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Constructed wetland-based wastewater treatment of a coffee-washing plant and its impacts: a case study of Kege processing plant, Ethiopia

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ABSTRACT

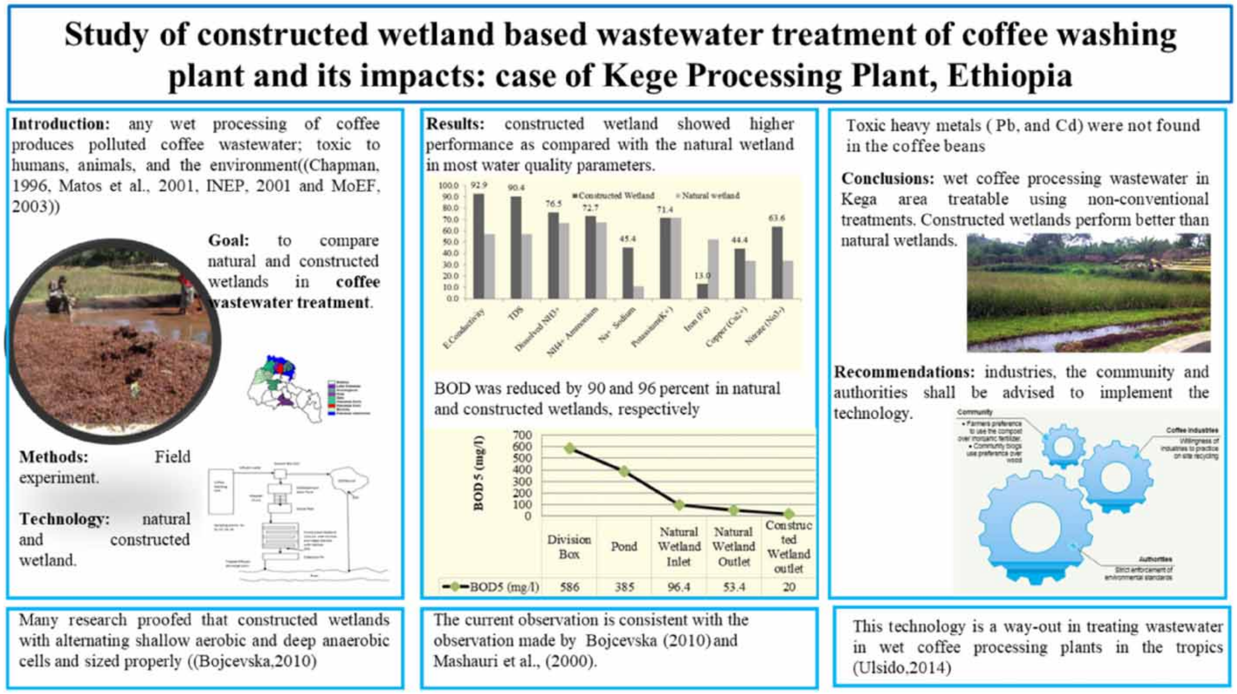
Coffee washing units in Sidama Regional State, Southern Ethiopia pose a serious threat to surface water sources and coffee growing soils. A comparison field performance test was conducted on the capacity of natural and constructed wetland on wastewater treatment. The study indicates that treating the effluent from the processing plants using constructed wetland supported by sedimentation pond, filtration, and gravity aeration can reduce pollutant levels significantly. The treated waste water can be safely disposed-of to the natural river. It was observed that BOD_5 was reduced by 90 and 96% in natural and constructed wetlands, respectively. TDS was reduced substantially whereas nitrate was reduced by 63%. Soil quality parameters from the wetland are within the permissible limits of Ethiopian Environmental Protection Agency. Heavy metals from coffee beans produced from the surrounding farms using water from Gidabo River discharged with treated effluent from the processing units are within the permissible limits. It is evidenced that wetlands in general and constructed wetlands in particular are promising technologies to treat the effluent water and recommended to be adopted by all the processing units in the region.

Key words: constructed wetland, effluent treatment, soil quality, water quality

HIGHLIGHTS

- Effluent treatment of coffee-washing plants.
- Analyzing the performance of constructed wetlands in effluent treatment.
- Water quality parameters during treatment phases are evaluated.
- Soil quality parameters are evaluated from wetlands and from coffee bean farms.
- Presence of heavy metals in coffee beans cultivated using treated wastewater was evaluated.

GRAPHICAL ABSTRACT



INTRODUCTION

Coffee is a valuable trading good which is produced in the tropics and mainly consumed in Europe and the United States (Fairtrade 2022). Arabica (*Coffea arabica*) and Robusta (*Coffea canephora*) are the two varieties which are internationally traded. Arabica fetches higher prices due to more favorable taste characteristics and makes up 61% of the world's production (Deutsche 2002). Robusta coffee is an important component of commercial coffee blends due to its rich 'body' (body is the viscosity, fullness and weight in the mouth of a beverage, ranging from 'thin, watery' to 'thick, heavy'). Coffee is cultivated and exported as a raw, roasted or soluble product to more than 165 countries worldwide providing a livelihood for an estimated 100 million people in the world (ICO 2021). Many countries are involved in coffee production, trade, and communication and it is estimated that about 125 export and re-export coffee products. Ethiopia is the world's third largest coffee exporter after Burundi and El Salvador producing Arabica coffee and an original home of coffee along with the highest diversity in its genetic resource (Haadis & Rani 2008). Coffee plant was founded and cultivated by the Oromo people in the Kaffa province of Ethiopia from which it got its name around 1,000 A.D. Arab people took the coffee seeds from this region and started the first coffee plantation. Then, it spread to the whole of Europe (Adams 1980; Haadis & Rani 2008). Sidama Regional State (SRS) is one of the areas in Ethiopia where coffee is cultivated and processing plants are erected in large numbers. Sidama coffee is a type of Arabica coffee of single origin grown exclusively in the Sidama Province of Ethiopia. Like most African coffees, Ethiopia Sidamo features a small and greyish bean, yet is valued for its deep, spice- and wine- or chocolate-like taste and floral aroma. The most distinctive flavor notes found in all Sidamo coffees are lemon and citrus with bright crisp acidity. Sidama coffee is of very high quality. The SRS, one of Ethiopia's best-known coffee-growing areas, is home to more than 300 wet mills.

