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ABSTRACT: Constructed wetlands are engineered systems built to use natural processes and remove pollutants from contaminated water in a more controlled environment. The research was an experimental research carried out to assess the effectiveness of natural and constructed wetland systems in the treatment of coffee wastewater. The 2 vertical flow constructed wetland was built. The first wetland covered an area of 132 m². It has 12 m width and 11 m length. Open space is constructed between 2 constructed wetlands with a dimension of 11 m × 3 m × 1 m. The second wetland was constructed and its function is similar to the first one, from this wetland water is discharged to the river. The construction of the wetland is accomplished by constructing 20 cm wide furrows with a spacing of 30 cm. Vetiver grasses have planted with a spacing of 20 cm intervals. The physicochemical data were recorded, organized, and analyzed using R software (version 4.1) and Microsoft Excel. Data were processed using parametric (one-way ANOVA) and nonparametric (Mann-Whitney's *U* test) statistical tests of homogeneity. One-way analysis of Variance (ANOVA) was used to determine the significance of differences in variations in physicochemical variables within the constructed wetland sites. Tukey's multiple comparisons for differences between means were also assessed. Findings indicated that a natural wetland had a mean influent and effluent of total suspended solids (TSS) of 2190.78 ± 448.46 mg/l and 972.67 ± 234.312 mg/l, respectively. A Mann-Whitney *U* test revealed that TSS were significantly higher in natural wetland (median = 1551.50) compared to constructed wetland (median = 922.5), $U = 676.5$, $z = -2.435$, $P = .015$, $r = .257$. Natural wetlands had a mean influent of biological oxygen demand (BOD) was 4277.94 ± 157.02 mg/l, while in the effluent of BOD it was 326.83 ± 112.24 mg/l. While in constructed wetland it was 4192.4 ± 191.3 mg/l, 782.72 ± 507.6 mg/l, and 88.28 ± 20.08 mg/l in influent, middle, and effluent respectively. Average chemical oxygen demand (COD) value at influent in natural wetlands was 8085.61 ± 536.99 mg/l and in the effluent it was 675.33 ± 201.4 mg/l. In constructed wetland, it was found to be 8409.8 ± 592.9, 1372.6 ± 387.94, and 249.0 ± 7.68 for influent, middle, and effluent respectively. Comparatively, the purification efficiency of organic pollutants (TSS, BOD, and COD) of constructed wetlands was better than natural wetlands, whereas natural wetlands had better purification efficiency of nitrogen compounds such as ammonium, nitrite, and nitrate. On average, removal rates for nitrogen compounds were 39.53% and −24.41% for ammonium, 79.44% and 55.4% for nitrite, and 68.90% and 60.6% for nitrate in natural and constructed wetlands respectively, while the phosphate removal rate was 43.17% and 58.7% in natural and constructed wetlands, respectively. A Mann-Whitney *U* test revealed that there is no significance difference in nitrite, nitrate, ammonium, and phosphate concentration between natural and constructed wetlands($P > .05$). Based on these results, both systems of treatment were effective in treating the coffee effluent since most of the values obtained were below the permissible EEPA limits. Even though the constructed wetland treatment plant performed better overall, in comparison, the natural wetlands had better purification efficiency for nitrogen compounds like ammonium, nitrite, and nitrate and the constructed wetlands had better purification efficiency for organic pollutants (TSS, BOD, and COD).

KEYWORDS: Removal capacity, surface-flow constructed wetland wastewater treatment, *Vetiveria zizanioides*

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Introduction

Coffee wastewater discharged carelessly into neighboring natural waterways causing pollution to both the surface and groundwater.[1] Although the effluent generated by agro-based industries has a high amount of pollutants, which can cause irreversible environmental harm if not properly disposed of Gururaj et al.[2] According to Avellone et al,[3] Fia et al,[4] and Gururaj et al,[2] the effluent from coffee processing plants consists of different sugars, crude protein, crude fiber, different nutrients and chemicals which are generated from both pulping and mucilage fermentation processes. Haddis and Devi[5] and Gururaj et al[2] indicated that the effluent also consists of different toxic chemicals such as tannins, alkaloids (caffeine), and polyphenolic compounds and nutrients like nitrate and phosphate. Moreover, Selvamurugan et al[6] and Mussatto et al[7] noted that the discharge of such kinds of untreated coffee washed effluent into the open environment and the river can bring various environmental and public health problems.

The use of natural and artificial (constructed) wetlands for wastewater treatment has been proposed as an intermediate technological solution for handling wastewater.[8] These systems are economically attractive and relatively energy-efficient for wastewater treatment, specially constructed wetland (CW) technology is one of the emerging and acceptable technologies because it can effectively remove all most all types of pollutants from wastewaters without harming the environment.[9] Constructed wetlands are recommended as superior options for treating industrial or domestic wastewater because of their numerous benefits, including the provision of high wastewater treatment levels. Constructed wetlands are also recommended because they are environmentally friendly. It has been shown that this method can reduce wastewater contaminants to tolerable levels. The low cost of building is further aided by the fact that wetland systems require little to no energy and nothing in the way of equipment. Before considering using this method for complete or maximum contamination removal, it must first be fully established. Here, establishment denotes complete development/growth.[10] Several countries, particularly in the developing world, are promoting the reclamation and reuse of wastewater[11] with an emphasis on the application of CWs as the technology for wastewater remediation. Nonetheless, local expertise and awareness in the application of the technology remain a challenge; for example, there has yet to be a national specific coordinated policy on wetlands in Ethiopia[12]

In the case of wetlands, plant selection is critical, and the plants chosen must be tolerant of toxicity as well as variations in the entering wastewater character.[13] The vetiver system was originally created for the aim of soil and water conservation, particularly in the fields of wastewater treatment and solid waste dumps.[14] Vetiver grass is one of the most promising plants because of its rapid growth, deep and broad root system, and strong tolerance to environmental stress such as drastic temperature changes (22°C-60°C), soil pH (3.0-10.5) and, most critically, excellent tolerance to heavy metal stress.[14,15] Therefore, the coffee berry wastewater treatment with vetiver grass is the alternative way emphasizing during this study.

For the past 2 decades, urbanization and expansion of industrial activities on forest and wetland reserves has become an acute problem in Ethiopia. Not only does encroachment account for wetland and forest loss, but also biodiversity and aquatic life diversity depletion as well. Draining of wetlands and clearing of forests for urbanization and industrial development has had serious consequences on surface water hydrology and accelerated the process of water pollution. Limited data are available about the potential of constructed wetland oriented wastewater treatment of Coffee Berry Processing Agro-industry (CBPA), especially using Vetiver grass in Africa in general, and particularly in Ethiopia. The constructed wetland system does not require high construction and operation costs as it is required for the construction of a conventional wastewater treatment system.[14,16] With this in mind, we designed, built, and operated the constructed wetlands in the Kege processing plant for the treatment of coffee wastewater. The scope of this study is to the analysis of the physicochemical parameters of wastewater. physicochemical parameters of wastewater such as, pH, Temperature, EC, Turbidity, TDS, nitrite, nitrate, ammonia, phosphate, TSS, BOD, COD, and DO. This study aims the treatment performance assessment of natural and constructed wetlands on wastewater from Kege coffee processing plant in Dale Woreda, Sidama Regional State, Ethiopia.

Methods

Study area

Kege wet coffee processing plant located in Sidama Regional State (SRS) is the leading coffee producing plant located in Dale Woreda near Aposto at the Gidabo River Bridge, at the side of the highway from Addis Ababa to Kenya. The regional state environmental protection office reported that 63 562 t of coffee was produced in Sidama Regional State and Gedeo combined in the year ending in 2019 based on inspection records from the Ethiopian Coffee and Tea Authority. This represents 63% of the Southern Nations, Nationalities, and Peoples' Region (SNNPR's) output and 28% of Ethiopia's total output (Figure 1). The mean annual temperature ranges between 9.6°C and 29.2°C. The area has a bimodal rainfall pattern with the first peak from April to May and the second peak from August to October. The lowest rainfall was recorded between November and February. The mean annual rainfall of the area is 1102 mm/year. Agroforestry practices appear to be the major features of the land use systems in the area. During maximum coffee production, 64 000 l or 64 m^3 of wastewater is discharged from the Kege coffee processing plant.

