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Coffee Processing Plants and the Effluent Effect on the Surrounding Water Bodies-Review

Adugna Bayata*

Department of Natural Resource Management, Jimma Agricultural Research Center, Ethiopia

**Corresponding author*

Abstract

Environmental pollution (air, land, water, etc) because of improper waste management is an alarming challenge for developing countries. Many reports indicate that Coffee production is only environmentally friendly when water is used efficiently and polluted water released from the process is treated accordingly. Disposal of coffee effluent is an important environmental consideration for coffee processing as wastewater is a form of industrial water pollution. Coffee wastewaters are high in organic loadings and exhibit a high acidity. Several reported researches revealed significant river water quality deterioration as a result of disposing untreated coffee waste into running water courses. In this study, the researchers found significant reductions in water quality downstream from coffee processing plants during the wet season. According to different researches, characteristic wastewater from coffee processing have pH 7.71 to 2.51, high concentration of COD (upstream 18.5mg/l and downstream 3244mg/L), BOD (upstream 1.9mg/l and downstream 2967mg/L), total dissolved solid (upstream 73mg/L and downstream 9037mg/l),electrical conductivity (upstream 45mg/l and downstream 1240mg/L) reported that, BOD from (472–551mg/L), COD (9270–14,800 mg/L) and pH 4.40 – 4.27 which indicate that high potential pollution of the coffee effluent when discharged to nearby water bodies and it needs serious treatment before discharging to the environment.

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Keywords

Water, effluent, environment, coffee plant, processing.

Introduction

The process of separating the beans of coffee from the cherries during wet processing generates enormous volumes of waste material (solid and liquid). Coffee processing is a seasonal agricultural activity, but it is not realized that whether or not the rivers purify themselves during the off season from the contaminants (4). The unpicked fruit of the coffee tree, known as the coffee cherry, undergoes a long process to make it ready for consumption. The researchers study revealed that there was high level of organic pollution at locations below coffee effluent discharge points and the physicochemical characterization of water samples indicated that the level of pollution in most of the streams require a serious attention (Solomon Endris *et al.,* 2008). And also the researchers stated that large volumes of coffee processing effluent are generated from wet processing stations that are found scattered along the rivers.

Coffee processing produces higher quality coffee and produces large amounts of processing effluents which have the potential to damage the environment. Coffee effluent that are released to nearby water bodies pollutes the sources, damage or threatens the aquatic ecosystems, health of nearby residents and also affects the income benefits obtained from coffee production(4)

The coffee curing process has been causing environmental problems at the local level not only due to the consumption of water and firewood, but more due to the discharge of effluents with large volumes of organic waste. Due to the great demand of coffee, coffee industries are responsible for the generation of large amount of residues, which are toxic and represent serious environmental problems (Solange *et al.*, 2011).

Pollutants in coffee wastewater emerge from the organic matter set free during pulping, especially due to the difficulty in degrading the mucilage layer surrounding the beans(Prevention & Control of Pollution Act 1974). People living nearby the plant were affected with different health problems such as eye irritation 32 %, skin irritation 85%, stomach problem 42%, breathing problem 75% and nausea 25% (5).

Treatment of coffee effluent

Efforts have been made to develop an efficient and economic process for treating the wastewater from wet coffee processing. The first recorded effort to treat such wastewater was made in Kenya in the 1950s'.Buffering with limestone ($CaCO_3$) is one way of treating waste water to raise up its pH to an appropriate condition. In theory, 250 milligrams of limestone is needed to buffer 1 litre of acid water (Treagust 1999). The main objective of this review was to assess the effect of coffee processing plant effluenton receiving water andto consider the effect of coffee processing plant effluent on physicochemical properties of the receiving water bodies.

Literature Review

Coffee processing produces higher quality and also emanates large amounts of processing effluents which have a potential to damage the environment. To treat wastewater properly and at reasonable costs, the amounts of wastewater released to nearby river must be minimized.

Many papers indicated that coffee processing uses large quantities of water and produces considerable amounts of solid and liquid waste and the type of waste is as a result of the type of process that the coffee cherries go through. The conversion of the cherry to oro or green bean (the dried coffee bean which is ready to be exported) is achieved through either a dry, semi-washed or fully washed process. Values for Biological Oxygen Demand (BOD) indicating the amount of oxygen needed to break down organic matter are high in coffee wastewater (up to 20.000 mg/l for effluents from pulper and up to 8.000 mg/l from fermentation tanks). The BOD should be reduced to less than 200 mg/l before let into natural waterways.

