Waste Water Management in Wet Coffee Processing Mills and their Impact on the Water quality status of Gidabo River and its Tributaries, Southern Ethiopia

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ABSTRACT: The Gidabo River and its tributaries are the main sources of water for more than 1,584,646 inhabitants. It is an important source of water for the surrounding rural communities for various uses such as domestic, irrigation, livestock watering, fishing, and recreation. The river is the main tributary of Lake Abaya. The present study was designed to investigate the water quality status of the Gidabo River and its tributaries for domestic and aquatic life. To assess the water quality status, water samples were collected in monthly intervals for a period of 3 months from September to November (coffee processing time), 2022. Arc GIS 9.3, 3 DEM, and spreadsheet were used to analyze the data collected from SRTM (Shuttle Radar Thematic Mapper, 90 m) and field observation. Of all the water quality parameters analyzed; turbidity, BOD_5, DO, COD, pH, Ni, Fe, NO_3^-, and PO_4^{3-} were higher than the recommended limits of national and international standards for aquatic life. Based on the Weighted Arithmetic Mean (WAM), Water Quality Index (WQI) calculations of the River, WQI value of the river ranges between 34.83 and 54.31 in different reaches of the watershed which is classified under bad category. The wet coffee processing industry which is the main sources of contamination in the watershed uses 63 L of processing water to produce 1 kg of green coffee beans. Traditional lagoons, with an average hydraulic retention time (HRT) of 1.99 days, are the most common methods of treating wastewater. The river is at higher risk from harmful anthropogenic activities in the watershed and requires urgent monitoring and mitigation to prevent further degradation.

KEYWORDS: Coffee, Gidabo River, HRT, lagoon, water quality index

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Introduction

One of the major factors affecting water quality is the rapid pace of industrialization and water-intensive cropping despite varying soil textures and natural and climatic condition. In Ethiopia, despite the current phenomenal strides in agricultural progress and industrial expansion, inadequate dissemination and limited access to environment-friendly technologies along with negligent enforcement of environmental regulations, have resulted in the extravagance of unhealthy industrial practices causing cascading environmental pollution in the receiving watershed. Large scale apathy on the part of industries as well as the state has led to massive release of industrial wastes and toxic effluents discharge into nearby banks of water bodies causing immense orders of environmental pollution and health hazards to major life forms and natural activities. Often such industrial effluents contain products and by-products of toxic and deadly untreated chemicals such as chromium, lead, cadmium, arsenic and mercury etc., which not only pollute the water and environment but also endanger the health of millions of human inhabitants as well as domestic and wild animals in general.[1-3]

There are more than 285 wet coffee processing plants in the Gidabo Watershed distributed and concentrated around the Gidabo River and its tributaries. Quality coffee has its own production method. Basically, there are 2 coffee processing methods which are dry and wet coffee processing. The type of processing determines the quality of the final product. In addition, each processing technique has a different potential for environmental pollution. The simplest and least polluting processing is the dry method, which is mostly used for Robusta coffee.[4] In this method, cherries are picked and left in the sun until the whole fruit reaches a moisture content of around 11%. After drying, the outer pulp and the parchment are removed in 1 step.

Unlike the dry method, wet processing requires a higher level of processing expertise and is mainly used for Arabica coffee. Wet processing is produces a higher quality product, known as "mild coffees." The finer quality is achieved by pre-sorting step of the cherries to ensure that only ripe cherries enter the process. This is done during an approximate fermentation period of approximately 36 hours, depending on natural conditions like altitude and temperature.[5] Only after the mucilage layer has been hydrolyzed are all residues are washed off and the clean parchment is ready for further processing such as drying.[6] Wet coffee processing procedure requires mechanical removal of pulp using the water, resulting a significant amount of wastewater. The water used for de-pulping of the coffee cherries is known as pulping water and it accounts for over half of the water used in the process.

Wastewater generated from coffee processing has high concentration of organic pollutants such as pectin, proteins and sugars, nitrate and phosphate, which can be dangerous for the water bodies, human health and the local environment in general.[7] Therefore, it must be properly treated before its final disposal in water bodies.

According to Blinová et al,[8] wet and semi-wet coffee processing has a significant negative impact on the environment. Due to the high organic content and acidic nature of the nearby water bodies, coffee waste from wet processing has the potential to cause environmental concerns and contributes to water contamination.[9] Water bodies and ecosystems downstream of wet coffee processing facilities are at serious risk of ecological disruption, and local populations may also suffer serious health impacts. Coffee has about 1500 chemical components, of which 850 are volatile and 700 are soluble since proper preparation of coffee requires 13 different chemical and physical variables.[10] Large volumes of effluents, rather than their intrinsic toxicity, because problems when they are dumped into watercourses that are highly loaded with organic debris. As long as the watercourse's capacity for self-purification is surpassed, microbial degradation lowers oxygen levels to anaerobic conditions, which are incompatible with the existence of higher aquatic life.