Constructed wetland unit preparation/field Experiment Design

This study is a randomized controlled trial (RCTS), which is a type of comparative Randomized Experiment—In this RCTS experiment, the performance of a well-managed constructed wetland performance is tested against a well-managed natural wetland by providing a given amount of wastewater. A variety of different wetland designs and testing methods (either based on either volume or area) are available. Each method carries its own set of assumptions, and different equation sets have their own strengths and weaknesses. Volume-based methods use a hydraulic retention time (HRT) to assess pollutant reduction,[17] whereas areal-based methods assess pollutant reduction using the overall wetland area.[18]

Biodegradation of less degradable pollutants generally requires a combination of anaerobic and aerobic processes. To treat such pollutants in constructed wetlands, therefore, anaerobic and aerobic processes should properly incorporate with

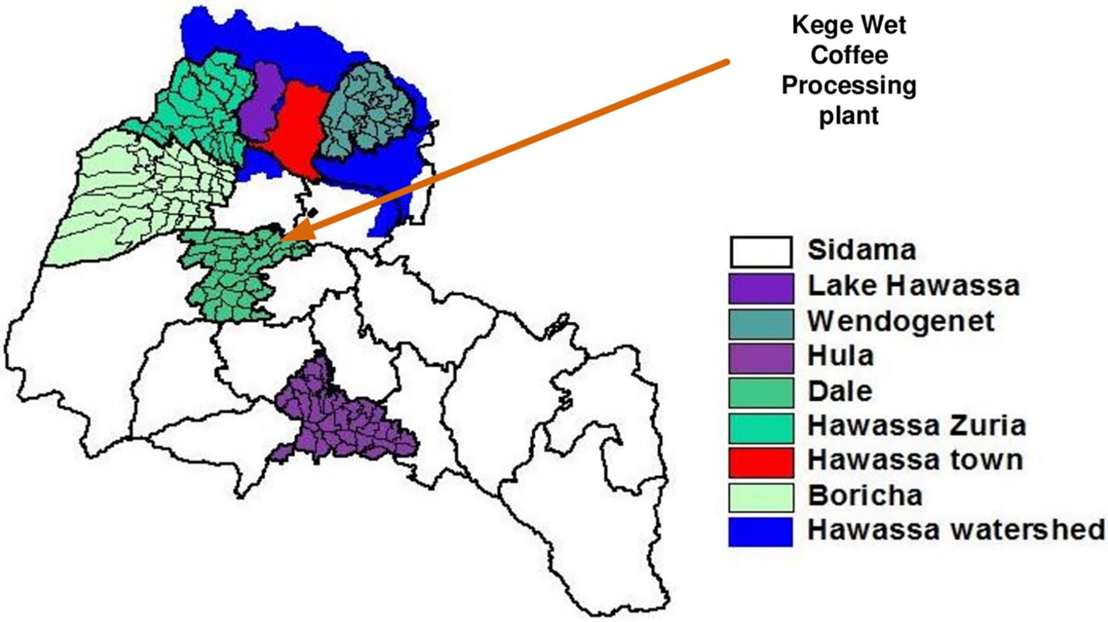

Figure 1. Kege Wet Coffee Processing Plant in SRS.

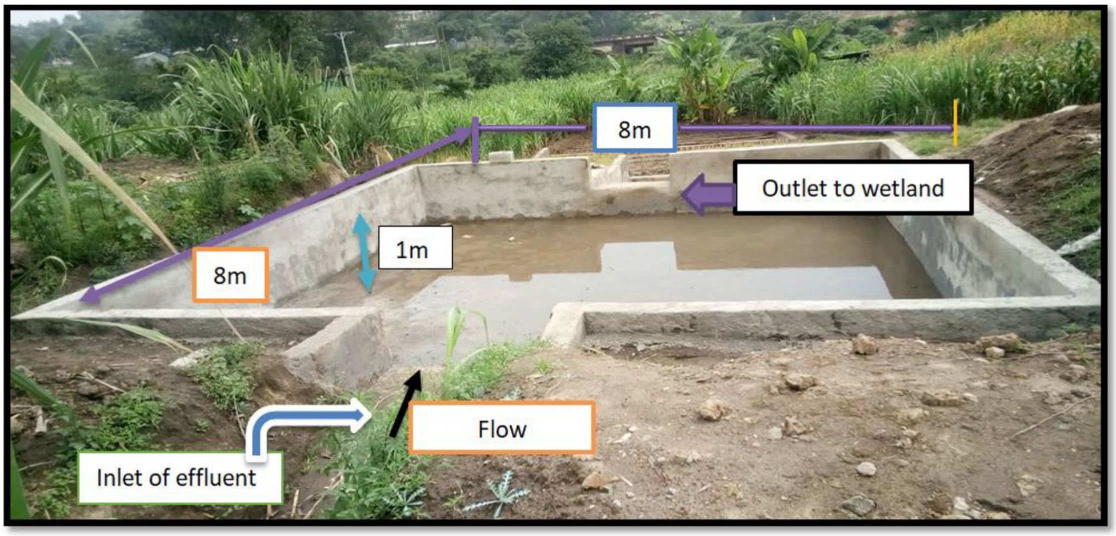

Figure 2. Sedimentation pond.

wetland systems. Vertical flow constructed wetland systems in which anaerobic and aerobic processes occur sequentially are the most promising options for this purpose

The pond with 8 m × 8 m × 1 m is constructed for storing wastewater discharged from the coffee processing plant. The pond is used to facilitate the sedimentation process in which heavy solid particles of wastewater are allowed to settle down in the pond. The dimensions of the pond are determined from the daily maximum discharge of wastewater. According to this, during maximum coffee production, 64 000 l or 64 m^3 of wastewater is discharged from the coffee processing plant. Therefore, the sedimentation ponds needs to have the capacity of storing this much wastewater per day. That is why the pond is constructed with 8 m × 8 m × 1 m dimensions.as it is shown in Figure 2.This stabilization pond was used for only for the constructed wetland.

Drop structure was constructed to facilitate the mixing of wastewater with air (Figure 3). This helps the wastewater for gaining adequate oxygen that requires for the next aerobic reaction (especially the breakdown of acetic acid resulted from fermentation of sugars and pectin). In sedimentation pond due to excess amount of organic pollution there will be oxygen shortage, thus, there happens anaerobic reaction which leads to bad smell through "rotting" and good growth conditions for health threatening bacteria. Therefore, due to drop structures, the wastewater flows were highly disturbed and this helps to get enough oxygen from air so that there will be aerobic reaction in the next stage treatment unit.

(a) (b)

Figure 3. Drop structure (a) during construction and (b) after construction.

Figure 4. Filtration channel.

Filtration channel was constructed on area of 15 m², that is 1 m × 10 m length with 1.5 m width. It is constructed between the drop structure and the first wetland (Figure 4) .The depth of the channel filled with different sized gravels. The channel was used as filter media for filtration processes. Although heavy solid particles of wastewater are removed by sedimentation processes in the sedimentation pond, fine suspended particles remain in the wastewater so far and continue flowing with water in the succeeding steps. Since the channel was filled with different sized gravels, which were used as filtering media, wastewater from drop structures immediately enter in to the channel where it moves down and up through the gravels. Here the filtration processes have occurred. Through this filtration process, the fine solid particles were removed from wastewater. That is why this structure is constructed.