In municipal wastewater treatment systems, the common water quality variables of concern were biological oxygen demand (BOD), chemical oxygen demand (COD), dissolved oxygen (DO), suspended solids, nitrate, nitrite and ammonia nitrogen, phosphate, salinity and a range of other nutrients and trace metals and the presence of high concentrations of these pollutants above the critical values stipulated by national and international regulatory bodies is considered unacceptable in receiving water bodies metals (DeCico, 1979; Brooks, 1996). This is because, apart from causing a major drawback in wastewater treatment systems, they also lead to eutrophication and various health impacts in humans and animals (EPA, 2000; CDC, 2002; Runion, 2008).

According to (Mburu *et al.*,1994), the effluent from 1 ton parchment coffee processed following the wet processing method generate BOD comparable to BOD of the human waste that can be generated by 2,000 people per day.

Many reported researches indicate that, untreated wastewater that are released to water from coffee processing industries are threatening the world and severe developing countries (Joshi and Sukumaran 1991; Beyene *et al.*, 2009).

Haddis and Devi (2008) assessed the effect of effluent generated from coffee processing plant on water bodies and human health in its vicinity and indicated that it caused severe water pollution and illness like skin irritation, stomach problem, breathing difficulties and nausea among downstream users.

According to Kansal *et al.*, (1998), these discharges were of environmental concern due to the decrease in the dissolved oxygen concentration in the water which brings great impact over the biotic environment, and can be fatal to fish and other aquatic animals, as well as originated odoriferous products resulted from an anaerobic processes and decreased suitability of surface water for different purposes.

Coulthard (1979) reported that, average water consumption is about 8.4 m^3 per tonne of fruit processed. Water usage for coffee processing by Indian coffee estates varies from 2.25 to 23 m^3 per tonne of fruit processed (ASTRA, 2002a).

A considerable amount of water is required(40 m^3 water per tonne for coffee processing in Ethiopia (Coste, 1999). While comparing the amount of water required per tonne for coffee processing depending on different papers, there were great variation in the amount of water used and also the effluent released to the nearby rivers and streams. The constituents of effluents (pulper, washer and secondary wash) are predominantly organic and biological in nature. They rapidly ferment to produce organic acids, lowered pH, eutrophication of receiving water bodies and malodors.

Coffee processing

There are two ways by which coffee can be processed. These are dry (natural) processing and wet (fermented and washed) processing. In most cases, wet processing is regarded as producing a higher quality product. Approximately, half of the world coffee harvest is processed by the wet method in which the coffee berry is subjected to mechanical and biological operation to separate the bean or seed from the exocarp (skin), mesocarp (mucilagenous pulp) and the endocarp (parchment) (Clark, 1985). Adams and Dougan (1981) reported that the skin and most of the pulp is separated in the pulpers. This fraction represents about 40% of the weight of the fresh fruit and presently is underutilized, causing serious pollution problems if it is discharged to the environment without treatment.

Human activities degrade water resources by changing one or more of five principal groups of attributes: water quality, habitat structure, flow regime, energy source and biotic interactions (Karr, Chu 1999) The composition of coffee pulps and husks can vary depending on the processing mode, cultivar, soil type and other factors (Pandey *et al.,* 2000)

Characteristics of coffee effluent

Several studies indicated that the environmental impact of wet and semi-wet processing is considerable. Problems occur through large amounts of effluents disposed into watercourses heavily loaded with organic matter than its inherent toxicity (Adams *et al.,* 1987). According to (ASTRA 2002a), coffee effluent is acidic and has a high content of suspended and dissolved organic matter. The researcher stated that coffee wastewater is rich in sugars and pectins and is thus amenable to rapid biodegradation. Field studies have determined coffee processing to discharge up to 45 kg COD per tonne of fruit processed (ASTRA, 2002a). 1000 kg of fresh berry gives about 400 kg of wet waste pulp (Padmapriya *et al.,* 2013).Though the researchers study showed different data, coffee processing has releases huge amount of environmental polluting wastes.