After harvesting, coffee can be processed in two ways: dry (natural) processing and wet (washed) processing. Wet processing is done with the help of water, especially to remove the outer red skin and the white fleshy pulp (Wintgens 2004). In addition, the amorphous gel of mucilage around the beans is removed by fermentation. Wet coffee processing can be done in a conventional system, as most of the processing plants do in Ethiopia. The advanced method is currently being practiced in some parts of the country. These technologies are expected to increase the quality of the product and safeguard the environment from pollution. However, the potential of these advanced systems in achieving the required standard is to be evaluated.

The SRS, one of Ethiopia's best-known coffee-growing areas, is home to more than 316CBP wet mills, most of which have not been upgraded to reduce water consumption or treat their waste. For many people in the area, coffee is the sole source of income, providing money for school fees and basic necessities.

Currently, the wastewater frequently released from these agro-industries is impacting the quality and safety of the water for those downstream. More than 1 million people live nearby and rely on the river for their water needs. All wet mill operators in the region lacked the technical knowledge needed to build an adequate treatment system. Better water treatment technologies like constructed wetlands will not only improve water quality for families who depend on the river but will also promote a more sustainable and competitive coffee industry. Therefore, assessing the performance of the newly constructed pilot wetland in the Kege wet coffee-processing plant plays a significant role in this regard for better understanding of the technology.

The overall goal of this research was to compare and establish the potential of natural and constructed wetlands in wastewater treatment of Coffee Berries Processing Agro-industry (CBPA) effluents. The research is conducted under tropical conditions in order to improve the management of agro-industrial liquid effluents in coffee-producing areas of the SRS. The study also evaluated the quality parameters of coffee beans and the soil of the wetland.

MATERIALS AND METHODS

Study area

The Kege wet coffee-processing plant located in the SRS (Figure 1) is the leading coffee-producing plant located in Dale Woreda near Aposto at the Gidabo River Bridge, which contributes greatly to the foreign exchange of the federal government. The regional state environmental protection office reported that 63,562 tons of coffee were produced in SRS and Gedeo combined in the year ending in 2005, based on inspection records from the Ethiopian Coffee and Tea Authority. This represents 63% of the SNNPR's output and 28% of Ethiopia's total output. The region is also rich in water resources, which are underutilized. The leading causes of morbidity and mortality in the SNNP region are mostly attributable to lack of clean drinking water, poor sanitation and low public awareness of environmental health and personal hygiene practices.

Biophysical setting of the study area

Climate

The climate of the study area is dry and sub-humid, as per local climate classification, with a mean annual temperature of about 19 °C and altitude range of 1,500–3,000 masl. The area is predominantly categorized as the Midland (Woina Dega) Zone and classified as temperate (Figure 2). The important weather systems that cause rainfall over the study area are the northward migration of Inter Tropical Convergence Zone (ITCZ), the development of the Tropical Easterly Jet (TEJ) and its persistence.

Rainfall

In general, the rainfall in the study area is a bimodal type and the main rainy seasons are from June to October and March to May. The maximum rainfall over the northern highlands of the catchment area reaches as high as 180 mm mostly in October and over the western parts it reaches 160 mm in September. The analysis of monthly rainfall indicates that the rainfall pattern over the project area is predominantly bimodal (i.e. the rainfall occurs over a continuous period, but is dominated by two rainfall peaks).

Temperature

The air temperature of the study area is treated on the basis of observation data obtained from class 3 and class 1 meteorological stations located within and nearby the catchment area of the sub-basin. The monthly temperature data used in this study are the minimum, maximum and the mean temperature. The monthly minimum and maximum temperature values in the Yirgaalem Station (Figure 1), as per the data covering the period from 1986 to 2010, are 14 and 26 °C, respectively.

Relative humidity

According to the EPA, humidity above 50% is typically considered too high, while humidity below 30% is usually too low. The average relative humidity (RH) of the study area is 57.5%.