The first wetland covered an area of 132 m². It has 12 m width and 11 m length (Figure 5). The design approach used for the Constructed Wetland design of Kege Wet Coffee Processing Plant is based on hydraulic and organic removal design criteria. In this work, the entire wetland design process mainly follows the criteria given by Kadlec and Knight[18] and USEPA[19] for vertical flow constructed wetland systems. The construction of the wetland is accomplished by constructing 20 cm wide furrows with a spacing of 30 cm. Vetiver grasses have planted with a spacing of 20 cm intervals.[14] Each pilot unit was filled with soil and sand for plant cultivation to a depth of 60 cm and it was built with a slope of 1% from the inlet toward the outlet zones to prevent backflow.[14] Water is allowed to flow uniformly via the gravel zone overtopping the masonry wall on the surface of the first vertical flow constructed wetland and then drains down through the filter layer which consists of coarse sand and joins the open water pond downstream underground after passing through the first *Vetiveria zizanioides* plantation. Please refer the schematics plan found in Supplemental File 1 for further information. All pilots were planted with vetiver grass (*Vetiveria zizanioides*) for wastewater treatment.

Open space is constructed between 2 constructed wetlands with a dimension of 11 m × 3 m × 1 m. Thus, it covered an area of 33 m². Half of its depth is filled with different sized gravels. Purpose of open space used as filter media next to the first wetland. Since it is open, water can get sunlight for chemical reaction (Figure 6).

The construction of the second wetland (Figure 7) was constructed in a similar manner to the first one and it has a similar function with the first one as it is discussed previously. From this wetland, water is discharged to the river.

Figure 5. First wetland.

(a) (b)

Figure 6. Construction of open space between 2 wetlands: (a) during excavation and (b) after construction.

Young plants of *Vetiveria zizanioides* collected from natural wetlands were planted directly into the wetland cells (Figure 8). Vetiver grasses are plated in rows with the spacing of 20 cm so that wastewater flow in a meander way to take a long time in the wetland for the natural processes to have enough hydraulic detention time for the service of natural processes. Before planting, the tiller roots were carefully rinsed with tap water to get rid of any silt and soil that had adhered to them. The vetiver tillers' shoots and roots were cut back to 10 and 5 cm, respectively. The experimental plants were acclimatized in the constructed wetlands by irrigating tap water for 3 weeks. After that, plants were given 3 months to grow in wastewater[14] (before the real experimental treatments), by which time the majority had grown to a height of 1.0 to 1.5 m.

Construction of the footbridge and division boxes was constructed. Footbridge is used for traveling between the wetland and coffee processing units, whereas a division box is used to divide wastewater to the newly constructed wetland and the natural existing one during excess wastewater discharge (Figure 9). Overall component of the wetland was presented in Figure 10. The area of the natural wetland was 4500 m^2. It has 150 m length and 30 m width. The natural wetland's length to width ratio was 5 to 1. The water's depth ranged from 0.3 to 1.2 m, and its maximum depth was 1.2 m. The design inflow rate was 0.25 m^3/s, and the intended resident time was 3 days.

Figure 7. Second wetland cells.

Selection of sampling sites, wastewater sample collection, transportation, and storage

The experiment was conducted using a triplicate sample to minimize the variation of all samples collected from the same sample site. Wet coffee processing in Sidama Region usually begins at the end of September and proceeds until December. Consequently, wastewater samples were collected from Kege Coffee Processing Plant during the months of October and December 2021. Because in the study area, the main coffee harvesting month is October and proceeds until December. Water samples from both natural and pilot CWs were collected. Water samples from influents (the wastewater that enters in to the wetland), and effluents (wastewater that exits the wetlands) were collected every 2 weeks from the influents and effluents of the natural wetlands and constructed wetland

Figure 8. Planting on wetlands.

Figure 9. Foot bridge.

Figure 10. Whole system of wetland.

from 10th October 2021 to 25th December 2021. At each sampling site, 3 samples were collected from Natural wetland influent site (WS3), Natural wetland effluent (WS6), Constructed wetland influent (WS4), Constructed wetland middle (WS5), and Constructed wetland effluent (WS7).

Two liters of wastewater samples were collected in polyethylene sampling bottles. The wastewater samples were collected using sampling procedures described in American Public Health Association.[20] These bottles were washed and rinsed thoroughly with distilled water and then re-rinsed 3 times with the respective water samples before sample collection. By employing the depth-integrated sampling technique, water samples were taken by inserting polyethylene sampling bottles in the opposite direction of the water flow and immediately capping them after filling them up to the tip of the mouth. Water sampling and preservation techniques followed the standard preservation.[20]

Sample analysis method

Wastewater quality variables such as pH, water temperature, TDS, dissolved oxygen, turbidity, and electrical conductivity were measured by in-situ using multi parameters (Adwa AD8000, AD8000, Romania). For other water quality, the samples were properly and carefully labeled and transported to the laboratory of Sidama Regional State Water Bureau (SRSWB) and to the Laboratory of Chemistry Department, Hawassa University.

For all rest parameters such as ammonium, nitrite, nitrate, sulfate, phosphate were done using spectrophotometer (Hach, DR6000, US), DO was done using DO meter (Hach P/N HQ30d, Loveland, CO, USA), BOD using Winkles methods, and the analytical method used for determination of COD was dichromate test method.

Wetland pollutants removal calculation method

During the monitoring period, the wetland's removal efficiency (E) was calculated by using the formula as shown below.

$$E = \frac{\text{Ci} - \text{Ce}}{\text{Ci}} x100 \quad (1)$$

Where C_i = influent concentration of a pollutant
C_e = effluent concentration of a pollutant, and
E = wetland's removal efficiency (%).

Data quality assurance

Certified standard methods were used for all procedures in the set of experiments. The methodologies used in the series of experiments were all approved standard methods. The reagents were all analytical grade. A triplicate sample analysis was performed for each test to verify accuracy. With a prepared data registration form, all test results were recorded honestly and cautiously.

Data analysis

The physicochemical data were recorded, organized, and analyzed using R software (version 4.1) and Microsoft Excel. Data were processed using parametric (one-way ANOVA) and non-parametric (Mann-Whitney's *U*-test) statistical tests of homogeneity. The results of testing normality and homogeneity of variance for data from constructed wetlands were determined using Kolmogorov-Smirnov and Levene's tests, respectively, and the data confirm that the constructed wetland data has not compromised the assumptions. One-way Analysis of Variance (ANOVA) was used to determine the significance of differences in variations in physicochemical variables and metal concentrations within the constructed wetland sites. Tukey's multiple comparisons for differences between means were also assessed. Physico-chemical parameters were also correlated to see if statistical significance relations between them were employed. In addition, A Mann-Whitney test was performed to evaluate the presence of significant differences of physico-chemical between the 2 wetlands at a 5% degree of error. The nonparametric statistical tests were chosen because the data from natural wetlands did not meet the assumption of normality. Statistical significance was set at $P<.05$ for all tests to identify differences. Data was presented using tables, figures, etc. Mean and percentage removal efficiency calculations were done to describe the data.

