sites (UPS and DS2) were classified as having a fair and fairly poor level of water quality. But the immediate downstream sampling points were classified as having a very poor level of water quality. On the contrary, the final downstream sampling point of the study site was somewhat less polluted than the above (DS1) points and was classified in the category of poor level of water quality which might be due to the self-purification of a stream.

Turkmen and Kazanci[13] indicated values measuring using the Simpson diversity index range between 0 and 1. Zero represents minimum evenness and 1 for the maximum. Based on this fact, all the sites have fallen in the range from 0.1 to 0.6 in which higher values were present in the upstream sampling site while lower values were present downstream of the stream which indicates the presence of severe pollution of Orsha River which was because of wastewater discharged from Bokaso coffee processing plant.

A study conducted by Turkmen and Kazanci[13] showed that Pielou Evenness Index (J) is the ratio of the observed value of the Shannon index to the maximum value. The values are between 0 and 1. When the value is getting closer to 1, it means that the individuals are distributed equally. Based on this fact, the first 2 downstream sampling points, the mean value of Shannon evenness index were 0.42 and 0.26 which is less than 0.5 which implies the presence of unequal distribution among different taxa in the sampling point. The possible justification for this finding might be due to the difference in the tolerance level for water pollution by discharges from coffee processing plants.

Greater macroinvertebrate diversity was observed upstream than downstream. But in the downstream sensitive organisms were present which may be due to the self-recovery process of the river through the natural process especially in the last downstream sampling point. But the abundance and diversity level remained lower than compared with the upper stream sites of the Orsha river which was in line with the study conducted.[18]

The dominant taxa greater than 35% indicates poor water quality, between 25% and 35% indicates fair water quality, and less than 25% indicates good water quality.[18] Based on this criterion, 2 sampling points were classified under poor water while the remaining sampling point was classified under fair water quality.

Macroinvertebrate indicators were strongly positively correlated with pH and DO while negative correlations were noticed in BOD and COD of river water quality. This showed that there was hypoxia or anoxia which affected taxa richness and all diversity indices

Conclusion

Raw wastewater of both coffee processing plants was characterized by a high concentration of organic matter (COD and BOD), Nitrate, phosphate, and solid matters (TS and TSS) which was much higher than the national and international standard limits. The same was true for the river water quality too.

Even though one of the coffee processing plants (Bokaso) has a constructed wetland for the treatment of the wastewater, The overall treatment performance was low and its final effluent did not comply with national and international standard limits for the majority of the physicochemical parameters.

Benthic macroinvertebrate index analysis using Simpson diversity index and Shannon Weiner diversity index showed that the level of pollution of Oesha River increased due to the discharge of coffee processing wastewater.

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Author Contributions

All authors have made an essential intellectual contribution to this study. WG and MBA designed the study, conducted the experiments, collected, analyzed, and interpreted the data, and wrote the manuscript. DD supervised the experiment, provided comments, and suggestions for the whole work. GGK supervised and provided pertinent comments and suggestions on the manuscript. All authors read and approved the final manuscript.

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Availability of Data and Materials

The dataset and materials used for this manuscript is available and can be shared whenever necessary. Data was generated by the author from the field sample collection and laboratory analysis.

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