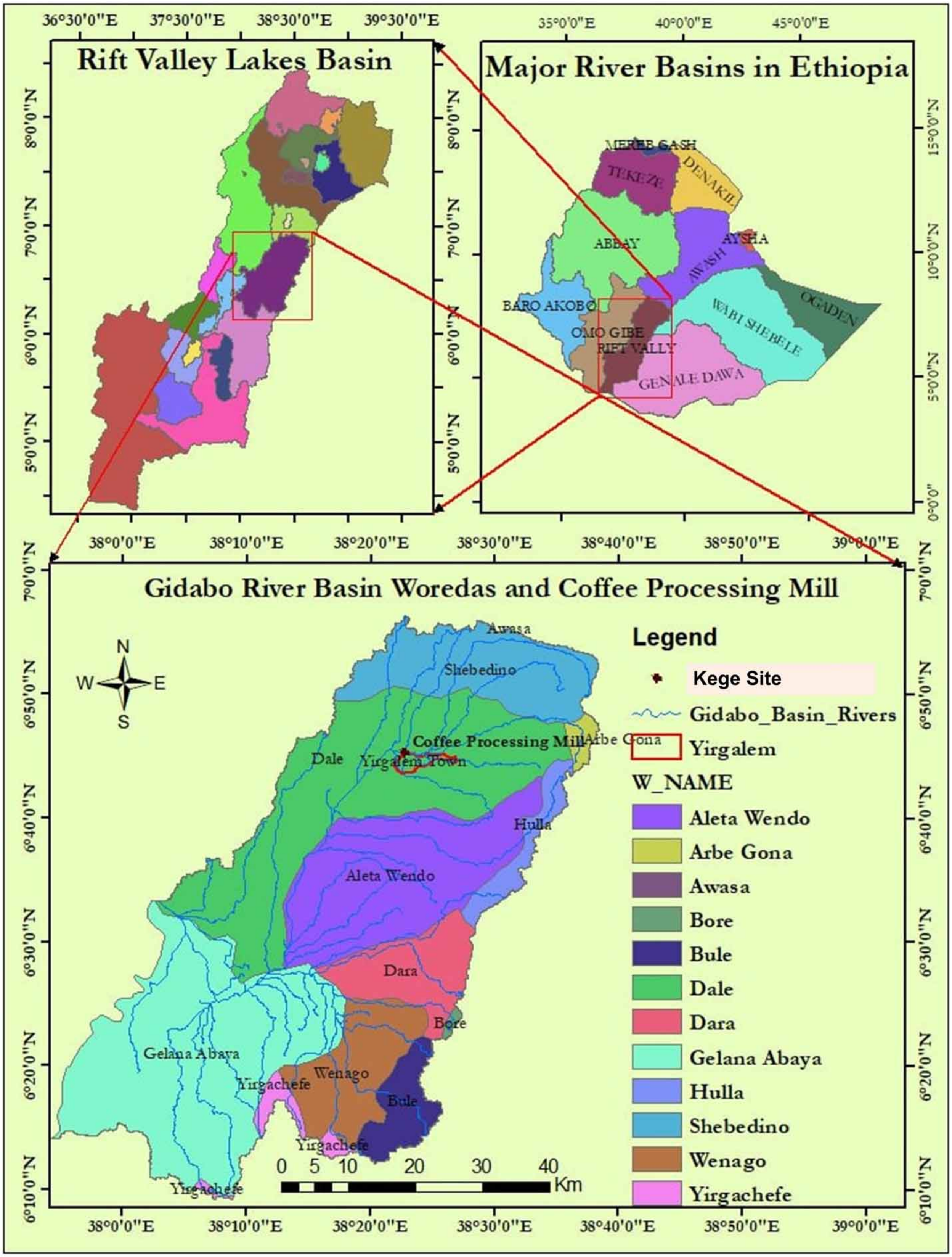


Figure 1 | Location of Kege wet coffee-processing plant.

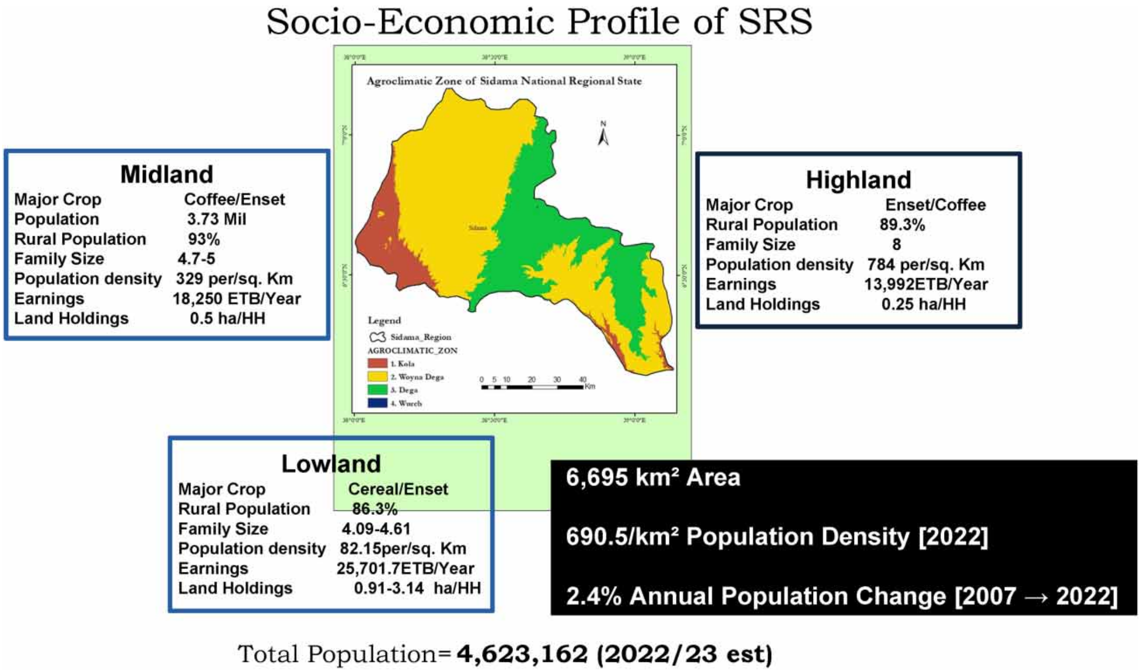


Figure 2 | Socioeconomic profile of the Sidama National Regional State.

Experimental design

This research is based on primary data collected from the experimental treatment system (Figure 3) at the Kege wet coffee-processing plant located in the SRS, comprising of flow division structure, sedimentation pond, pebble filter, stepped chute and constructed wetland. The division structure was used to divert the inflow to the experimental treatment system and the remaining water flows to the existing natural pond. The processing plant utilizes 64 cubic meters of water per day for washing coffee beans. The size of sedimentation is 8×8 with 1-m depth which results in a maximum of 1 day detention time for the raw water allowing sedimentation of macroparticles. Stepped chute was constructed for 2-m elevation transition and natural aeration by diffusion. A filter chamber of $7 \times 7 \times 1$ m filled with pebbles was constructed to remove suspended particles. Then, water was allowed to pass through a wetland of 12×11 m size with interconnected furrows 30 cm wide and ridges of 20 cm height planted with Vettiver grass to absorb pollutants biologically along a total furrow length of 230 m. Loamy soil is observed in the experimental plot. A controlled volume of wastewater coming from the washing plant was allowed to pass through the experimental treatment system and composite water sampling was taken for 3 months in October, November and December 2021. Evaluation of the constructed wetland was performed by comparing effluent and influent water quality from the coffee-processing unit in selected points. Soil samples from the wetlands were also tested for quality. Wetland leachate collection was done using rhizosphere pore water samplers.

Water quality testing

The water quality parameters which were analyzed in this study are given in Table 1.

For the digestion of coffee beans, a procedure for the digestion of coffee powder as recommended by Dubale (2021) was used. For the digestion of soil samples, the EPA 3050B method was applied.