Results and Discussion

Suspended solids and organic matter (BOD, COD)

As presented in Table 1, the mean influent and effluent TSS values of natural wetlands were 2190.78 ± 448.46 mg/l and 972.67 ± 234.312 mg/l, respectively which was above the permissible limits recommendation by WHO (50 ppm), ISI (500 ppm) for irrigation and national (Ethiopian) effluent discharge guideline (100 ppm). Removal of other pollutants like BOD, COD, and heavy metals from water also leads to decrease in TSS concentration.[21] However, in the constructed wetland, the mean TSS values in influent (WS4), middle (WS5), and effluent (WS7) were 2253.2 ± 508.2 mg/l, 1048.61 ± 258.6 mg/l and 255.44 ± 248.2 mg/l respectively, which was above the permissible limits recommendation by WHO (50 ppm) for irrigation and EEPA (100 ppm) for effluent discharge guideline. The data analysis revealed that the mean TSS value of WS4, WS5, and WS7 statistically significant different at ($P<.05$).The decrease in TSS concentration noted in the effluent can be attributed to the luxuriant vegetation of the wetland which reduces the speed of the water flowing through the wetland hence causing most of the suspended solids to settle within the water column and removal of BOD, COD, and pollutants like heavy metals from the water also leads to decrease in TSS concentration.[21]

The concentrations of TSS in the natural wetlands (972.67 ± 234.312 mg/l) of the studied effluent were much lower (2880 mg/l) than coffee effluents analyzed by Haddis and Devi.[5] However, higher than coffee effluents (259.5 ± 65.3 mg/l) reported by Tilahun et al[22] in natural wetland. In the present study, the mean effluent value of TSS in the constructed wetlands was 255.44 ± 248.2 mg/l with the range of 80 to 701 mg/l which were much lower than the coffee effluents of TSS (399.3 mg/l) reported by Said et al,[23] reported by Bisekwa et al[24] TSS was in the range of 2481.3 ± 45.6 to 2640.9 ± 60.0 mg/l and reported by Genanaw et al[25] TSS (1852.3 ± 875.5) in treating coffee wastewater at Bokaso coffee processing plant.[25] Those differences are due to the different type and level of coffee processing involved in each production plant, the chemicals or additional ingredients used, and how the waste was handled individually in each plant. Because of the slow hydrolysis rate of the organic part of the material, solids discharge raises the turbidity of water and produces a long-term demand for oxygen. Sugar, proteins, and carbohydrates are all possible components of this biological substance. The natural biodegradation of proteins will eventually lead to the discharge of ammonium, ammonium oxidations into nitrite and nitrate by nitrifying bacteria, leading to extra consumption of oxygen on its oxidation by bacteria.[26] On comparing TSS values with EEPA permissible limits for discharging of treated effluent for irrigation purpose as given in Table 1, it was found that the concentration of TSS in wetland were very high (Figure 11). The mean removal efficiency of TSS in natural wetlands was 55.6%.whereas, in constructed wetlands the average removal efficiencies of TSS were 88.7%. The finding of the present study of the constructed wetlands is in agreement with the removal efficiency of TSS (89%) in the study done previously[27] and TSS (94%) in coffee industry effluent.[23] A Mann-Whitney U test revealed that TSS were significantly higher in natural wetland (median = 1551.50) compared to constructed wetland (median = 922.5), U = 676.5, z = −2.435, P = .015, r = .257. As contrast to natural wetland wastewater treatment systems, the usage of constructed wetlands in wastewater treatment may offer solutions for reducing footprint and preserving the environment.

COD and BOD were used to calculate the organic load. The BOD/COD ratio represents the biodegradability of an effluent.[28] In the current study, the effluent of coffee processing obtains BOD/COD comparison as 0.48 and 0.36 in natural and constructed wetland, respectively, which indicates that the ratio was between 0.36 and 0.54, indicating that the effluent from the production of coffee can be broken down and handled in a biodegradable manner.[29] Biological oxygen demand of inflow natural wetland was (4277.94 ± 157.02 mg/l) while the mean effluent of BOD (326.83 ± 112.24 mg/l) (Figure 12). The mean BOD value of the examined effluents (326.83 ± 112.24 mg/l) in natural wetlands was much lower (1697 ± 390.67 mg/l) than reported by Tilahun et al.[22] However, much higher (38.9 mg/l) than reported by Gitau and Kitur[21] and reported by Xu et al,[30] BOD (8-15 mg/l) in natural wetlands. The reason for the this difference might be due to fact that the volume and strength of the effluent varies every day and primarily depends on the quantum of water used for coffee processing (i.e., lesser the water, higher the strength of effluent and vice-versa).[31]

The mean BOD at influent of constructed wetland was (4192.4 ± 191.3 mg/l) while at middle wetland (782.72 ± 507.6 mg/l) and the mean effluent of BOD (88.28 ± 20.08 mg/l). The mean BOD of the studied effluent (88.28 ± 20.08 mg/l) in the constructed wetlands were much lower than the coffee effluent of BOD (3149 ± 103.0) in treating coffee wastewater at Bokaso coffee processing plant,[25] BOD (171.5 mg/l) effluent of coffee processing plant

Table 1. Mean value of physicochemical parameter and the removal efficiency of the wetlands in Dale Woreda, Sidama Region.

	NATURAL WETLAND			CONSTRUCTED WETLAND				EEPA DISCHARGE
	INFLUENT (WS3)	EFFLUENT (WS6)	% OF REMOVAL	INFLUENT (WS4)	MIDDLE (WS5)	EFFLUENT (WS7)	% OF REMOVAL	
pH	4.72 ± 0.27	7.12 ± 0.215	−50.85	4.769 ± 0.247[a]	6.25 ± 0.723[b]	6.9 ± 0.914[c]	−44.68	6-9
T⁰c	24.29 ± 0.55	23.30 ± 0.49	4.08	24.26 ± 0.51[a]	23.31 ± 0.35[b]	21.36 ± 1.26[c]	11.95	40
EC	363.78 ± 66.81	245.83 ± 105.4	32.42	370.67 ± 67.32[a]	269.44 ± 117.93[b]	224.83 ± 57.35[b]	39.33	<1000
TDS	189.78 ± 48.7	123.06 ± 52.36	35.16	187.61 ± 36.66[a]	128.72 ± 57.63[b]	119.89 ± 43.09[b]	36.1	3000
Turb	386.83 ± 194.69	226.19 ± 191.98	41.53	343.72 ± 165.6[a]	229.56 ± 139.09[ab]	138.94 ± 148.25[b]	59.6	—
NH_4^+	0.86 ± 0.71	0.52 ± 0.59	39.53	0.88 ± 0.715[a]	0.968 ± 1.095[a]	1.13 ± 1.578[a]	−24.41	⩽1
NO_2^-	0.18 ± 0 0.262	0.037 ± 0.014	79.44	0.287 ± 0.407[a]	0.203 ± 0.243[a]	0.128 ± 0 0.164[a]	55.4	—
NO_3^-	33.05 ± 24.21	10.28 ± 3.168	68.90	33.99 ± 25.29[a]	22.24 ± 22.30[ab]	13.38 ± 20.58[b]	60.6	<10
SO_4^{2-}	4.49 ± 4.27	3.19 ± 3.69	28.95	4.47 ± 4.26[a]	1.27 ± 1.324[b]	0.42 ± 0.61[b]	90.6	200
PO_4^{3-}	3.66 ± 0.75	2.08 ± 0 0.42	43.17	3.78 ± 0.87[a]	2.45 ± 0.624[b]	1.56 ± 0.621[c]	58.7	10
DO	0.513 ± 0.039	3.67 ± 0.19	—	0.54 ± 0 0.056[a]	3.263 ± 0.694[b]	4.56 ± 1.011[c]	—	—
TSS	2190.78 ± 448.46	972.67 ± 234.312	55.60	2253.2 ± 508.2[a]	1048.61 ± 258.6[b]	255.44 ± 248.2[c]	88.7	100
BOD	4277.94 ± 157.02	326.83 ± 112.24	92.36	4192.4 ± 191.3[a]	782.72 ± 507.6[b]	88.28 ± 20.08[c]	97.9	80
COD	8085.61 ± 536.99	675.33 ± 201.4	91.65	8409.8 ± 592.9[a]	1372.6 ± 387.94[b]	249.0 ± 7.68[c]	97	250

For constructed wetland one way ANOVA was done; numbers followed by the same letter superscripts in the same row do not vary significantly by Tukey's multiple comparisons test at $P < .05$.