According to Duguma and Chewaka,[11] coffee effluents have the ability to destroy microorganisms and plants that remove and absorb contaminants from water. The direct dumping of wastewater into adjacent water bodies has been linked to a number of serious health issues, including spinning feeling, skin, ear, and eye irritation, nausea, stomach pain, and breathing difficulties in the local population. Wet coffee processing facilities not only have an impact on human health but also provide environmental risks because of the widespread dumping of coffee pulp, husk, and effluents from these facilities. The harmful substances such phenols that are present in these leftovers limit their practical application in farming.[9] Furthermore, using fresh coffee pulp carelessly damages crops by causing acidification and localized heat generation during the fermentation process.

Although a gradual decline in water quality has been observed in the Central Rift Valley Lakes Basin of Ethiopia (CRVLBE) due to the recent increase in anthropogenic activities, stringent measures are required by the concerned agencies to control the levels of potentially toxic elements in various water bodies.[12] Consumption of onions in CRVLBE contributes to the daily dietary requirement of many important metals, including major (Na, K, Ca, and Mg) and trace (Cu, Co, Cr, Mn, and Zn). The absence of lead (Pb) in the contaminated irrigation water and onion bulbs indicates that Ethiopian onions from Meki Town, which is part of the CRVLBE, either have very low levels of Pb (less than 0.5 mg/kg) or may be completely free of this element. On the other hand,[13] Meki onions grown using water from Lake Ziway and a well were found to have Cd levels of 0.5 and 0.6 mg/kg, respectively.

In general, the discharge of untreated wastewater is a significant contributor to degradation of the quality of life and health of local water bodies.[14] For the sake of sustainable coffee production, the aforementioned findings highlight the need for more research into the planning and execution of coffee waste valuation and treatment.[15]

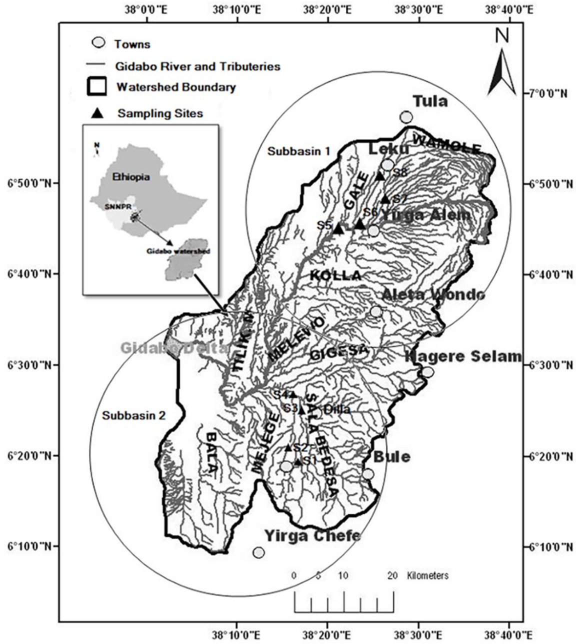

Figure 1. The study area (Gidabo Watershed).

The number of people living in water-stressed conditions worldwide is between 1.4 and 2.1 billion.[16] Contamination of water bodies by foreign substances impairs their suitability for intended uses and aggravates the problems of water scarcity. Due to the lack of intensive research on the rivers water quality status on the regular basis and its impact on the river ecosystems; the potential of the river were not well addressed to use these water resources for multiple designated water uses. Therefore, this study aimed at identifying the impacts of wet coffee processing wet mills on the water quality status of rivers and tributaries in Gidabo Watershed of Ethiopia. The study also evaluates if certain wastewater management strategies of these industries have any impact on the water quality. From September to January, majority of the wastewater in the watershed comes from hundreds of wet coffee processing industries in the watershed. This watershed is considered as a home for quality brooks and the green gold, Arabica coffee of *Sidama* and *Cheffe* varieties, exported to the international market. It is hypothesized that the effluent from these wet coffee processing industries has affected the quality of the rivers and tributaries in the watershed.

Material and methods

The study area. The absolute geographical location of the watershed is between 6.09°N and 6.6°N latitude and 38°E and 38.38°E longitude with an area and perimeter of 3342.37 km^2 and 305.25 km respectively. The total length of the watershed is about 76 km with maximum flow distance of about 117 km. The length of the longest river in the watershed is about 38 km and the maximum stream slope is 0.15% (Figure 1).

Table 1. Sampling sites locations.