Water Quantities

Depending on the processing technology applied, quantities of coffee wastewater varies. Modern mechanical mucilage removal machines use only about 1 m^3 per ton fresh cherry whereas the traditional fully washed technique without recycling uses up to 20 m^3 per ton cherry (Mburu *et al.,* 1994). In order to treat waste water properly and at reasonable costs, the amounts of waste water must be minimized(4).

Different countries used different amount of water depending on the technology and method of coffee processing For instance Kenya fully washed 4 to 6 m^3, Columbia fully washed 1 to 6 m^3 and Vietnam semi-wet and fully washed 4 to 15 m^3. The quality of water which is discharged to the environment can be determined, whether or not it is permissible by WHO (Table 1) and /or Ethiopian EPA to be discharged to the environment.

Organic Components

The composition of coffee pulp is organic and mainly contains carbohydrates, proteins, fibers, fat, caffeine, polyphenols, and pectin's (Gathua *et al.,* 1991). This huge organic component of the coffee pulp needs high amount of oxygen to be degraded. The main pollution in coffee waste water stems from the organic matter set free during pulping when the mesocarp is removed and the mucilage texture surrounding the parchment is partly disintegrated (Mburu *et al.,* 1994).

Coffee pulp contains caffeine, ether extract, crude fiber, crude protein, ash, and other organic residues with different amount which has an impact on the environment if disposed improperly (see Table 2 below)

The researcher found in his study that organic and acetic acids from the fermentation of the sugars made the wastewater very acidic condition in which higher plants and animals can hardly survive.

The total suspended solids in the effluents are high; in particular, the digested mucilage, when precipitated out of the solution, built a crust on the surface, clogging up waterways and further contributed to the anaerobic condition. Mucilage contains water, protein, sugar (reduced and non-reduced), ash and pectin(Table 3)

The decomposition of this organic waste in the rivers makes the water unsuitable for various uses and damages the aquatic ecosystem. The main pollution in coffee wastewater stems from the organic matter set free during pulping when the mesocarp is removed and the mucilage texture surrounding the parchment is partly disintegrated (Mburu *et al.*, 1994). Pulp and mucilage consists to a large extend of proteins, sugars and the mucilage in particular of pectin's, that is polysaccharide carbohydrates (Avellone *et al.*, 1999).

Acidity

During the fermentation process in the effluents from pulpers, in fermentation tanks and mechanical mucilage removers, sugars were fermented in the presence of yeasts to alcohol and CO_2 (Jan C. von Enden, Ken C. Calvert). In this reaction, the alcohol was converted to vinegar or acetic acid in the fermented pulping water(6). The biological fermentation of sugars by yeasts to ethanol:

$$C_6H_{12}O_6 \rightarrow 2CH_3CH_2OH + 2CO_2$$

Ethanol is broken down by bacteria into acetic acids. This complex enzymatic catalyzed reaction is:

$$2CH_3CH_2OH + O_2 \rightarrow CH_3COOH$$

According to the researchers reaction result, the acidification of sugars will lowers the pH and the digested mucilage were precipitated out of solution and built a thick crust on the surface of the wastewater

From the above, Table 4, even though the physicochemical parameters varied among the rivers, the major difference was observed between impacted and un-impacted sites Table 4.

The minimum BOD (0.5mg/l) and the maximum BOD (1900mg/l) were respectively measured at upstream sites which were free from coffee effluent impact and downstream sites receiving the waste. DO was depleted below 0.01mg/l at the impacted sites. During peak off season the disposed coffee effluent consumed DO as a result of decomposition. The other most important parameter was nitrate which showed similar trend like BOD at the impacted sites and had higher nitrate content than the un-impacted sites. Coffee wastewater was known to lower the pH and acidic waters (pH 4.6) recorded during the peak coffee processing season Table 4. TSS, TDS and SRP were also significantly higher ($p<0.05$) at impacted sites than un-impacted sites. Based on the average value presented in Table 4,nitrate, ammonia, pH and TDS were in the range of permissible limits to protect the aquatic life. BOD, DO,SRP and TSS were beyond the range of permissible limits to protect the aquatic life Table 4

The researchers indicated that the main ecological effect of organic pollution in a watercourse (into which effluents have been discharged) was the decrease in oxygen content. The organic substances diluted in the wastewater broken down very slowly by microbiological processes, using up oxygen from the water. Due to the decrease in oxygen content, the demand for oxygen to break down organic material in the wastewater exceeded the supply, dissolved in the water, thus creating anaerobic conditions.