RESULTS AND DISCUSSION

Performance analysis of the constructed wetland

Before treatment, analysis of wastewater from the coffee-processing plant revealed a high BOD_5 value (586 mg/l) at the exit point of wastewater (division box) from the coffee-processing plant as shown in Figure 4. This value is much higher than the national discharge limit (60 mg/l) (Abrha & Chen 2017). If this wastewater is discharged to water resources without any treatment, rapid depletion of oxygen occurs due to the high requirement of dissolved oxygen for the biological oxidation of organic

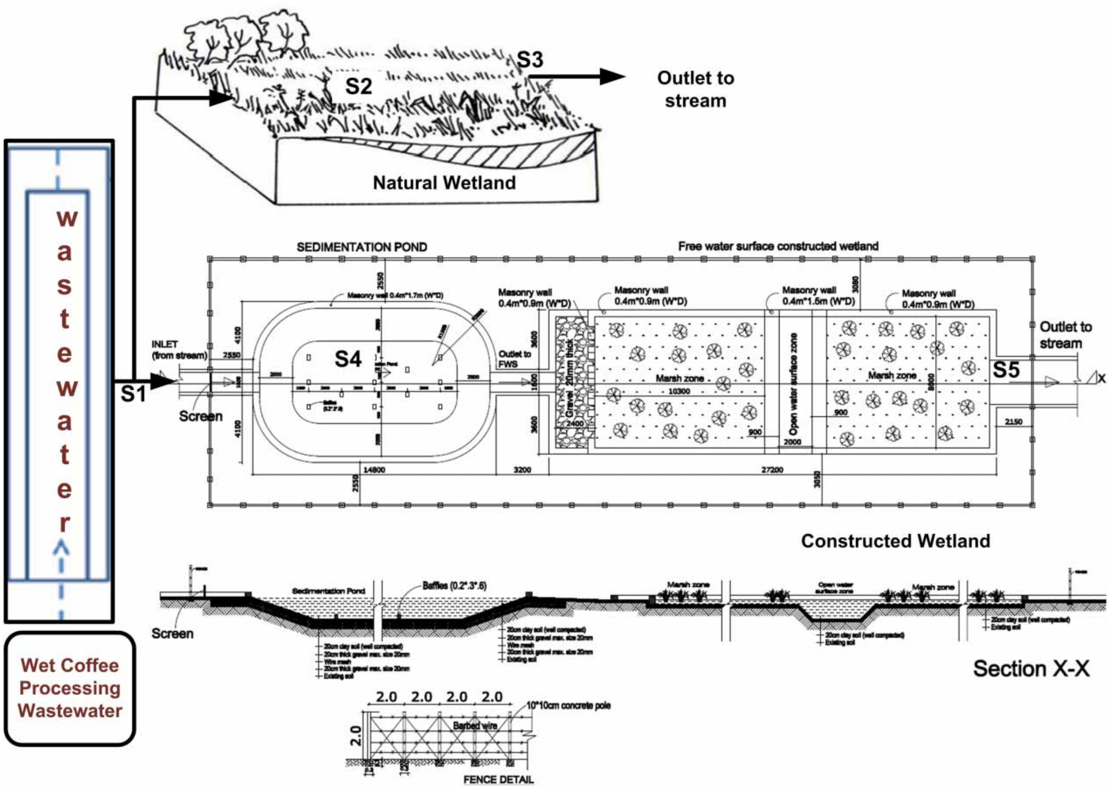


Figure 3 | Layout of experimental setup.

Table 1 | Water quality parameters investigated, methods and apparatus used

Parameters	Methods and apparatus
pH, temperature, EC, TDS	pH and conductivity meter (HANNA pH211)
PO_4^{3}, NO_3^-	Photometric measurements using flame photometer
COD	Dichromate reflux method through oxidation of the sample with potassium dichromate in sulfuric acid solution followed by titration
BOD_5 and DO	Winkler-Azide dilution technique
Turbidity	Nephelometeric (HACH, model 2100A)
Mg, Ca, Cr, Ni and others	Atomic absorption spectrometer, AASP (Varian SP-20) using their respective standard hollow cathode lamps (APHA, 1995).
Iron	UNICAM UV-300 thermo electrode.

matter in the stream, thus resulting in less oxygen available to aquatic life. The consequences of high BOD_5 are the same as those for low dissolved oxygen: aquatic organisms become stressed, suffocate, and die.

Next to the division box, there is a constructed sedimentation pond. In this pond, the value of BOD_5 decreased to 385 mg/l, i.e. 34.3% of BOD_5 was reduced . This reduction can be used as a gauge of the effectiveness of constructed wetlands in the treatment of coffee-processing wastewater. The BOD_5 assimilation capacity of this sedimentation pond is 65.7%.

The third point to be checked in the performance of wastewater treatment is the natural existing wetland. It reduces organic matter from the wastewater to 53.4 mg/l against the influent load of 586 mg/l at the division box, where wastewater is

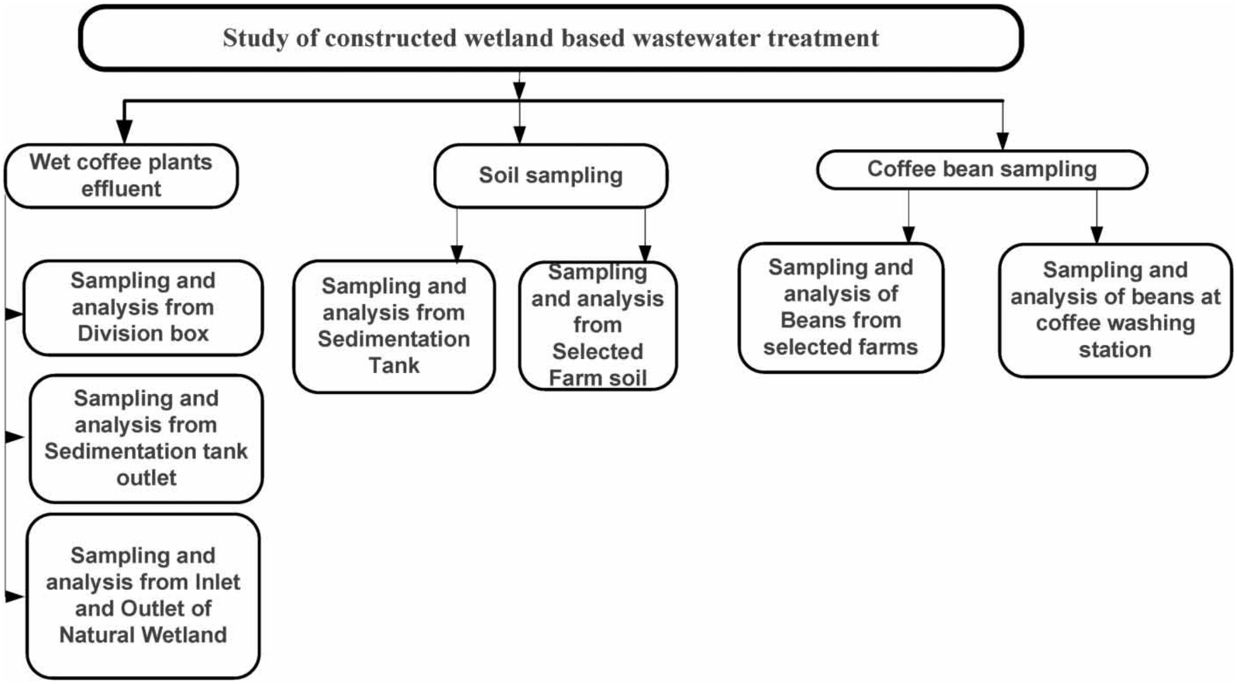


Figure 4 | Schematics of the research.

discharged immediately from the coffee-processing plant. That is, it reduced 91% of the oxygen requirement for biological oxidation and it shows wastewater is going to be free from the concentration of organic matter and BOD_5 becomes less than the national discharge limit at natural wetlands as well as at the constructed wetland.