NO	LOCATION	SAMPLE NUMBERS							
		SUB BASIN 2				SUB BASIN 1			
		S1	S2	S3	S4	S5	S6	S7	S8
1	Northing	708019	708214	711115	712485	746571	746572	751625	758343
2	Easting	419521	420734	421590	419192	431182	435553	437534	439213
3	Site	Bedessa	Dilla S.	Dilla N.	Bridge	Aposto	Arada	Chume	Teremesa
4	District	Dila Zuria	Dila Zuria	Dila Zuria	Dilla-Dara	Dale	Dale	Dale	Shebedino

Sample collection and analysis. The method of sample collection was in accordance with the WHO guidelines for wastewater[17] and the American Public Health Association guidelines.[18] A total of 15 water quality parameters were collected from 8 sample sites in the Gidabo Watershed to investigate the water quality status of the river and its tributaries. In addition, 2 additional effluent samples from wet coffee processing industries downstream of sites S1 and S8 were collected to investigate the characteristics of the effluent in comparison to the water quality measured at sites S1 and S8, respectively.

Grab samples were taken at monthly intervals for 3 months, from 21 September 2022 to 21 November 2022, at 8 selected sampling sites at 12 noon, 30 cm from the surface and 1 m above the river bed. All samples were triplicated at each sampling time. Mean values were used for analysis. Sampling sites were purposively selected based on the relative importance, location and magnitude of industrial impacts from wet coffee processing. Sampling site S1 (upstream of Small Bedessa River), S2 (south of Dilla town in Dilla Zuria District), S3 (Chicu River, north of Dilla town), S4 (on the stream between Dilla Zuria District of Gedio Zone and Dara District of Sidama Zone), S5 (at the Kege and Wenenta wet coffee processing mills on the Gidabo River bridge near Aposto town), S6 (Gidabo River at the old Yirgalem town of Dale district), S7 (Gidabo at Chume village of Dale district), S8 (Telamo stream at Teremessa village of Shebedino district). The geographical distributions and coordinate locations are presented in Figure 1 and Table 1, respectively. The water quality parameters analyzed in this study are presented in the following table.

Data points mapping. Comprehensive surveys were carried out by providing tabular questioners for 11 districts in the catchment on the status of wet mills. Using the tabular sheet variables such as: District name, name of the coffee washing plant, its location (village name, northing (UTM, Universal Transverse Mercator system), easting (UTM), number of lagoons in each mill, lagoon size (m3), average total daily water requirement (m3), weight of fruit pulped per day (kg/day), management of solid and liquid waste in the industry. Using this data, each wet coffee processing industry was mapped on a GIS interface for decision making. The topographic map was generated from a Digital Elevation Model (DEM) derived from a 90 m resolution Shuttle Radar Terrain Model (SRTM). Arc GIS 9.3 software from ESRI was used to produce all the maps in this document.

Data aggregation. Separate descriptions of each water quality parameters are time consuming and do not yield appropriate understanding to monitor and control the water bodies. Water quality indexing was employed to aggregate individual water quality parameters. One of the best tools for informing concerned citizens and policymakers about the quality of the water is the Water Quality Index (WQI).[19] It is capable of comparing data from several sites and months by quantitatively condensing the information from multiple water quality parameters into a single value. The results of examination pertaining to a water body are made simpler by the use of the Water Quality Index (WQI), which condenses all analyzed parameters into a single value.[20] There are a number of indices developed in many parts of the world to evaluate water quality status and pollution extents of the water bodies like U.S NSFWQI,[21] BCWQI,[22] OWQI,[23] and Smith's Index.[24] For this investigation, the water quality index, WQI, was calculated based on the weighted arithmetic mean (WAM) model where different water quality parameters are multiplied by a weighting factor and then are aggregated using simple arithmetic mean as:

$$WQI = \sum_{i=1}^{n} SI_i \times W_i \tag{1}$$

Where SI_i = Sub-index i, n = No of sub-indices, W_i = Weight given to sub-index

The normalized objective water quality index (equation (2)) which was modified from WAM-WQI proposed by Conesa and other researchers.[25-27] It is written as:

$$WQI = K \frac{\sum_{i=1}^{n} C_i \times W_i}{\sum_{i=1}^{n} W_i} \tag{2}$$

Where: C_i = Normalization Factor (Sub-index i), W_i = Weight given to sub-index, k is a subjective constant which represents the visual impression of river contamination. It can take a value

Table 2. Water quality parameters investigated, methods and apparatus used.

PARAMETERS	METHODS AND APPARATUSES
pH, temperature, EC, TDS	pH and conductivity meter (HANNA pH211)
PO_4^{3-}, NO_3^-	Photometric measurements using spectro photometer
COD	dichromate reflux method through oxidation of the sample with potassium dichromate in sulfuric acid solution followed by titration
BOD_5&DO	Winkler-Azide dilution technique
Turbidity	Nephelometeric (HACH, model 2100A)
Mg, Ca, Cr, Ni	Atomic absorption spectrometer, AASP (Varian SP-20) using their respective standard hollow cathode lamps.[30]
Iron	UNICAM UV-300 thermo electrode.