The amount of biological oxygen demand (BOD) was as high as 15,000 mg/l, while the amount of dissolved oxygen required combining with chemicals in the wastewater, that is, the chemical oxygen demand (COD),it could be between 15,000 and 25,000 mg/l.

The resulted anaerobic conditions were fatal to aquatic creatures and also caused a bad odor. A sample study of five coffee estates in Karnataka has revealed alarming levels of pollution Table 5. The researcher had found in his study in other parts of the world too that coffee wastewater had high pollutant potential(for example, de Matos, *et al.*, 2001). Thus, the high acidity and depleted life supporting oxygen from the water were major concerns for coffee wastewater treatment.

The output from the laboratory indicated that result of pH indicates that it was below the permissible limits, but TS,BOD, and COD were in the acceptable range and it didn't bring any effect either to the environment or the aquatic life if the effluent is discharged to the nearby river.

Odor problems and mosquito breeding (public health issues), potential for groundwater contamination and low loading rates were some of the disadvantages the effluents discharged to the surrounding.

Materials and Methods

Sample collection and analysis

According to the researchers report, coffee processing begins in Jimma at the end of August and proceeded until mid-December.

Wastewater was taken from a minimum of 100m below and above the discharge receiving river. Samples were also taken from the effluent released from the coffee processing plant for wastewater characterization. To have a representative composite sample, the wastewater samples were collected at the peak hours of coffee processing from three points across the width of the river. All samples were collected using polyethylene plastic bottle and were carefully labeled, sealed and transported to laboratory for analysis.

Sampling from 3–5 points is sufficient and fewer points are needed for narrow and shallow rivers and streams (Bartram and Ballance 1996)

The researchers measured pH,DO, Conductivity and Turbidity onsite during sampling using portable thermometer, pH meter, DO meter, Conductivity and Turbidity meters, respectively from the raw water and wastewater effluent of wet coffee processing plants.

Determination of BOD_5

Preparation of dilution water was done following standard procedure. 2L of water was taken into a volumetric flask and 1mL of each(phosphate buffer, $MgSO_4$, $CaCl_2$, and $FeCl_3$ solutions/L were added to water. From the prepared solution 299 ml were taken and 1ml of incubation samples was added. Initial dissolved oxygen was measured using dissolved oxygen meter. Five day incubation was done and final dissolved oxygen measurement was taken

Determination of COD

Reactor digestion method

100ml of sample was homogenized using blender for 30 sec. and mixed settled solids**.** 2ml of homogenized sample was added to $K_2Cr_2O_7$**. P**repared blank by adding 2ml of de-ionized water into $K_2Cr_2O_7$**. V**ials of the sample and blank was heated for 2hr in COD reactor at 150^{o}C and the samples were cooled at room temp and the reading was taken by spectrometer

Determination of TSS

Gravimetric method

Disk with wrinkled side up filtration apparatus was inserted and filtered and then, the filter was removed and dried in an oven at 103 ^{o}C to 105 ^{o}C for an hr and cooled in desiccator

Determination of Nitrogen (Nitrate) (NO_3^-)

Phenol disulphonic acid (PDA) method

The clarified sample was neutralized to pH 7.0. Suitable aliquot of the sample was taken into a beaker, evaporated to dryness on water bath. The residue was dissolved using glass rod with 2mL phenol disulphonic acid reagent and diluted. 12N KOH 8-10mL was added. EDTA was added to drop avoid turbidity dissolves.

Filter and make up to 100mL.To avoid turbidity 10mL added conc.NH_4OH. Blank was Prepared in the same way using distilled water in place of sample. The intensity of color was read at 410nm with a light path of 1cm. and recorded NO_3^- in mg/L.