Physiochemical analysis

pH affects the solubility and availability of micronutrients and how they can be utilized by aquatic organisms. The pH of observed samples ranges between 5.2 and 9 measured at the division box and 9 for the pond (sedimentation pond), respectively. Of the five sampling points, three of them show higher pH than neutrality. The decomposition of basic matter or organic matter that are released from the coffee-processing industries leads to an increase in pH (WHO 1984). The observation (Table 2) showed that the natural as well as the constructed wetlands fulfilled local permissible limits for natural river release, 6–9 (EPA, 2003) as well as international standards for aquatic life 6.5–8.5 (WHO 2006).

In all observation points, the turbidity level is below the existing standards. The consumption of more turbid water may constitute a health risk as excessive turbidity can protect pathogenic microorganisms from the effect of disinfectants, and stimulate the growth of bacteria (Zvikomborero 2005).

Nitrogen can exist in water in four forms, NH_3, NO_3^-, NO_2^- and NH_4^+, which may cause groundwater and surface water pollution in excessive quantity through leaching, stimulate algal growth in surface water that increases maintenance costs in irrigation practices, is carcinogenic in nature and causes blue-baby diseases in human infants. The concentration of NO_3^- in the constructed wetland is below the permissible limit (WHO 2006) for drinking and irrigation water uses. Nitrate is highly soluble and mostly susceptible to leaching, causing groundwater pollution. Its main source is the decomposition of organic matter like coffee waste, fecal matter and municipality waste. The concentration of phosphate in the constructed wetland is lower than the recommended limits for freshwater healthy ecosystems as well (EPA, 2003).

Determination of metallic elements in coffee bean samples from farms

Trace levels of dissolved metals in surface water are essential for proper biological functioning in both plants and animals (CCME 2007). Even though the concentration of some trace metals in the wastewater is below the standard, their source shall be verified to minimize their cumulative effect on the ecosystem. Hence, their presence in coffee beans as well as inside the constructed wetland soil was evaluated (Table 3).

Table 2 | Physiochemical analysis of wastewater

Parameter	Division box (S_1)	Natural Wetland near inlet (S_2)	Natural wetland outlet (S_3)	Pond (S_4)	Constructed wetland outlet (S_5)	Standard (EPA)
pH	5.2	7.5	6.5	9	6.8	6.5–8.5
Temperature	25.5	30	21.4	28.9	25	40°C
E.Conductivity	1,443	406	624	913	103	1,000
TDS	722	203	312	457	69.3	1,000
Turbidity (NTU)	0	0	0	0	4	5
Total chlorine	<0.02	0.02	0.02	0.03	0.02	5
Total hardness	62	168	130	268	100	300
Calcium hardness	50	134	104	186	80	300
Magnesium hardness	12	34	26	82	14	300
Total alkalinity	144	240	168	506	160	500
Bicarbonate Alkalinity	144	240	168	506	134	500
Carbonate Alkalinity	0	0	0	0	0	500
Hydroxide Alkalinity	0	0	0	0	0	500
Dissolved NH^{3+}	0.85	0.24	0.28	0.17	0.2	1.5
NH^{4+} Ammonium	1.1	0.31	0.36	0.22	0.3	1.5
Na^+ Sodium	18.3	31.9	16.3	104	10	1.5
Potassium(K^+)	42	5.6	12	32	12	1.5
Calcium (Ca^{2+})	20	53.6	41.6	74.4	35.36	100
Magnesium (Mg^{2+})	2.9	8.3	6.3	19.9	4.04	30
Iron (Fe)	0.23	0.04	0.11	0.2	0.2	0.3
Copper (Cu^{2+})	0.9	<0.04	0.6	0.7	0.5	2
Manganese(Mn^{2+})	<0.1	<0.1	<0.1	<0.1	<0.2	0.5
Chromium (Cr^{2+})	<0.01	<0.01	<0.01	<0.01	<0.02	0.05
Chloride (Cl^-)	<10	<10	<10	<10	<11	250
Fluoride(F^-)	0.6	0.6	0.6	0.6	1.6	1.5
Bromine(Br^2)	<0.05	<0.05	<0.05	<0.05	<0.06	1.5
Nitrite (No^{2-})	0.03	0.17	0.2	0.1	1.2	3
Nitrate (No^{3-})	13.2	2.2	8.8	22	4.8	50
Sulphate (SO_4^{2-})	<2	<2	<2	2	<3	250
Phosphate (PO_4^{2-})	3	0.09	3.5	6	3.5	250
Bicarbonate (HCO_3^-)	176	293	205	617	200	250
Carbonate (CO_3^{2-})	0	0	0	0	0	250

All units are in mg/l except temperature, turbidity, EC, and pH which are expressed in °C, NTU, μS cm^{-1}, and [H^+] respectively.

Metal distribution patterns in soil samples

Calcium had the highest concentration of macroelements in all soil samples, followed by K and Na (Table 3). Similarly, Cu was detected in greater abundance among the microelements, followed by Mn and Zn. Co > Cd > Ni was assigned to the remaining trace metals.