Table 3. Parameters considered for WQI calculation adapted from Pesce and Wunderlin.[25]

WQP	WEIGHT (W_i)	NORMALIZATION FACTOR (C_i)										
		100	90	80	70	60	50	40	30	20	10	0
BOD_5	3	<0.5	<2	<3	<4	<5	<6	<8	<10	<12	≤15	>15
Ca^{2+}	1	<10	<50	<100	<150	<200	<300	<400	<500	<600	≤1000	>1000
EC	2	<750	<1000	<1250	<1500	<2000	<2500	<3000	<5000	<8000	≤12000	>12000
COD	3	<5	<10	<20	<30	<40	<50	<60	<80	<100	≤150	>150
DO	4	≥7.5	>7.0	>6.5	>6.0	>5.0	>4.0	>3.5	>3.0	>2.0	≥1.0	<1.0
Mg^{2+}	1	<10	<25	<50	<75	<100	<150	<200	<250	<300	≤500	<500
NO_3^-	2	<0.5	<2.0	<4.0	<6.0	<8.0	<10.0	<15.0	<20.0	<50.0	≤100.0	>100.0
pH	1	7	7-8	7-8.5	7-9	6.5-7	6-9.5	5-10	4-11	3-12	2-13	1-14
PO_4^{3-}	1	<0.16	<1.60	<3.20	<6.40	<9.60	<16.0	<32.0	<64.0	<96.0	≤160.0	>160.0
TDS	2	<100	<500	<750	<1000	<1500	<2000	<3000	<5000	≤10000	≤20,000	>20,000
T	1	21/16	22/15	24/14	26/12	28/10	30/5	32/0	36/–2	40/–4	45/–6	>45/<-6
Turbidity	2	<5	<10	<15	<20	<25	<30	<40	<60	<80	≤100	>100
Fe	1	<0.3	<0.5	<1	<1.5	<2	<3	<4	<5	<6	≤8	>8
Nickel	1	<0.02	<0.025	<0.035	<0.045	<0.055	<0.065	<0.075	<0.085	<0.095	≤0.097	>0.097
Chromium	1	<0.05	<0.055	<0.065	<0.075	<0.085	<0.095	<0.105	<0.115	<0.125	≤0.135	>0.135

Abbreviations: C_i, normalization Factor; W_i, relative weight; WQP, water quality parameters.

of 1 for water without apparent contamination or 0.75 for a slightly contaminated river or 0.5 for turbid contaminated water. For highly contaminated water characterized by blackish color, hard odor, visible fermentation, a value of 0.25 is assigned. To avoid subjectivity, for this research a value of unity was considered for k.[28,29]

C_i is the value assigned to each parameter after normalization (Table 2). W_i is the relative weight assigned to each parameter (Table 3). W_i value range from 1 to 4, with 4 representing a parameter that has the most importance for aquatic life preservation (Total dissolved solid and dissolved oxygen), while a value of 1 means that such parameter has a smaller impact (like pH, trace elements, and temperature in Gidabo Watershed. Only those parameters shown in Tables 1 and 3 were considered for WQI calculation.[26]

The resultant WQI values range between 0 and 100, where 0 represents the "worst" water quality and 100 represents the "best" water quality. When the values of WQI are in the range of 0 to 25, the water is be classified as "very bad"; for a WQI value in the range of 26 to 50 the water is classified as "bad"; for WQI values in the range of 51 to 70 the water classification is "medium"; finally, when the WQI values are within the range of 71 to 90 and 91 to 100 the water is classified as "good" and as "excellent," respectively.[29,31]

Results and Discussion

Trends in wet coffee processing mills distribution

Mapping of 285 wet coffee processing plants showed that most of them are concentrated upstream of the main Gidabo River or upstream of major tributaries (Figure 2). The large volume of clean water required for many processing activities, especially for washing the fermented beans after fermentation tanks, encourage industries to look for relatively clean water. With the perception that clean water found only in upstream creeks, their distribution shows hanging-up at the upstream river trends contaminating the rivers from their sources. Industries located downstream used either groundwater or public water supplies for processing. These industries have been positioned near the river only for the purpose of looking for cheap waste disposal sites, the river. It is observed that all the industries are using water extensively.