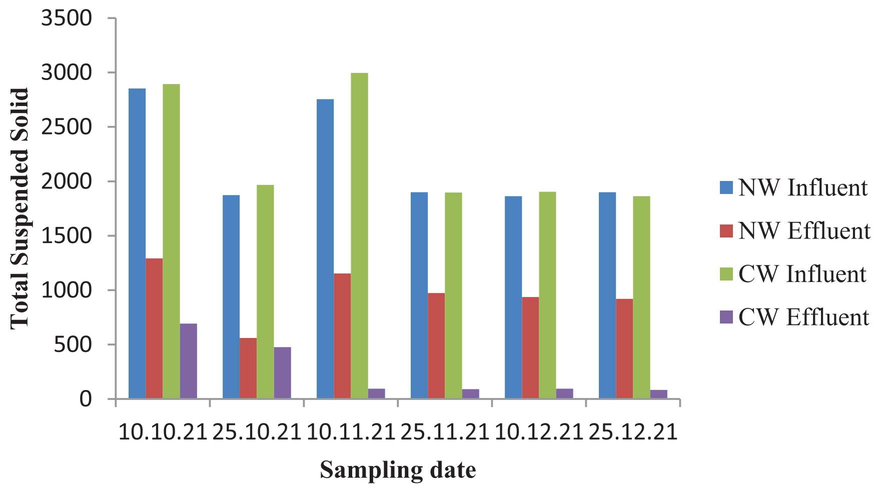

Figure 11. Influent and effluent of TSS in 2 these wetland.
Abbreviations: CW, constructed wetland; NW, natural wetland.

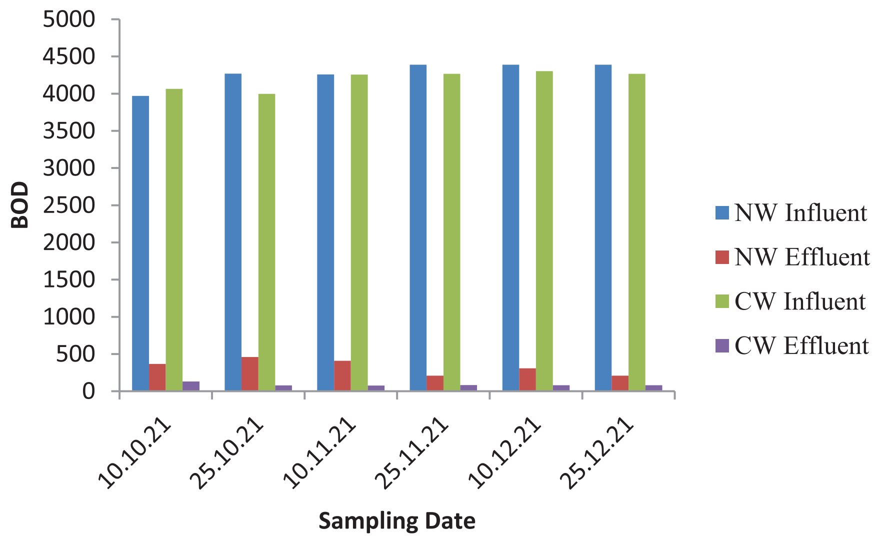

Figure 12. Influent and effluent of BOD in 2 these wetland.
Abbreviations: CW, constructed wetland; NW, natural wetland.

in Pulau Pinang, Malaysia[23] and BOD (1946 mg/l) effluent of coffee reported by Saxena.[32] However, higher than the concentration of BOD (16 mg/l) in a pilot-scale constructed wetland for industrial wastewater treatment at Bahco Argentina,[33] reported by Xu et al[30] BOD (3.61-27.67 mg) in the constructed wetland and BOD (25-49 mg/l) concentration of effluent in Hayatabad Industrial Estate.[34] Those differences might be due to the different types and levels of coffee processing involved in each production plant, the chemicals or additional ingredients used, and how the waste was handled individually in each plant. In both natural and constructed wetland, mean effluents are above the permissible limit set by WHO[35] for irrigation and EEPA[36] standard limits of 80 mg/l for effluent discharge. The reduction in BOD_5 concentration at the outlet can be attributed to the biodegradation of the organic matter by microbial bacteria's in the wetland and the trapping of particulate organic matter by wetland vegetation, which might have also contributed to the decrease in BOD5 concentration in the effluent as the organic matter settle as sediment off the water column.[21] BOD_5 removal efficiency was 92.36% and 97.9% for natural and constructed wetlands, respectively. A Mann-Whitney U test revealed that there is a significance difference in BOD concentration between natural wetlands (median = 2195) and constructed wetlands (median = 630), U = 756.5, z = −1.776, P = .05, r = .187. Because it is easier to administer and regulate a well-designed manufactured wetland, it can perform better than a natural wetland. This is why the constructed wetlands outperformed the natural wetlands.

COD shows the oxygen needs for the chemical oxidation process of organic substances. COD score indicates the number of dissolved organic substances which can be oxidized including all unravel material content.[37] In the present study, COD of influent in natural wetlands fluctuated between 7198

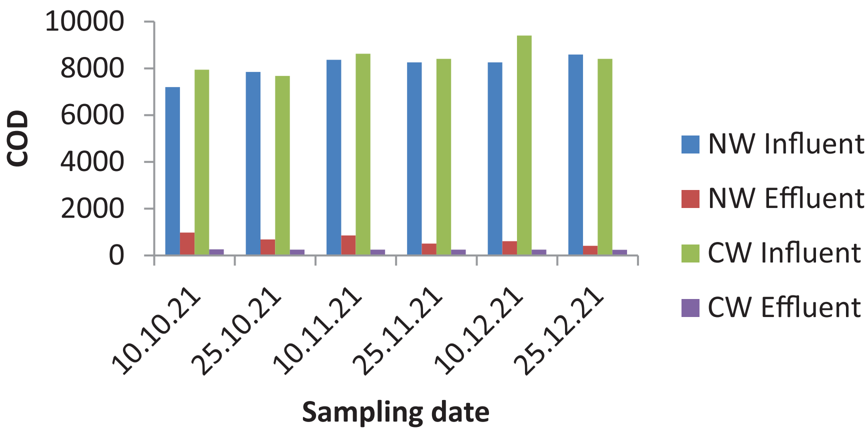

Figure 13. Influent and effluent of COD in 2 these wetland.
Abbreviations: CW, constructed wetland; NW, natural wetland.

and 9210 mg/l with an average of 8085.61 ± 536.99 mg/l. The COD was reduced dramatically in the effluent of the system (Figure 13), which found in the range of 400 to 1000 mg/l with an average effluent of 675.33 ± 201.4 mg/l which is above the national (Ethiopian) effluent direct discharge to rivers. The effluents of COD in natural wetland were lower (9780 mg/l) than reported by Haddis and Devi[5] and reported by Tilahun et al[22] COD (5682.5 ± 304.45). The possible justifications could be different flow velocity, surface area, and microbial activities in the wetland.

Whereas, the mean COD values in the constructed wetlands were found to be 8409.8 ± 592.9, 1372.6 ± 387.94, and 249.0 ± 7.68 for influent, middle, and effluent respectively. COD content of coffee effluent in the constructed wetlands (249.0 ± 7.68) were noticed to be within the EEPA[36] limit value for direct discharge to the river which is less than 250 mg/l. A one-way ANOVA revealed that the mean COD of wastewater at WS4, WS5, and WS7 were statistically significantly different from each other's ($P < .05$). As shown in Table 1, COD in the effluent wastewater (WS7) samples were significantly lower ($P < .05$) than the influent (WS4) of the CW, indicating that the CW has effectively removed the COD from the wastewater.

In the present study, the effluent of COD (249.0 ± 7.68 mg/l) values in the constructed wetland was much higher than what was reported by others researchers such as Terzakis et al[27] who reported COD (44-55.0 mg/l) and Xi[38] who reported COD (197-394 mg/l). But lower than the COD (3260 ± 620 mg/l) reported by Genanaw et al,[25] reported by Said et al[23] concentration of COD (13 000 mg/l) of coffee effluents in Malaysia, reported by Tadesse and Alemayehu[39] COD effluent ranged (1451-2735 mg/l), and COD (7785 mg/l) reported by Saxena.[32] This difference might be due to the chemical composition which will vary from plant to plant from different geographic locations, depending on their age, climate, and soil conditions.[40] The COD removal was approximately 91.65% and 92% in natural and constructed wetlands, respectively. High COD removal efficiency as obtained in this research was mostly caused by sedimentation, filtration, and absorption process. By using bacterial decomposition, sedimentation of particulate matter, and filtering by plant roots, COD was reduced.[6] A Mann-Whitney U test revealed that there is an insignificance difference in COD concentration between natural wetlands (median = 4099) and constructed wetlands (median = 1550), $U = 838$, $z = -1.104$, $P = .27$, $r = .116$. A Mann-Whitney U tests are given in Table 2.