DISCUSSION

Comparing pollutant reduction percentages from both natural wetlands and constructed wetlands, the latter performed better in reducing pollutants; particularly, EC, TDS, dissolved ammonia, ammonium, sodium, potassium, copper and nitrate (Figures 5 and 6). This is mainly attributed to the effect of filtration, aeration and nutrient absorption by Vettiver in

Table 3 | Mean concentration (mean ± SD, $n = 3$, ppm) of elements in coffee beans and soil samples

Elements	Coffee beans	Soil samples
Ni	0.055 ± 0.004	0.191 ± 0.009
Zn	0.073 ± 0.003	0.161 ± 0.007
Co	nd.	5.33 ± 0.305
Cu	0.22 ± 0.0026	42.66 ± 2.52
Cr	nd.	nd.
Ca	15.15 ± 0.614	1,355 ± 18.02
Mn	0.927 ± 0.004	0.62 ± 0.238
Na	22.04 ± 0.042	111.63 ± 0.35
K	99.93 ± 0.037	673 ± 2.65
Pb	nd.	nd.
Cd	nd.	3.1 ± 0.1

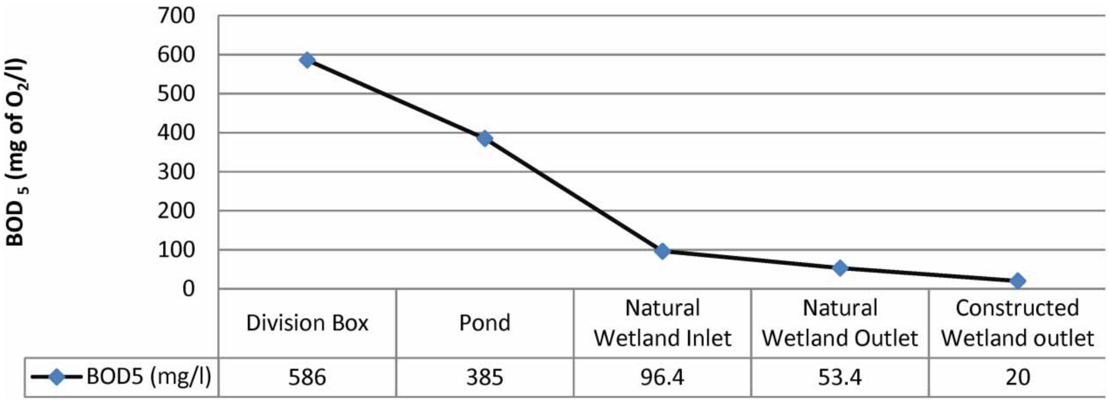


Figure 5 | BOD_5 in mg of O_2/l of wastewater at observation points.

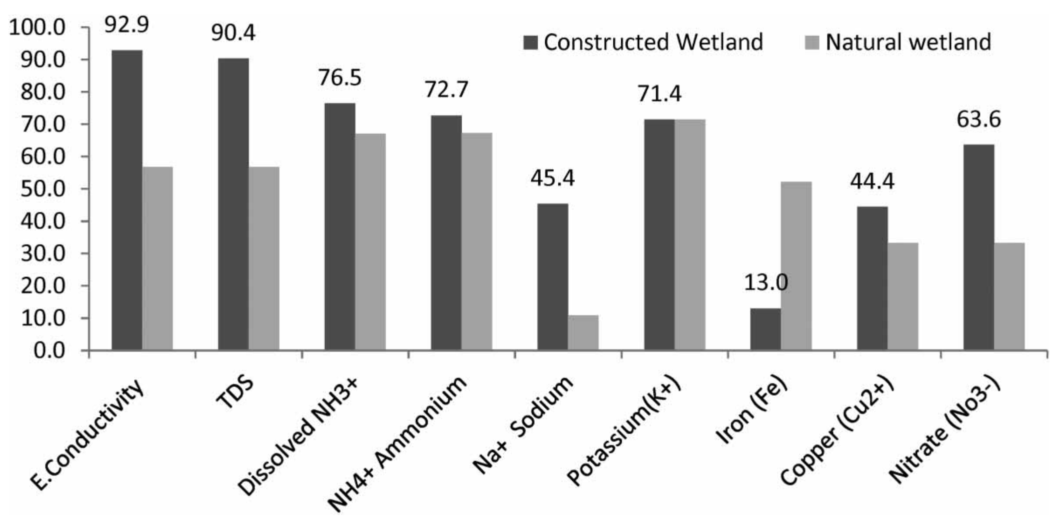


Figure 6 | Reduction of pollutants in treated effluent.

the constructed wetland treatment system. The iron reduction was better in natural wetlands. BOD_5 water reduced greatly at the inlet of the natural wetland due to the long distance traveled by the effluent from the division box. Around 6% higher BOD_5 was reduced by the constructed wetland as compared to the natural wetland. However, the area required for a natural wetland is much larger compared to the constructed wetland which needs less space for almost equal treatment by natural wetlands. Moreover, it is not always possible to have natural wetlands in the proximity of coffee-washing stations. Similar research conducted in Ethiopia with *Cyperus ustulatus* plant in the wetland and sedimentation tank aerated for 25 days resulted in 97.8% BOD_5 removal (Zerihun 2021). In the current research, instead of mechanical aeration, natural aeration by chute improves oxygen levels in the water and is also cost-effective. After the chute, provision of stone filter treats the effluent biologically and supports the reduction of pollutants by bacterial slime formed on the stone filter. In the current research, Vetiver grass performed on a par with *C. ustulatus* plant in reducing pollutants, particularly BOD_5. Maximum reduction of pollutants is observed for electrical conductivity which is an indirect measure of total dissolved salts in the treated effluent discharged out of the constructed wetland.

Potassium was found to have the greatest content among the macroelements (99.93 ± 0.037 ppm) in coffee beans. The highest amounts of K in coffee beans are likely attributable to the fact that nutrients like K, N, P, S and Mg are highly mobile in plant tissues and can be translocated from old to young plant tissues (Weis & Weis 2004). Another reason for increased K concentrations is that this element is among the most important nutrients for plants. The amount of K reported by the present study is much lower than that found in the Gedeo zone, Ethiopia (Dubale 2021) (Table 3). On the other hand, values reported for K in sample beans from other studies (Omer *et al.* 2019) are comparable with the results obtained. The concentrations of elements in coffee beans are mostly determined by the ambient conditions in the cultivation area as well as the plant's genetic features (Kelly *et al.* 2005). As a result, changes in the nature of the soil, climate, agronomic methods, or genetic properties of the coffee beans described in this study could be attributed to low K concentrations in coffee beans.