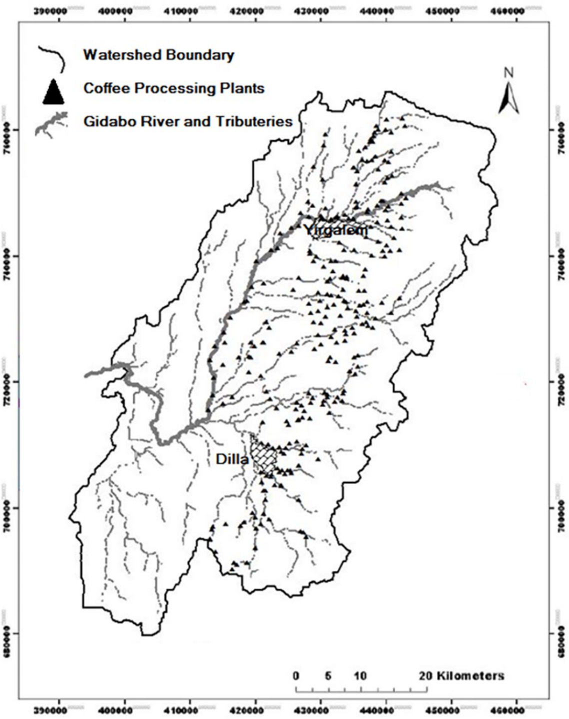

Figure 2. Distribution of wet coffee processing industries in Gidabo Watershed.

If the industry's water recirculation system is fully functional they only consume about 221 of water to completely wash a kilogram of coffee (Table 4). However, due to nonfunctional recycling systems, currently they are consuming on average 631 of water to wash a kilogram of coffee (Table 4).

From the data collected 90% of the industries lack either a water recycling system or was not functional. According to the data, 68% of the private and 92% of cooperatives owned industries have none functioning water circulation system.

Water quality status of the watershed at different reaches

Among the water quality parameters tested turbidity, BOD_5, DO, COD, pH, Ni, Fe, NO_3^-, and $PO4^{3-}$ were the main constraining parameters which were above the recommended limits of WHO for domestic water uses or EPA guidelines or aquatic life. In the range of temperature between 14°C and 25°C, the expected amount of dissolved oxygen varies between 10 and 8 $mg\ L^{-1}$ but it was observed that in all sites the amount of dissolved oxygen was almost empty. This shows that the water is already dead which cannot support any life forms.

pH is very important since it affects the solubility and availability of micronutrients and how they can be utilized by aquatic organisms. The pH of the river and its tributaries ranged in between 4.6 and 7.48 with 4.6 measured at the main Gidabo River and 7.48 for the upstream creek located at Shebedino Woreda (Table 5). From the 8 sampling points, 7 of them show lower pH than neutrality. These may reveals the increment of either acidic waste or organic matter load to the river ecosystem from the coffee processing industries as decomposition of organic matter leads to decrease in pH, acidity.[36]At 6 observation points, it surpasses the local permissible limits

Table 4. Experiences on water use in wet coffee processing industries.

S.N	COUNTRY	WATER USE (L/KG)	RECYCLING	REMARK	REFERENCE
1	Costa Rica	22.52	Yes	Minimum water use	Adams[32]
2	Costa Rica	90.07	No	Maximum water use	Adams[32]
3	Nicaragua	80.00	Yes	Traditional, fully washed	Marsolek et al[33]
4	Vietnam	22.08	Yes	Robusta coffee	Mels[34]
5	India	77.50	No	Traditional, fully washed	Chanakya and De Alwis[35]
6	Ethiopia	63	No		Current Research

Table 5. Physicochemical water quality characteristics of Gidabo River and its tributaries.

PARA.	SITE SAMPLE TAKEN								WHO[a]	LOCAL[b]	NATURAL WATER[c]
	S1	S2	S3	S4	S5	S6	S7	S8			
EC	103.3	581	404	486.1	752	742.5	749.1	179.1	1500	**1000**	
TDS	69.3	405.8	280.2	338.3	522	517.4	521.3	117.2	1000	3000	176
pH	6.3	**4.6**	**5.4**	**4.6**	**5.04**	**5.12**	**5.05**	7.48	6.5-8.5	6-9	6-9
Temp	**14.1**	18	15.5	18.6	26	25	25.7	24.2	15-30	40	15
DO	**0.06**	**0.01**	**0.01**	**0**	**0**	**0**	**0**	**0.04**	>5	**>4**	>9
Turb.	**34.6**	**241**	**45.3**	**95.3**	**516**	**447**	**486**	**20.6**	**<5**	50	**<5**
Fe	**1.2**	**13.5**	**1.4**	**17.8**	**7.6**	**2**	**7.3**	**7.6**	0.3	10	
BOD_5	**540**	**600**	**402**	**346**	**392**	**254**	**300**	**300**	**<5**	80	**<5**
COD	**1330**	**3830**	**1102**	**2735**	**3710**	**1618**	**2669**	**2665**		250	**<10**
Mg^{2+}	4.04	5.62	5.6	5.8	6.2	6.2	3.94	3.96	200	100	
Ca^{2+}	35.36	89.72	31.43	70.97	**160**	**167.3**	39.29	37.5	100	150	
NO_3^-	4.8	**60**	**130**	**100**	**145**	**200**	**48**	**53**	45	20	<10
PO_4^{3-}	**0.57**	**1.25**	**8.75**	**7.5**	**22**	**40.5**	**0.15**	**0.08**	**0.02**	5	10-50*
Cr	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.05	**0.5**	
Ni	**0.04**	**0.08**	0.005	**0.041**	**0.15**	**0.13**	**0.14**	**0.13**	0.02	3	