Onsite measurements/Parameter

Physicochemical parameters of samples from the natural and constructed wetlands such as pH, temperature, conductivity, turbidity, and TDS were analyzed immediately after collection (Table 1). The influent and effluent pH values in natural wetlands had the mean value of 4.72 ± 0.27 and 7.12 ± 0.215, respectively. The mean inflow, middle, and effluent pH in constructed wetland were 4.769 ± 0.247, 6.25 ± 0.723, and 6.9 ± 0.914 respectively. A one-way ANOVA revealed a statistically significant difference ($P < .01$) in pH across the constructed wetland sites (WS4, WS5, and WS7). In both wetlands there was an increase in pH of the effluent. This could be attributed to carbon dioxide released from the breaking down of organic wastes by bacteria and organic acids resulting from decaying vegetation.[41] However, the mean effluent of pH values from Natural wetlands (7.12 ± 0.215) and from constructed wetlands (6.9 ± 0.914) were found within EEPA (6-9) for direct discharge to the river and WHO (6.5-9.2) for irrigation.

The mean pH (6.9 ± 0.914 mg/l) of the effluent in the constructed wetlands was comparable to that reported in a prior study, which was pH(7.2 ± 0.3) that used constructed wetlands in the treatment of aerated coffee processing wastewater[42] and pH (6.51-6.85) that used a constructed wetland to treat coffee wastewater.[43] However, the studied effluent had a much higher than coffee effluent (3.37 ± 0.2 mg/l)

Table 2. Mann-Whitney *U* test statistics comparison of natural and constructed wastewater wetland.

	TYPE OF WETLAND	MEDIAN	*U*	*Z*	*R*	*P* VALUE
pH	Natural	5.950	954.50	−0.145	.00153	.885
	Constructed	6.400				
T^0	Natural	23.95	696.0	−2.295	.242	**.022**
	Constructed	23.40				
EC	Natural	312.5	876.5	−0.787	.083	.431
	Constructed	300				
TDS	Natural	157.5	896.50	−0.622	.066	.534
	Constructed	147.50				
Turb	Natural	295	794	−1.468	.155	.142
	Constructed	260				
NH_4+	Natural	0.29	954	−2.148	.226	**.0442**
	Constructed	0.4				
NO_2^-	Natural	0.048	893.5	0.648	.0168	.517
	Constructed	0.046				
NO_3^-	Natural	12.5	872.5	−0.82	.08	.412
	Constructed	11.9				
PO_4^{3-}	Natural	2.5	827.0	−1.195	.126	.232
	Constructed	2.4				
DO	Natural	1.98	737.0	1.937	.204	**.05**
	Constructed	3.30				
TSS	Natural	1551.50	676.5	−2.435	.257	**.015**
	Constructed	922.5				
BOD	Natural	2195	765.5	−1.776	.187	**.05**
	Constructed	630				
COD	Natural	4099	838	−1.104	.116	.27
	Constructed	1550				

Mann-Whitney *U* test statistics shown in bold are significant at $P < .05$.

studied by other researchers[25] and the treated effluent of pH (4.82 and 5.29) conducted in coffee processing plants, case of coffee processing in Burundi.[44] The low pH of the effluent in previous research could be attributed to a variety of issues, including poor construction design, plant and substrate type, hydraulic retention time and rate, flow rate, and other factors. To evaluate the difference between natural and constructed wetlands regarding pH testing using the Mann-Whitney *U* test, the test revealed that the median pH value of the natural wetland (median = 5.95) and the constructed wetland (median = 6.4), $U = 954.50$, $z = -0.145$, $P = .85$, $r = .001528$, which shows no significant difference between the 2 wetland types (Table 2).

The mean inflow and effluent value for temperature in the natural wetlands had 24.29 ± 0.55and, 23.30 ± 0.49, respectively, whereas, in the constructed wetlands the mean temperature in the influent wetland (WS4) was 24.26 ± 0.51, while at the middle wetland (WS5) and effluent wetland (WS7) it was 23.31 ± 0.35 and 21.36 ± 1.26 respectively. One way ANOVA revealed that there was a significant difference in temperature along the constructed wetland sites. These values were below the permissible limit recommendation by the national (Ethiopian) effluent direct discharge to rivers which is (40°C). Decrease in temperature in the effluent of wetlands could be attributed to the shady effect of wetland vegetation and decreased organic matter concentration[21] and naturally, a local weather change could also be another reason. A Mann-Whitney *U* test revealed that temperatures were significantly lower in the constructed wetlands (median = 23.40) compared to natural wetlands (median = 23.95), $U = 696.0$, $z = -2.295$, $P = .022$, $r = .242$.

The mean influent and effluent conductivity values in natural wetland were 363.78 ± 66.81 mg/l and 245.83 ± 105.4 mg/l, respectively. The mean influent (WS4), middle wetland (WS5), and effluent (WS7) conductivity values were 370.67 ± 67.32, 269.44 ± 117.93, and 224.83 ± 57.35 respectively. The data analysis revealed that the mean concentration of WS4 and WS5, and WS4 and WS7were differed by statistically significant ($P < .01$). However, there was no statistically significant difference in WS5 between and WS7 ($P > .05$). Variation of EC in the wetland sites can be attributed to the physico-chemical processes occurring there, which include removal of ions through sedimentation, precipitation, adsorption, and uptake by aquatic plants. These values are below the permissible limit endorsed by WHO[35] (500 µs/cm) for irrigation and EEPA[36] (1000 µs/cm) for direct discharge to rivers. Decrease in the conductivity level after the wetland could be attributed to decrease in the concentration of TDS and TSS and the conversion of NO_3-N into diatomic molecular nitrogen (N_2) as the concentration of charged ions decreases.[21] A Mann-Whitney *U* test revealed that there is an insignificance difference in conductivity between natural wetlands (median = 312) and constructed wetlands (median = 300), $U = 876.50$, $z = -0.787$, $P = .431$, $r = .083$.

The mean TDS level in natural wetland influent and effluent was 189.78 ± 48.7 mg/l and 123.06 ± 52.36 mg/l, respectively. While in the constructed wetlands the mean TDS at the influent wetland was 187.61 ± 36.66 mg/l, while at the middle wetland (WS5) and effluent wetland (WS7) it was 128.72 ± 57.63 mg/l and 119.89 ± 43.09 mg/l, respectively. The decrease in TDS observed in the effluent of the 2 wetlands could be attributable to solid deposition caused by the slower water speed as it passes through the wetland, as well as the uptake of some of the dissolved solids by wetland plants and could be ascribed to the presence of organic matter to decaying of plant and animal remains solids and ions deposition in wetland.[21] The high values of TDS can be toxic to fresh water animals causing osmotic stress and can give increase to obnoxious odors from the decay of organic matter and vulgar smell.[24,45] The results show that the efficiency of TDS was noted with 35.16% and 36.1% removal efficiency in natural and constructed wetlands, respectively. A Mann-Whitney *U* test revealed that there is insignificance difference in TDS value between natural wetland (median = 157.5) and constructed wetland (median = 147.50), $U = 896.50$, $z = -0.622$, $P = .534$, $r = .066$ (Table 2).