The findings of the present study revealed that Na and Ca were also detected in significant amounts in coffee bean samples from farms, with concentrations of 22.04 ± 0.042 ppm and 17.23 ± 0.36 ppm, respectively. This result is consistent with that reported in Saudi Arabia (Omer *et al.* 2019).

Mn was the most accumulating microelement in coffee bean samples, followed by Ni, Cu and Zn. Higher manganese levels in coffee beans might be attributed to the availability of this micronutrient in relatively acidic soils of the farmland. The availability of Mn in soil is known to be influenced by the pH of the soil (Wood 1985). Because Mn has a high solubility at low pH, its concentration in acidic soil is likely to be high (Wood 1985). The high concentration of trace metals Ni, Cu and Zn in coffee beans may be due to the fact that these ions are easily transmitted from soil to plants and accumulate in them (Wood 1985; Tsegaye & Struik 2001; Saadia & Nabila 2013).

In the coffee beans of the selected study site, the toxic heavy metals (Pb and Cd) were not found in the coffee beans. This finding is consistent with the previous study reported by Getachew & Worku (2014) on raw and roasted coffee beans, by Abera Gure *et al.* (2017) in raw coffee beans and Dubale in coffee bean samples from farms. These toxic metals were not detected in the present study area, because there is no environmental degradation owing to industrial operations in Dale Woreda, toxic metals (Pb and Cd) concentrations in coffee beans and soils are expected to be quite low. Furthermore, the absence of commercial fertilizers and pesticides for coffee plantations in the woreda may be evidenced by the low amounts of hazardous metals. Furthermore, Pb and Cd have no nutritional value for humans, despite their very low concentration with no health risks as a result of these hazardous substances in Dale Woreda coffee beans.

In coffee beans from Kege farmers' farms, Mn was determined to be the most abundant minor element, followed by Cu, Zn and Ni, of which Mn (0.927 ± 0.004 ppm) was present in higher concentration than the other microelements (Table 3). Likewise, the levels of Cu (0.22 ± 0.0026 ppm) and Zn (0.073 ± 0.003 ppm) were higher than that of Ni (0.055 ± 0.004 ppm) (Table 3) except for Pb, Cd, Co and Cr, which were not detected in coffee bean.

Soil sample analysis shows that calcium ($1,355 \pm 18.02$ ppm) was the largest of all the detected metals. K and Na were found in larger amounts next to calcium with values of 673 ± 2.65 ppm and 111.63 ± 0.35 ppm, respectively. Out of the analyzed microelements, Cu (42.66 ± 2.52) was found to be in larger amounts followed by Co (5.33 ± 0.305 ppm) and Mn (0.62 ± 0.238 ppm). Likewise, the concentrations of Cd, Ni and Zn were found to be 3.1 ± 0.1 ppm, 0.191 ± 0.009 ppm and 0.161 ± 0.007 ppm, respectively. The average metal concentrations in the constructed wetland soil were determined to be in the following order: Ca > K > Na > Cu > Co > Cd > Mn > Ni > Zn.

Metal concentrations in coffee beans

Even though sample preparation and analysis methodologies differed, the results obtained in this study were compared to those reported by other studies (Table 4). The concentration of essential and non-essential metals in raw and roasted coffee beans cultivated in various parts of the world, including Ethiopia, has been documented by a number of writers. In Table 4, the concentrations of metals in coffee beans obtained in the current investigation are compared to reported levels.

The results show that the metal content found is more or less comparable to levels published in the literature. In this investigation, however, the concentration of K was found to be lower than previously reported values. This may indicate that Ethiopian coffee is grown without the use of fertilizers. Pb and Cd concentrations were much below the technique detection limits, exactly as they had been in previous studies (Ashu & Chandravanshi 2011; Gure *et al.* 2017; Dubale 2021).

The findings of this study are more or less compatible with those reported by different researchers from various nations. Cu and Mn contents, on the other hand, are lower than the previous studies (Gure *et al.* 2017; Silva *et al.* 2017; Dubale 2021). The current study's findings are in good agreement with the majority of published values. Furthermore, for macroelements K > Na > Ca, the general trend of metal concentration is in good agreement. Mostly trace microelements trend follows Mn > Cu > Ni > Zn in coffee beans from different farms.

Maximum allowable limits of heavy metals in coffee beans were not found in the literature. As a result, standards for other foods and herbal plants were used to compare (Table 5). Trace heavy metal concentrations in plants were critical for animal and human health, but the metals should be kept within allowed ranges, as established by FAO/WHO and other standard-setting authorities. Health is harmed by concentrations that are higher or lower than the prescribed limits (FAO/WHO 1993; WHO 2005).

Nickel concentrations in coffee beans from farms (CBFF) and coffee from the washing industry varied from 0.05 to 0.08 ppm (CBWI). FAO/WHO (1993) defined a tolerable level of 1.63 ppm in edible plants. When the metal limits in the researched medicinal plants are compared to those proposed by FAO/WHO (1993), it is discovered that all plants collect Ni below this level. The WHO (2005) limits for Ni have not yet been defined for medicinal plants. Because Ni absorption by the body is quite low, Ni poisoning in humans is not very common (Onianwa *et al.* 2000).

Zn levels in CBFF varied from 0.054–0.076 ppm to 0.051–0.09 ppm in CBWI. FAO/WHO (1993) defined an acceptable level of 27.4 ppm in edible plants. Following a comparison of the metal limit in the investigated coffee beans with those specified by FAO/WHO (1993), it was discovered that all samples fall within this range. The WHO (2005) limits for Zn have not yet been defined for medicinal plants.

Cu levels in CBFF and CBWI were 0.14–0.29 ppm and 0.14–0.28 ppm, respectively. FAO/WHO (1993) defined an acceptable level of 3.00 ppm in edible plants. After comparing the metal limit in the investigated coffee beans to the FAO/WHO

Table 4 | Metal concentrations in coffee beans compared to literature values

	Present study				(Dubale 2021) Ethiopia	
Metals	**CBFF**	**CBWI**	**(Silva *et al.* 2017) in Brazil**	**(Suseela *et al.* 2001) in India**	**CBFF**	**CBWI**
Ni	0.05–0.08	0.05–0.08	0.03–1.95	NR	1.66–2.43	1.56–2.32
Zn	0.054–0.076	0.051–0.09	5.53–55.8	2–9	8.74–12.7	9.41–13.0
Co	nd.	nd.	NR	NR	2.47–2.86	2.31–2.75
Cu	0.14–0.29	0.14–0.28	0.7–17.18	0.4–16	23.4–28.5	23.1–28.2
Cr	nd.	nd.	0.03–0.10	0.4–1.00	1.04–1.92	0.94–1.90
Ca	3.0–17.27	2.80–4.37	NR	869–1,171	1,037–1,253	1,090–1,270
Mn	0.08–0.11	0.07–0.10	9.81–39.8	7–13	17.3–23.6	17.2–22.6
Na	3.0–22.1	1.40–15.09	NR	NR	NR	NR
K	69.0–99.97	61.4–78	NR	14,000–29,000	14,631–15,043	14,602–14,980
Pb	nd.	nd.	0.03–1.58	NR	nd.	nd.
Cd	nd.	nd.	0.03–0.10	NR	nd.	nd.