All units are in mg L^{-1} except Temperature, Turbidity, EC, and pH which are expressed in °C, NTU, µS cm^{-1}, and [H^+] respectively, *µg L^{-1}. Bold test indicates result above or below WHO limits.

[a] World Health Organization standard for domestic use.

[b] Ethiopia's National Standard for release to natural rivers.

[c] Natural unpolluted water quality values .

for natural river release, 6 to 9[37] as well as international standards for aquatic life 6.5 to 9([38]).

The level of turbidity exceeds all current standards at every monitoring site. Consumption of excessively turbid water can be a health hazard as it shields harmful microorganisms from the effects of disinfectants and promotes the growth of bacteria.[39] Therefore, the turbidity level of the river water is higher than the prescribed limits <5NTU WHO[40] and EPA.[37] The amount of oxygen that bacteria will take in during the aerobic decomposition of organic materials is measured by BOD.[41] Unpolluted, natural waters should have a maximum BOD_5 and COD value of 5 and 10 mg L^{-1} or less respectively but on this study the river and its tributaries water BOD_5 (the lowest value was 254 mg L^{-1} and the highest value was 600 mg L^{-1}) value was above all standard. Similarly, river and its tributaries water for COD (the lowest value was 1102 mg L^{-1} and the highest value was 3830 mg L^{-1}) which are above all standards. The elevated values of BOD_5 and COD in the river may indicate the heavy pollution of the river by various activities in the catchment area.

There are 4 forms of nitrogen that can be found in water: NH_3, NO_3^-, NO_2^-, and NH_4^+. These forms of nitrogen can cause excessive leaching into surface and groundwater, encourage the growth of algae in surface water, raise the cost of irrigation practice maintenance, and cause cancer and blue-baby diseases in human infants. The amount of NO_3^- (at S2 it was 60 mg L^{-1},S3 130 mg L^{-1},S3 100 mg L^{-1},S4 145 mg L^{-1},S5 200 mg L^{-1},S6 48 mg L^{-1},S7 53 mg L^{-1}) in river water is higher than what is allowed[38] for drinking and irrigation water uses. Nitrate is the most soluble and highly susceptible for leaching thus it can cause even ground water pollution. Its main source is decomposition of organic matter like coffee waste, fecal matter and municipality waste. The concentration of phosphate in river water is higher than the recommended limits to freshwater healthy ecosystem.[37] This observation is in conformity with the observations by Abiy et al[42] in Omo River which was above recommended limit of EPA[37] due to this the river is categorized in eutrophic state index as Carlson.[43] Agricultural chemicals may drain into rivers, increasing phosphate level, or phosphate additions used in detergent may have leached into water bodies through home, industrial, or municipal waste waters.[44] Nonetheless, Chapman[45] asserts that both point and non-point forms of pollution have significantly harmed the river ecosystem as seen by the nutrients in river water. For aquatic life to be hospitable, nitrite and nitrate levels should be less than 0.001 and 0.1 mg L^{-1}, respectively.[46] However, river water has significant nutrient contents that deviate considerably from naturally desired levels.

For both plants and animals to function biologically properly, surface water must include trace amounts of dissolved metals.[47] Due to point sources of pollution from those factories that discharge their waste directly into this river, the concentration of metals in the river was significant. All specified water uses are permitted to employ additional metals, with the exception of nickel and iron.[47-49]

Aggregated water quality values

A water quality index analysis is carried out separately to aggregate the individual water quality parameters in different parts of the water shed.

Based on the above separate water quality index computation for aquatic life support system, the mean WQI value of 39.98 observed at sub basin 1 indicated that the main Gidabo River is already polluted at the upstream source (Table 6). This analysis is coinciding with the high population of wet coffee processing industries at the same reach (Figure 2). Except at sampling site 8, all sampling points showed that the water quality of the river and its tributaries between September and November are bad for domestic and aquatic life. The present finding was similar with the recent research done in Lower Omo river revealed that the water quality index value was very poor.[42] So, mitigation measures should be developed in the watershed overall activities, particularly remediating the solid waste and liquid wastewater releases from wet coffee processing industries.