During the present study, the influent turbidity value in the natural wetlands ranged between 200.0 and 812.0 NTU, while that of the effluent ranged between 15.0 and 750 NTU with mean values of 386.83 ± 194.69 NTU and 226.19 ± 191.98 NTU at the influent and effluent, respectively. However, the influent ranged between 114 and 700 NTU in the constructed wetland, while the outlet ranged between 15 and 410 NTU, with mean values of 343.72165 and 138.94148.25 NTU at the inlet and outlet, respectively. Turbidity values in the effluent(138.94 ± 148.25) of the constructed wetlands were found to be lower (378 ± 102.8) than the effluent reported by[25] in Bokaso coffee processing plant effluent and turbidity in coffee wastewater might be attributable to a variety of solid by-products such as coffee pulp, skin, parchment, and bean. A mean reduction in turbidity was obtained with a removal efficiency of 41.53% and 59.6% in natural and constructed wetlands, respectively. A Mann-Whitney *U* test revealed that there is an insignificance difference in turbidity value between natural wetlands (median = 295) and constructed wetlands (median = 260), $U = 794$, $z = -1.468$, $P = .142$, $r = .155$.

Nutrients (NH_4^+, NO_2^-, NO_3^-, $PO4_3^-$) and DO

The mean Ammonium (NH_4^+) concentration in natural wetland was 0.86 ± 0.71 mg/l and 0.52 ± 0.59 mg/l in the influent and effluent, respectively. While in constructed wetland the ammonium concentration was 0.88 ± 0.715 mg/l, 0.968 ± 1.095 mg/l, and 1.13 ± 1.578 mg/l in the influent, middle, and effluent, respectively. The mean effluent of Ammonium (NH_4^+) concentration from Natural wetland (0.52 ± 0.59 mg/l) were found within the national (Ethiopian) effluent discharge to rivers which is (⩽1 mg/l) .However, the mean effluent in constructed wetland was above the standard discharge limit for rivers. The results show that the mean effluent (0.52 ± 0.59 mg/l) of natural wetlands was lower (4.99 ± 0.36 ppm) than that reported by Mosissa et al[46] and reported by Bisekwa et al[47] with a mean of 5.55 ± 2.23 mg/l. This might be due to previous studies where wastewater effluents released without any treatment.

The mean concentrations of NH_4 were increased in the effluent (WS7), but the variation was non-significant. The enrichment of NH_4 in constructed wetland systems occurs for a variety of reasons, including the following: The process of ammonification produces ammonia from organic nitrogen in the effluent. Both anaerobic and aerobic conditions can support this activity. In the wetland system, ammonification occurred due to anaerobic conditions. As opposed to this, an aerobic environment controls the nitrification process. In an oxic circumstance, the availability of inorganic carbon and NH_4, as well as temperature and pH ranges of 30°C to 40°C and 7.5 to 8.0, respectively, enhance nitrification rates in wetlands. It was warm enough for cultivated plants to develop quickly. As a result, nitrogen transformation from NH_4 to NO_3-N was completely inhibited due to the lack of nitrification process.[30] Ammonium is a critical parameter for fish in aquaculture due to its toxicity and it can eventually cause cell death in the central nervous system when it is in high concentration.[48] The removal efficiency of ammonium was 39.53% in the natural wetland, whereas in the constructed wetlands it was −28.41%, with a little enlargement of ammonium during the flow through the constructed wetland. A Mann-Whitney U test revealed that there is a significance difference in ammonium concentration between natural wetlands (median = 0.29) and constructed wetlands (median = 0.4), U = 954, z = −2.148, P = .0442, r = .226.

Nitrite (NO_2^-) concentrations were a mean of 0.18 ± 0.262 mg/l in the influent of natural wetland, whereas in the effluent, nitrite concentrations were a mean 0.037 ± 0.014 mg/l. The mean nitrite concentration in the influent of a constructed wetland was 0.287 ± 0.407 mg/l, whereas the nitrite concentration in the middle constructed wetland was 0.203 ± 0.243 mg/l and the effluents were 0.128 ± 0.164 mg/l. One way ANOVA revealed that there was no statistically significant difference in nitrite between WS4, WS5, and WS7 (P > .05).

The results show that the mean effluents (0.037 ± 0.014 mg/l) of nitrite in the natural wetlands of the current study were comparable (0.001-0.121 mg/l) with what was reported by Xu et al[30] in natural wetland. But lower (0.6 ± 0.1 mg/l) than reported by Bisekwa et al[24] at Kayanza Wet Coffee Processing Plant. The mean nitrite concentrations of the effluent (0.128 ± 0.164 mg/l) found in the constructed wetlands of this study were comparable with those reported by Hadad et al[33] who reported nitrite concentration (0.13 mg/l)[5] and reported by Xu et al[30] nitrite concentration (0.028-0.443 mg/l) in constructed wetland. The removal efficiencies of nitrite were 79.44% and 55.4% in natural and constructed wetlands, respectively. The nitrite values of the samples from all sites were below the recommended WHO[35] standards. A Mann-Whitney U test revealed that there is insignificance difference in nitrite between natural wetland (median = 0.048) and constructed wetland (median = 0.046), U = 893.5, z = −0.648, P = .517, r = .0168.

Organic nitrogen in wastewater was transformed into ammonia by oxidative decomposition under the action of microorganisms and then the ammonia was further removed through nitrification and denitrification processes.[30] Despite this, the nitrate content increased. The mean nitrate concentration in the influent of a natural wetland was 33.05 ± 24.21 mg/l, whereas the nitrates concentrations in the effluent were 10.28 ± 3.168. However, the mean nitrate concentration in the influent of a constructed wetland was 33.99 ± 25.29 mg/l, whereas the nitrate concentration in the middle constructed wetland was 22.24 ± 22.30 mg/l and the effluents were 13.38 ± 20.58 mg/l. The mean nitrate concentrations in wastewater WS4 and WS7 differed statistically significantly (P < .05) according to a one-way ANOVA. However, there were no statistically significant differences between WS4 and WS5 (P > .05), as well as WS5 and WS6 (P > .05). The mean effluent of nitrate concentration in each wetland was found to be higher than Ethiopia's (<10 mg/l) national effluent discharge to rivers.

The mean effluents (10.28 ± 3.168 mg/l) of nitrate in the natural wetlands in the present study were higher (3.39 ± 0.65) than reported by Tilahun et al[22] and reported by Xu et al[30] nitrate concentration (0.091-4.75 mg L), reported by Sileshi et al[49] nitrate concentration (0.26-1.11 mg/l), and reported by Dendup et al[50] nitrate concentration (0.7-1.5 ± 0.26 mg/l) in natural wetland. The disparity might be explained by variations in the treatment's removal efficiency of the natural wetlands. The mean effluent nitrate values (13.38 ± 20.58 mg/l) found in the constructed wetlands of the present study were comparable with those reported by Bisekwa et al[24] nitrate (12.6 ± 2.9 to 27.4 ± 3.8 mg/l).However, lower (49.8 ± 12.4) than reported by Genanaw et al[25] in constructed wetland at Bokaso coffee processing plant. But higher than that reported by Hadad et al,[33] who reported a nitrate(1.45 mg/l) content, reported by Tilahun et al[22] nitrate concentration (2.04 ± 0.34 mg/l), and reported by Xu et al[30] nitrate concentration (0.54-2.13 mg/l) in constructed wetland. The difference could be attributed to differences in the treatment's removal efficacy. The mean removal efficiencies of nitrate were 68.9% and 60.6% in natural and constructed wetlands, respectively. Decrease in nitrate concentration recorded in the wetland effluent could be attributed to denitrification where nitrate is converted to diatomic molecular nitrogen, deposition of nitrate in sediments at the wetland bottom and plant uptake.[21] The nitrate concentration level was above the Ethiopian standards,[36] which indicated that the wet coffee processing factories effluents contribute to the pollution of the receiving water bodies. A Mann-Whitney U test revealed that there is insignificance difference of nitrate between natural wetlands (median = 12.5) and constructed wetlands (median = 11.9), U = 872.5, z = −0.82, P = .412, r = .08.