Determination of Phosphate (PO_4^{3-})

Stannous chloride method

Suitable volume of the sample was taken into Nessler tubes. Pipette appropriate amounts of phosphate working solution to cover the range of 5-30mg/L or 0.3-2mg/L P when $SnCl_2$/Ascorbic acid reagent is used as a reducing agent. 4mL ammonium molybdate was added followed by 0.5mL stannous chloride. Blank was prepared using distilled water in the same way. The intensity of colored complex was measured at 690nm or 880nm between 10 and 12 minutes after the development of the color. Absorbance vs. phosphate concentration was plotted to give a straight line passing through the origin. From the calibration curve, the concentration of phosphate was computed

Results and Discussion

Physicochemical characterization of coffee processing effluents

Physicochemical characteristics of water samples of rivers at the upstream (U) and downstream (L) from the coffee processing plant discharge points (units in mg/l or otherwise stated)

The researchers revealed that, there were high variations in physicochemical parameters along the course receiving wastewater discharges as the results indicated Table 7.

For many parameters, higher concentrations were recorded at the downstream as it is observed from the Table 7. Unlike other parameters, p^H is higher at the upstream and lower at the downstream which is below the permissible limit to discharge to the rivers.

As a result, the acidity of the lower discharge Receiver Rivers (like Yebu, Urgessa and Chiseche) is high. The researcher found relatively lower concentrations of physicochemical parameters were observed in the downstream of Sunde, Gurracho and Funtule rivers.

WHO standard for effluent discharges on land for irrigation and to receiving water has a limit value of (300 mg/l) COD and (100 mg/l) BOD_5, the maximum effluent concentration obtained from this analysis were higher than the acceptable limit and the reference samples respectively indicated the pollution strength of the wastewaters.

This study revealed that large amount of chemical and biological oxygen demanding substances in the effluent are released from the coffee processing wastewater into the river. They also indicated that there could be low oxygen available for living organisms in the wastewater when utilizing the organic matter present.

The TSS of the water samples among the upstream and downstream sites generally showed that no significant difference ($P > 0.05$) and results below the permissible limit. Based on the standard discharge limit value, the suspended solids in the Yebu, Urgessa and Chiseche rivers adversely affected the use of water for various purposes Table 7.As the Researchers studied, the total dissolved solid (TDS) profile of the upstream and receiving water body samples vary significantly ($P < 0.05$) and ranged from 73–246 mg/l for upstream and 349–9034 mg/l for downstream respectively and was high all along the sampling points as compared to the provisional discharge limits set by the WHO

Asrat Gebremariam *at al*. (2015) reported that the average value of coffee effluent (BOD 1306–2088 mg/l, COD 5379 –5987mg/l, NH_3 2.89 – 6.13mg/l, $PO4^{3-}$ 2.82– 3.82 mg/l, and NO_3 2.74– 4.04) which is high and posed an effect on the environment and Dejen Yemane Tekle at el. (2015) also reported Table 7 that all the parameters of analyzed coffee wastewater were beyond both the WHO and Ethiopia EPA permissible limits. This implies that the discharges which emanates from coffee industries were beyond the limits and the environment is exposed to this high toxic discharges.

This wastewater that stems from coffee processing have an advantage if it is used for irrigation purpose since it is nutrient rich that are helpful for plant growth. In other way, they are harmful if not treated in a well manner and disposed to the environment and some insects may bread each other, also its odor might pollute the environment.

Having the research outputs as a baseline, the study implied that additional environmental burden is perceived to be high. The traditional wet coffee processing industries are generating huge amounts of organic and nutrient rich and acidic wastewater.

This ample untreated wastewater is discharged directly into the nearby pits that are intended to serve as wastewater stabilization but are neither properly constructed nor the right dimension to accommodate the generated waste during peak processing time. This leads to overflow of raw effluents into the nearby rivers and severely damaged the surface waters and aquatic life.