Impacts of the wet coffee processing industries

In depth observation of the impacts of wet mills on the quality of the receiving water sources were conducted by taking additional samples from effluents from 2 industries located at sub basin 1 and sub basin 2 which takes S1 and S8 as their influent water sources. The data showed that the effluent water quality were significantly pollutes by organic and inorganic pollutants as compared with the influent water (Table 7).

The concentration of calcium and magnesium rose from influent to effluent level. As far as heavy metal (nickel and iron) measurement was concerned, it showed a raise in concentration from influent to effluent. On the other hand, chromium was not detected both in the influent and effluent samples. Effluent turbidity and COD were the 2 parameters that showed a higher percentage of increment as compared with the influent concentrations at sub-basin 1. Both of them are the contribution of the pulping operation of the processing industries. Thus, the data depicted that coffee liquid waste cause serious natural water turbidity and were sources of organic matter loading that impaired the rivers water quality in Gidabo Watershed. pH values also showed a shift from neutrality to acidity indicating that wet coffee processing industries are also a source of acidic effluent in the basin.

Effluent iron, NO_3^-, PO_4^{3-} and COD were the parameters that showed a higher percentage of increment as compared with the influent concentrations at sub-basin 2. The elevated iron concentration was partly associated with the corroding distribution system and old processing parts in the industrial complex. NO_3^-, PO_4^{3-} and COD were directly evolved from the wet coffee processing system. However, each wet coffee processing industries have at least 1 wastewater collection lagoons. Therefore, how cans wastewater reached the river? To investigate this scenario, wastewater management behavior of the industries were analyzed.

Handling of wastewater by wet coffee processing industry

For reduction of BOD and other contaminants in coffee Wastewater, lagoon based systems treatments are usually applied. Lagoons play a particular role in treatment of municipal sewage and intensive agro processing industry wastewater. They provide reasonable and effective treatment if properly managed. They are also used for treatment of waste water characteristics, the amount of wastewater loaded, the type of pond used (aerobic, anaerobic, facultative, aerated, maturation), arrangement of lagoons and weather conditions are major factors that affect the performance of lagoon based system treatment. The coffee washing plants have neither adequate number of lagoons nor have sufficient capacity to accommodate waste water for extended retention time. Most of the plants incorporate 2 lagoons with average depth of 1.5 m. Nearly all Lagoons are not lined, not systematically arranged or interconnected in such a way that waste water can be transferred from one to another in order to allow better oxidation for the minimization of BOD load within sufficient retention time.

One of the important factors that influence reduction of organic pollutants of wastewater in lagoons is the duration allowed to complete the oxidation process. It requires as long time as possible to achieve permissible effluent BOD level. Determination of residence time depends on some factors such as BOD load, pond depth and temperature. Almost all coffee washing plant ponds cannot accommodate the waste water for more than 3 days (Table 8). The average hydraulic retention time of 1.99 days was not enough to degrade the pollutants in the wastewater.

This clearly indicates that the wet coffee processing industries are surface or subsurface releasing non degraded wastewater to the nearby water sources. Hence, the observed water quality impairment from September to November 2022 in Gidabo Watershed was mainly caused by wet coffee processing industries in the watershed.

Table 6. WQI of Gidabo River at different reaches.

I	PARAMETER	W_I	SAMPLE NUMBERS															
			SUB BASIN 2								SUB BASIN 1							
			S1		S2		S3		S4		S5		S6		S7		S8	
			C_I	C_IW_I	C_I	C_IW_I	C_I	C_IW_I	C_I	C_IW_I	C_I	C_IW_I	C_I	C_IW_I	C_I	C_IW_I	C_I	C_IW_I
1	T	1	80	80	100	100	90	90	100	100	70	70	75	75	70	70	80	80
2	pH	1	55	55	35	35	45	45	35	35	40	40	43	43	40	40	90	90
3	DO	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	TDS	4	100	400	90	360	90	360	90	360	80	320	80	320	80	320	90	360
5	EC	3	100	300	100	300	100	300	100	300	90	270	100	300	100	300	100	300
6	Turbidity	2	40	80	0	0	30	60	10	20	0	0	0	0	0	0	60	120
7	NO_3^-	2	70	140	10	20	0	0	10	20	0	0	0	0	20	40	10	20
8	PO_4^{3-}	1	90	90	90	90	60	60	60	60	40	40	30	30	100	100	100	100
9	COD	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	BOD_5	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	Ni	1	70	70	30	30	100	100	70	70	0	0	0	0	0	0	0	0
12	Cr	1	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
13	Ca	1	90	90	80	80	90	90	80	80	60	60	60	60	90	90	90	90
14	Mg	1	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
15	Fe	1	70	70	0	0	70	70	0	0	10	10	60	60	10	10	10	10
	ΣW_i & ΣC_iW_i	29		1575		1215	1375		1245					1088		1170		1370
	$WQI = \sum CiWi / \sum Wi$		54.31		41.90		47.41		42.93		34.83		37.52		40.34		47.24	
	WQI_{mean}		46.63								39.98							
	Pollution state		Medium			Bad	Bad		Bad		Bad		Bad		Bad		Bad	

Table 7. Mean physicochemical analyses of influent and effluent waste.