The mean phosphate concentrations in the influent and effluent of natural wetlands were 3.66 ± 0.75 mg/l and 2.08 ± 0.42 mg/l, respectively. The mean phosphate concentrations in the constructed wetland's influent, middle, and effluent were 3.78 ± 0.87 mg/l, 2.45 ± 0.624, and 1.56 ± 0.621 mg/l, respectively. The concentration level of phosphate in the coffee wastewater of constructed wetland sites was found to be statistically significant (P < .05). The mean effluent of phosphate concentration in the natural and constructed wetlands was found to be below Ethiopia's (10 mg/l) national effluent discharge to rivers.

The current finding found in the discharge of wastewater (2.08 ± 0.42 mg/l) in natural wetlands was comparable (3.32 ± 0.5 mg/l) with reported by Tilahun et al.[22] However, much higher (0.047-0.26 mg/l) than reported by Xu et al,[30] reported by Sileshi et al[49] phosphate concentration (0.67 ± 0.52 mg/l), reported by Bisekwa et al[47] phosphate concentration (0.78 ± 0.34 mg/l), and reported by Dendup et al[50] phosphate concentration (0.56 to 0.81 ± 0.07 mg/l) in natural wetland. The findings of the present study were lower

(4.6 mg/l) than what was reported by Haddis and Devi.[5] This difference might be due to the complex combination of physical, chemical, and biological processes involving mainly adsorption, precipitation, sedimentation in the pores of the substrate media, peat accretion and burial, and to a lesser extent biomass uptake.[51]

The mean phosphate wastewater discharged (1.56 ± 0.621 mg/l) in the constructed wetlands of the present study was lower (3.9 mg/l) than those reported by Saxena[32] in the effluent Treatment Plant of an Instant Coffee Production Unit in India,[32] reported by Said et al[23] phosphate (12.2 mg/l) from a coffee processing plant in Pulau Pinang, Malaysia[23] and Genanaw et al[25] phosphate (20 ± 3.2 mg/l) coffee processing plant in Sidama Region, Ethiopia. However, the effluent from the constructed wetland was comparable with (2.26 ± 0.68) reported by Tilahun et al[22] and reported by Xu et al[30] who reported phosphate concentration was (0.41-2.13 mg/l). The difference could be attributed to differences in the treatment's removal efficacy. Phosphorus removal mechanism in wetlands includes filler adsorption, plant uptake, and microbial assimilation. Bacteria and algae containing wetlands is another factor for excess phosphorus removed from the effluent. Sedimentation of organic matter and incorporation into biomass by the macrophytes might cause this effect.[30] In both wetlands, phosphate concentrations of the effluent do not appear to pose any threat to the receiving water bodies according to EEPA.[36] As a result, the receiving water bodies were not altered or polluted by this characteristic. Average removal efficiencies of phosphate were 43.17% and 58.7% in natural and constructed wetlands, respectively. The plants' uptake of phosphate in both wetland effluents or some of it being deposited in the wetland bottom sediments and adsorption are 2 possible explanations for the lower concentration of phosphate.[21] Phosphate concentrations greater than 5 mg/l are attributed to human activities and contamination rise to excessive growth of algae[36] and the presence of $PO4^{3-}$ in water increases eutrophication and similarly promotes the growth of algae.[47] A Mann-Whitney U test revealed that there is no significance difference in phosphate concentration between natural wetlands (median = 2.5) and constructed wetlands (median = 2.4), $U = 827.0$, $z = -1.195$, $P = .232$, $r = .126$.

In both wetlands, the finding of the present study show an increasing range of dissolved oxygen in the effluent compared to influent. The increase in the level of dissolved oxygen at the outlet could be attributed to photosynthesis and biodegradation of compounds present in the wastewater that previously used dissolved oxygen for various oxidation-reduction reactions and thus the release of oxygen through roots into the rhizosphere.[21] In the present finding, the mean level of dissolved oxygen in natural wetlands was 0.513 ± 0.039 mg/l in influent, while that of the effluent was 3.67 ± 0.19 mg/l. The mean DO (3.67 ± 0.19 mg/l) effluent from natural wetland was comparable to (2.14 ± 0.72) reported by Tilahun et al[22] and reported by Sileshi et al[49] DO (3.12 ± 1.24 mg/l) in Boye natural wetland. However, higher than the mean DO (1.9 mg/l) Tibia Wetland in Treatment of Wastewater.[21] Lower DO concentrations in the outflow of the previous study might be due to higher microbial activity in the water due to the presence of biodegradable organic compounds.[50] Moreover, increased nutrient loading can be one of the reasons for the depletion of dissolved oxygen at the wetland outflow.[52]

Dissolved oxygen concentration at the influent of the constructed wetland was 0.54 ± 0.056 mg/l, at the middle wetland it was 3.263 ± 0.694 mg/l and at the effluent 4.56 ± 1.011 mg/l. A one-way ANOVA revealed that the mean DO of wastewater from WS4, WS5, and WS7 were statistically significantly different from each other's ($P < .01$). In the present study, the mean DO (4.56 ± 1.011 mg/l) of effluent in the constructed wetlands was comparable (4.38 ± 0.63 mg/l) with reported by Tilahun et al[22] in constructed wetland. But, it is much higher than coffee effluents (0.9 ± 0.46 mg/l) reported by Genanaw et al.[25] The difference might be due to poor construction design, plant and substrate type, hydraulic retention duration and rate, flow rate, and other variables.[25] The photosynthetic activities in plants increase the DO in water, thus creating aerobic conditions in the system, which also favors the aerobic bacterial activity to reduce BOD.[53] An increase in DO facilitates the oxidation process within the wetland system.[54] In the planted wetland, the effect of the root zone might have enhanced the concentration of DO. In addition to this, increase DO level in the effluent of the constructed wetlands might be related to the removal of organic substances through the various means.[52] The DO standard for sustaining aquatic life is set at 5 mg/l, and any concentration below this number has negative consequences for aquatic life.[26] All sample sites from the coffee processing plant had mean DO concentrations of less than 5 mg/l, discharging those effluents into rivers, as a result, would be harmful to aquatic life's survival. This study is in agreement with the study done previously[22,49] who reported DO concentrations less than 5 mg/l. A Mann-Whitney U test revealed that dissolved oxygen were significantly lower in natural wetlands (median = 1.98) compared to the constructed wetlands (median = 3.30), $U = 737.0$, $z = -1.937$, $P = .05$, $r = 0204$.

Limitations of the study

The limitation of this study includes non-consideration control group.

Conclusions

Measurements of physicochemical sampling were taken from the coffee processing wastewater samples using standard procedures. Findings indicate that the mean concentrations of TSS, BOD, and COD in water showed significant and reduced dramatically in the effluent of natural and constructed wetland .However, the mean nitrate, TSS, and BOD values of the effluent of the 2 wetlands were above the EPA and Ethiopian effluent allowable discharge limits into inland surface waters. Parameters which meet the regulation in natural and constructed wetlands were pH, temperature, EC, TDS, sulfate, and phosphate. Comparatively, the purification efficiency of organic pollutants (TSS, BOD, and COD) of constructed wetlands was better than natural wetlands, because constructed wetland systems are designed specifically for wastewater treatment, they work more efficiently than natural wetlands. Whereas regarding nitrogen compounds such as ammonium, nitrite, and nitrate, natural wetlands had better purification efficiency.

Except for ammonium and nitrite, the mean concentrations of other parameters such as TSS, BOD, COD, nitrate, phosphate, sulfate, DO, turbidity, TDS, and EC in the constructed wetland outlet (WS7) were significantly lower than in the inlet (WS4).

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Author Contributions

YSB, SSS, and MDU has conceived, designed the experiment and analyzed the data. YSB and EMB has performed the experiments. YSB has prepared the figures and tables. All authors drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Supplemental material

Supplemental material for this article is available online.

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