Table.1 WHO (1995) permissible limits for the treated effluents to be discharged on land for irrigation

SN	Parameters	WHO permissible limits	EEPA,2003)Permissible limit
1	Temperature (^oC)	20	
2	pH	6.5 - 8.5	6-9
3	BOD(mg/L (5 days at 20 ^oC)	100	80
4	COD (mg/L)	300	250
5	TSS (mg/L)	200	100
6	Phosphate (mg/L)	5	5
7	Nitrate (mg/L)	5	20

Table.2 Composition coffee pulp (GTZ-PPP,2002)

Content	Proportion %
caffeine	2.30
Total caffeic acid	1.60
Ether extract	0.48
Crude fiber	21.40
Crude protein	10.10
Ash	1.50
Nitrogen free extract	31.30
Tannanis	7.80
Pectic substance	6.50
Non-reducing sugar	2.00
Reducing sugars	12.40
Chlorogenic acid	2.60

Table.3 Composition of mucilage (GTZ-PPP, 2002)

Contents	Proportion %
Water	84.2
Protein	8.00
Sugar **-reduced(glucose)** **-Non reduced(sucrose)**	2.50 1.60
Ash	1.00
Pectin	0.70

Table.4 The range and average values (brackets) of the physicochemical characteristics of sites impacted by coffee processing versus un-impacted sites during 2007 G.C and 2008 G.C sampling periods. (Abebe Beyene *et al.*, 2012)

Parameters	Un-impacted	impacted	p-value
BOD (mg/l)	0.5–270(31)	2–1900(436)	0.000
DO(mg/l)	5–7.2 (6.2)	<0.1–7.0(5.2)	0.047
TDS(mg/l)	50–195(117)	50–-3150(170)	0.119
TSS(mg/l)	16–600(192)	142–970(598)	0.002
PH	6.6–7.3(7.0)	4.6 –7.4(6.2)	0.251
Nitrate(mg/l)	0.9–2.5(1.5)	6.1–12.4(6.8)	0.006
Ammonia(mg/l)	0.2–0.5(0.3)	5– 30(11)	0.000
Soluble Reactive Phosphorus(SRP)(mg/l)	6–26(14)	2– 48(19)	0.380

Table.5 Effluent characteristics (Adichunchanagiri Institute of Technology, Chikkamagalur, 2002)

	pH	BOD(mg/l After 5 days	COD (mg/l)	TS (mg/l)	Phosphorus (mg/l)	Nitrogen (mg/l)	Type of coffee
Estate A	3.94	15,200	27840	133605	5.0	123.3	Arabica
Estate B	4.22	3,600	6240	5440	6.8	95.57	Arabica
Estate C	4.13	15000	31520	12876	8.8	0.0	Arabica
Estate D	4.12	10,800	15040	6320	4.0	40.32	Robusta

Table.6 Physicochemical characteristics of coffee effluent range, (ASTRA, 2002a)

Parameters	Pulp water
pH	4–7
TS (g/l)	4 –10
COD (g/l)	1.5– 9
COD/BOD (g/l)	0.5– 0.86
Total sugars (g/l)	0.8– 6
Reducing sugars (g/l)	0.05– 1.8