CBFF, Coffee Beans from Farmer's Farms; CBWI, Coffee Beans from Washing Industries; nd, not detected, all units are in mg/l.

Table 5 | Comparison of results for coffee beans from farms (CBFF) and washing industry with maximum permissible limit (MPL)

Elements	Present study CBFF	CBWI	MPL (ppm)	Type of plant	References
Ni	0.05–0.08	0.05–0.08	1.63	Edible plant	FAO/WHO (1993)
			No MPL	Medicinal plant	WHO (2005)
Zn	0.054–0.076	0.051–0.09	50	Grain	USAD (2000)
			No MPL	Medicinal plant	WHO (2005)
			100	Beans	USAD (2000)
			27.4	Edible plant	FAO/WHO (1993)
Co	nd.	nd.	No MPL	Medicinal plant	WHO (2005)
Cu	0.14–0.29	0.14–0.28	40	food crops	FAO/WHO (1993)
			3	Edible plant	FAO/WHO (1993)
			20	Medicinal plant	WHO (2005) set by Singapore
			150	Medicinal plant	WHO (2005) set by china
Cr	nd.	nd.	2	Medicinal plant	WHO (2005)
			0.02	Edible plant	FAO/WHO (1993)
Ca	3.0–17.27	2.80–4.37	–	–	
Mn	0.08–0.11	0.07–0.10	No MPL	Medicinal plant	WHO (2005)
			2	Edible plant	FAO/WHO (1993)
Pb	nd.	nd.	0.43	Edible plant	FAO/WHO (1993)
			10	Medicinal plant	WHO (2005)
Cd	nd.	nd.	0.21	Edible plant	FAO/WHO (1993)
			0.3	Medicinal plant	WHO (2005)

All units are in mg/l; nd, not detected.

(1993) recommendations, it was discovered that all coffee beans collect Cu below this level. However, the WHO (2005) limits for Cu have not yet been determined for medicinal plants. Cu acceptable limits in medicinal plants were determined by China and Singapore at 20 and 150 ppm, respectively (WHO 2005). Cu levels in agricultural products should be between 4 and 15 parts per million, according to Allaway (1968).

Mn concentrations ranged from 0.08 to 0.11 ppm in CBFF and 0.07 to 0.10 ppm in CBWI. FAO/WHO (1993) defined an acceptable level of 2 ppm in edible plants. After comparing the metal limit in the investigated coffee bean to the FAO/WHO (1993) recommendations, it was discovered that all plants collect Mn below this level. The WHO (2005) limits for Mn have not yet been defined for medicinal plants. Dubale (2021) found that Mn levels in coffee beans ranged from 17.3–23.6 ppm in CBFF and 17.2–22.6 ppm in CBWI.

Pb and Cd contents in the coffee beans tested were well below the detection limits of the technique. The FAO/WHO (1993) permitted limit for Cd and Pb in edible plants was 0.21 and 0.43 ppm, respectively. However, the WHO (2005) set a permissible limit for Cd of 0.3 ppm and a maximum for Pb of 10 ppm for medicinal plants.

According to international heavy metal guidelines, the quantities of metals identified in coffee bean samples were below the maximum allowed limit. As a result, it may be concluded that there is now no health risk linked with the use of Dale Woreda coffee beans.

CONCLUSIONS

Coffee is one of the world's most popular and frequently consumed beverages, with significant commercial and social significance. In international trade, it is also one of the most important agricultural goods. As a result, the current study attempted to investigate the performance capacity of a constructed wetland in Dale Woreda of the SRS. The source of the contaminants was traced through the analysis of the concentrations of K, Na, Ca, Mn, Cu, Zn, Ni, Cr, Co, Cd, and Pb in coffee beans from farms and from the washing industry. The constructed wetland showed a superior performance in treating the wet coffee effluent to national and international standards. It reduced BOD_5 to 65.69% at the sedimentation pond and 3.4% at the outlet of the constructed wetland against 9.1% at the outlet of the natural wetland. The constructed wetland performs on par with the natural wetland in treating the effluent from the coffee-washing station. The levels of essential and non-essential metals in coffee beans (from farms and washing industries) and soil samples were determined in this study. Metal levels in coffee bean samples from farmers' farms are in the following order: K > Na > Ca > Mn > Cu > Ni > Zn. Metal levels were found to be K > Na > Ca > Mn > Cu > Zn > Ni in coffee beans from the washing industry. However, the average metal concentrations in the soil were determined to be in the following order: Ca > K > Na > Cu > Co > Cd > Mn > Ni > Zn. In both cases, the levels of toxic metals (Pb and Cd) were not detected, and trace heavy metal levels were below the FAO/WHO maximum permissible limits. As a result, there is no health risk linked with the use of coffee beans due to harmful and trace heavy metals.

According to the findings of this study, there are permitted levels of macro and trace elements in coffee beans from farms and washing plants. With the intervention of a constructed wetland at the wet coffee-processing plants, the organic contamination of rivers can easily be mitigated. As a result, organic as well as metal pollutants have no effect on the coffee grown in Dale Woreda.

RECOMMENDATIONS

Based on the results of this research, it is recommended to implement the constructed wetland for treating effluent from small coffee-washing stations in a cost-effective manner in the tropics. Policymakers are advised to enforce this technology in wet coffee-processing stations as an affordable intervention in the Gidabo Watershed of Southern Ethiopia. This study needs to be continued at least for 3 years to verify the sustainability of the treatment system. It is recommended to go for further research to optimize the effluent flow rate with the size of the constructed wetland.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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