NO	PARAMETERS	SAMPLE SITE					
		SUB BASIN 2 AT S1			SUB BASIN 1 AT S8		
		INFLUENT	EFFLUENT	CHANGE (%)	INFLUENT	EFFLUENT	CHANGE (%)
1	EC	103.3	486.1	370.6	179.1	749.1	318.3
2	TDS	69.3	338.3	388.2	117.2	521.3	344.8
3	pH	6.3	4.6	–27.0	7.48	5.05	–32.5
4	Temperature	14.1	18.6	31.9	24.2	25.7	6.2
5	DO (mg/L)	0.06	0.00	–100.0	0.04	0.00	–100.0
6	Turbidity (NTU)	34.6	95.3	175.4	20.6	486	2259.2
7	Iron (Fe), (mg/L)	1.2	17.8	1383.3	7.6	7.3	–3.9
8	BOD$_5$ (mg/L)	54	346	540.7	30	300	900.0
9	COD (mg/L)	133	2735	1956.4	64.5	2669	4038.0
10	Magnesium	4.04	5.8	43.6	3.96	3.94	–0.5
11	Calcium	35.36	70.97	100.7	37.50	39.29	4.8
12	NO$_3^-$	4.8	100	1983.3	48	48	0.0
13	PO$_4^{3-}$	0.57	7.5	1215.8	0.08	0.15	87.5
14	Chromium	<0.0001	<0.0001	0.0	<0.0001	<0.0001	0.0
15	Nickel	0.037	0.041	10.8	0.13	0.14	7.7

All units are in mg L^{-1} except Temperature, Turbidity, EC, and pH which are expressed in °C, NTU, μS cm^{-1}, and [H$^+$] respectively.

Table 8. Residence time (HRT) of wastewater at different districts of the Gidabo Watershed.

S/N	DISTRICTS OBSERVED	NUMBER OF LAGOONS	TOTAL LAGOON SIZE (M^3)	TOTAL DAILY WATER DISCHARGE ($M^3.DAY^{-1}$)	HRT (DAYS)
1	Bule	6	860.00	450.00	1.91
2	Dale	119	22779.00	8700.00	2.62
3	Dara	63	11721.00	4945.00	2.37
4	Wensho	32	11635.00	2720.00	4.28
5	Shebedino	48	11728.50	7280.50	1.61
6	Loka Abaya	13	1860.00	1680.00	1.11
7	Dilla Zuria	60	8771.99	5220.00	1.68
8	Wenago	34	8160.00	5040.00	1.62
9	Yirga Cheffe	2	650.00	250.00	2.60
10	Aleta Wendo	97	10494.00	9900.00	1.06
11	Chuko	57	6037.76	5696.00	1.06
	Total	531	94697.25	51881.50	
	Average		8608.84	4716.50	1.99

Conclusions and Recommendation

The present study evaluated the physico-chemical water quality characteristics of the Gidabo River and its tributaries. The water quality parameters analyzed and examined from various sampling sites in the river were showing unsuitability of the water for domestic use and aquatic life. Although both point and non-point sources of pollution, in addition to natural factors, weaken the quality, the river is mainly affected by effluents from wet coffee processing industries. Of 15 randomly selected water quality parameters, the Gidabo River and its tributaries failed to meet national and international standards for turbidity, BOD_5, DO, COD, pH, Ni, Fe, NO_3^- and PO_4^{3-}. Traditional treatment methods, wastewater and solid waste management techniques used by industries are the precursors of the problem. Therefore, monitoring the effluent standards of the surrounding industries, mainly the wet coffee processing industries, is essential to protect the river water quality from further deterioration. For other similar studies, the monthly evaluation of physico-chemical water quality characteristics for at least 2 years; twice in the coffee production season from September to January and twice in the off-season from February to June is recommended to get a coherent overview of the quality degradation scenarios and the regeneration capacity of the rivers in the watershed. We suggest that the application of constructed wetlands offers a simple, cheap and robust way out for coffee wastewater treatment in a country like Ethiopia, where land is available at a reasonable price and the tropical temperatures are right for biodegradation.

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Author Contribution

The research was planned, designed, and the data was collected & evaluated by MDU, MZG, and YSB. MDU, and MZG have conducted the process of gathering and verifying the field data. The tables and figures were created by MDU with the help of MZG and YSB. The article was written, revised, and critically reviewed by all authors, who also agreed on the journal to which the work was submitted and agreed to take responsibility for all parts of the work. The authors also approved the final version of the article to be published.

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