Fig.1 Schematic representation of Coffee processing

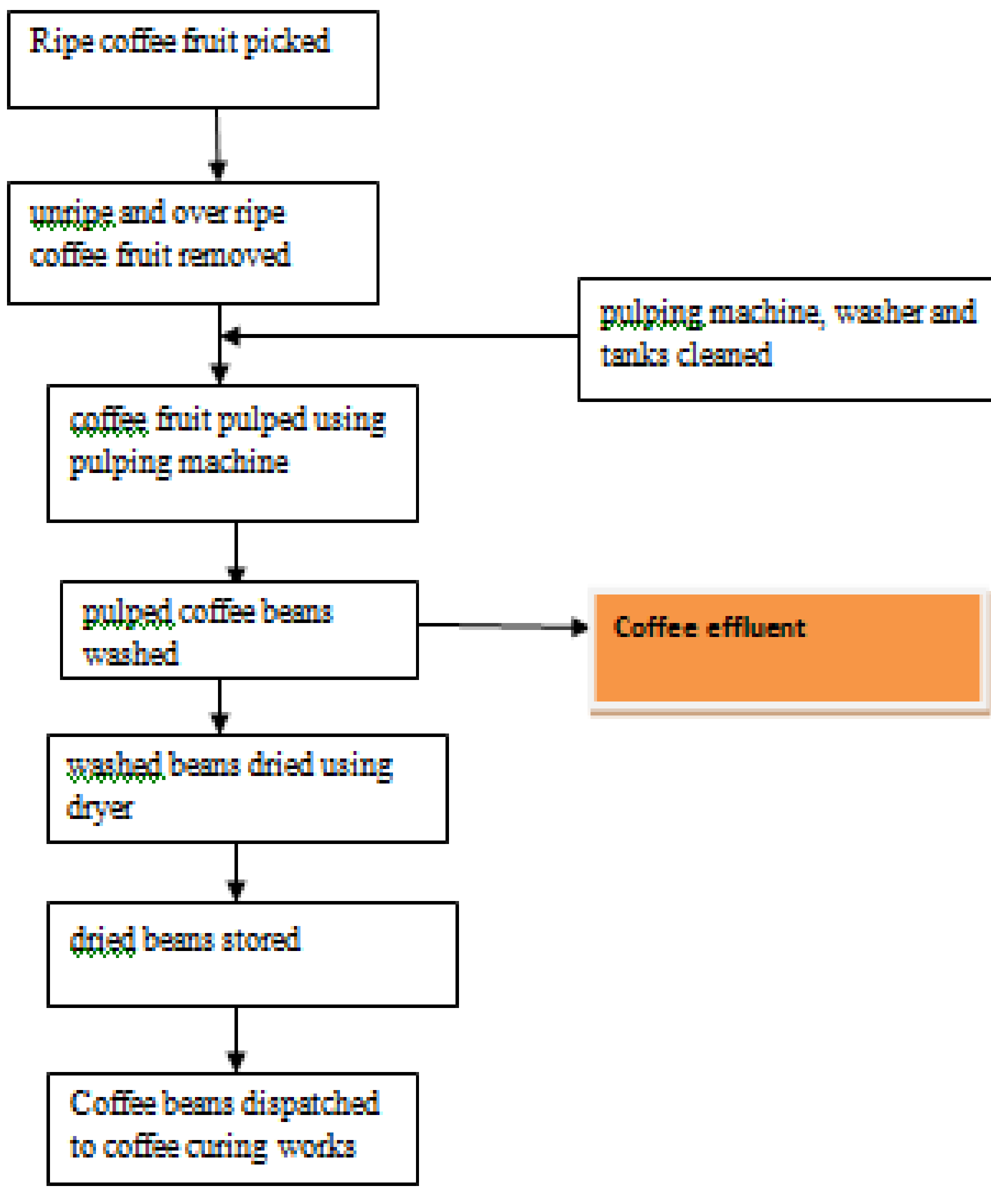

Table.7 Physicochemical characteristics of water samples of rivers at the upstream (U) and downstream (L) from the coffee processing plant discharge points (units in mg/l or otherwise stated).

Parameters	Sampling Site (mean values)											
	Yebu		Urgessa		Chiseche		Sunde		Gurracho		Funtule	
	U	L	U	L	U	L	U	L	U	L	U	L
BOD_5	12.6	1241	11.5	2967	18	1739	1.9	128	9.2	601	4.7	379
COD	29.5	2841	123	3244	28	1935	74	849	18.5	831.2	32.7	1247
NH_4^+	0.80	81.3	3.25	129.3	0.44	57.87	0.76	8.55	0.18	5.54	0.32	16.45
TDS	246	3051	113	9034	233	2147	73	709	118	1148	135	349
TSS	55	789	73	1105	85	2504	18	47	31	57	26	78
NO_3^-	1.52	11.9	0.96	13.2	0.37	8.86	3.07	19.3	2.97	27.1	1.1	32.7
PO_4^{-3}	0.08	12.1	5.72	18.5	1.4	13.12	0.59	7.6	0.26	10.84	0.05	9
VSS	62	753	41	867	47	605	16	294	23	92	26	561
TP	0.37	17.9	1.35	11.3	1.02	12.9	0.75	9.2	1.2	8	0.63	3.2
TN	30	101	31	155	12.9	97	7.8	63	10.2	78	13	84
Temp. (0C)	17.9	21.8	15.46	23.1	19.3	18.67	17.5	20.01	19.4	18.3	16.6	19.9
pH	6.93	3.14	7.71	2.51	6.59	3.73	7.06	5.8	7.58	4.37	6.77	4.24
EC (µS/cm)	312	1240	110	930	45	1106	90	520	70	197	160	710
Turb.(NTU)	36	279	19	347	25	741	12	183	11	253	7	68

Fig.2 Waste disposal

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