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The impact of traditional coffee processing on river water quality in Ethiopia and the urgency of adopting sound environmental practices

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Abstract Although waste from coffee processing is a valuable resource to make biogas, compost, and nutrient-rich animal food, it is usually dumped into nearby water courses. We carried out water quality assessment at 44 sampling sites along 18 rivers that receive untreated waste from 23 coffee pulping and processing plants in Jimma Zone, Ethiopia. Twenty upstream sampling sites free from coffee waste impact served as control, and 24 downstream sampling sites affected by coffee waste were selected for comparison. Physicochemical and biological results revealed a significant river water quality deterioration as a result of disposing untreated coffee waste into running water courses. During coffee-processing (wet) season, the highest organic load (1,900 mg/l), measured as biochemical oxygen demand, depleted dissolved oxygen (DO) to a level less than 0.01 mg/l, and thus curtailed nitrification. During off season, oxygen started to recuperate and augmented nitrification. The shift from significantly elevated organic load and reduced DO in the wet season to increased nitrate in the off season was found to be the determining factor for the difference in macroinvertebrate community structure as verified by ordination analysis. Macroinvertebrate diversity was significantly reduced in impacted sites during the wet season contrary to the off season. However, there was a significant difference in the ratio of sensitive to pollution-tolerant taxa in the off season, which remained

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depreciated in the longer term. This study highlights the urgency of research exploring on the feasibility of adopting appropriate pollution abatement technologies to implement ecologically sound coffee-processing systems in coffee-growing regions of Ethiopia.

Keywords Coffee processing · Waste · River pollution · Macroinvertebrates · Ethiopia

Introduction

Ethiopia is the origin of highland coffee (*Coffea arabica* Linnaeus) plant earlier known as *Jasminum arabicum laurifolia* Jussieu. This coffee tree species, the only native coffee in the world, has traditionally been tended and harvested as a wild tree in the highland forests of southwestern Ethiopia (Schmitt 2006), mostly in the former Kaffa Province (now part of Oromia Administrative Region). In Ethiopia, coffee trees are increasingly grown in plantations or planted in forests to meet the growing demand domestically and for export, with coffee constituting the major export items. Ethiopia is the largest coffee producer in Africa and one of the largest in the world, owning unique and world-renowned coffees (Petit 2007). The economy of Jimma Zone and Jimma Town, the former capital of Kaffa Province, largely depends on coffee production.

Several studies reported that untreated waste from traditional and modern processing industries is threatening surface waters worldwide and severe in developing countries (Joshi and Sukumaran 1991; Beyene et al. 2009a; b). Water pollution is the gloomy setback for development in coffee producing countries (e.g., Joshi and Sukumaran 1991; Mwaura and Mburu 1998), and this also appears to be the case in Ethiopia (Haddis and Devi 2008). Although traditional shedding coffee systems, which have social and economic value with minimal impact on biodiversity and environment (Perfecto et al. 1996; López-Gómez et al. 2008) prevail in Jimma Zone, untreated waste materials from coffee processing are routinely discharged into local streams and rivers. Coffee processing is vilified for the production of byproducts such as parchment husks, coffee pulp, and coffee husks all of which contribute to environmental pollution unless treated or recycled (Mburu and Mwaura 1996).

The wet coffee-processing method, commonly used in Jimma Zone, requires huge amounts of water to remove the coffee pulp mechanically resulting in the production of considerable quantities of wastewater with high levels of organic matter. The effluent from 1 ton of parchment coffee processed following the wet-processing method often generate a biochemical oxygen demand (BOD) comparable to the BOD of the human waste that can be generated by 2,000 people per day (Mburu et al. 1994). In Kenya, the coffee-processing plant effluent BOD ranged from 1,800 to 9,000 mg/l for pulping waters and 1,200 to 3,000 mg/l for fermentation and washing water depending on the volumes of water used (Mburu et al. 1994). Coffee wastewater unless treated, pollutes water sources, damages aquatic ecosystems, and threats the health of nearby residents and wildlife which offsets the economic benefits accrued from coffee production.

Few studies on the impacts of coffee waste have been documented in the coffee-producing regions such as Ethiopia. These studies were based merely on the physicochemical parameters measured at one point in time at few coffee-processing plants during one season (Mwaura and Mburu 1998; Haddis and Devi 2008). Coffee processing is a seasonal agricultural activity, but it is not known whether rivers fully purify themselves during the off season. A study on the effect of wet processing of coffee on river water quality in Kenya concluded that water pollution in coffee-growing regions is rampant and called for an environmental impact assessment before expanding coffee-processing facilities (Mwaura and Mburu 1998). Haddis and Devi (2008) assessed the effect of effluent generated from coffee-processing plant on water bodies and human health in its vicinity and indicated that it caused severe water pollution and illnesses like skin irritation, stomach problem, breathing difficulties, and nausea among downstream users. This study aims to establish the effect of coffee-processing waste on the physicochemical and biological integrity of rivers found in the coffee producing regions of Jimma Zone and to suggest remedial actions to avert possible environmental damage and associated public health problems.

In this study, we used both physicochemical and biological parameters, which are powerful indicators of the overall ecological integrity of water bodies (Cairns 1995; Fore et al. 1996). This is the most extensive study in Ethiopia to date, covering 23 traditional coffee-processing plants disposing their untreated waste into 18 rivers. Upstream sampling sites without coffee effluent as control and downstream sites impacted by coffee waste were selected for comparison to test the hypothesis that coffee impact is a severe threat to water quality and the aquatic environment which might seriously affect agriculture, human health, and wildlife. The major processes affecting the aquatic life as a result of disposing untreated coffee waste were conceptualized in a simple schematic model, which provides a basis for appropriate remedial actions. Seasonal changes between the peak coffee-processing period, during the end of major rainy season in late October 2007 and the off season before the onset of little rain in March 2008 also examined in this study to determine whether rivers recovered from coffee waste impacts by self purification.

Materials and methods

Study area and sampling sites

The study area is located in Mana and Gomma *Wereda* (District) in Jimma Zone (Fig. 1) and is known for growing coffee. It is located 390 km southwest of Addis Ababa and about 50 km northwest of Jimma Town. Agroecologically, Jimma Zone is classified as 96% wet midland and 4% lowland with altitudes ranging from 1,387 to 2,870 m.a.s.l.

To differentiate between rainy and dry months, we calculated the rainfall coefficient (RC) of each month in all station based on a 40-years (1967–2008) rainfall data (unpublished data from Ethiopian National Meteorological Agency). The rainfall coefficient is the ratio of mean monthly rainfall to one twelfth of the annual mean (Fournier 1960). A month is distinguished as dry and rainy month when the corresponding monthly rainfall coefficient reaches less than or equal to 0.6 and greater than 0.6, respectively. Gemechu (1977) classified rainy months of Ethiopia into small rains (0.6 to 0.9) and big rains (1.0 and above). The big rainy months are further classified into three periods of moderate rainfall (1.0 to 1.9), high rainfall (2.0 to 2.9), and very high rainfall (3.0 and above). Based on 40 years (1967–2008) of rainfall data, rainfall in Jimma Zone is unimodal. The wet season starts in March and ends in October and the rest of the months of the year are characterized as dry. The big rainfall starts in May and ends in October.

The three dominant soil types in Jimma Zone are eutric vertisols, humic acrisols, and humic nitosols, of which nitosols are the most abundant covering about 90% of the total area. Soluble salts, calcium, and magnesium carbonates and their combination, sodium chloride, and calcium sulfate, occur in relatively large quantities in rocks. As a result, they are the most

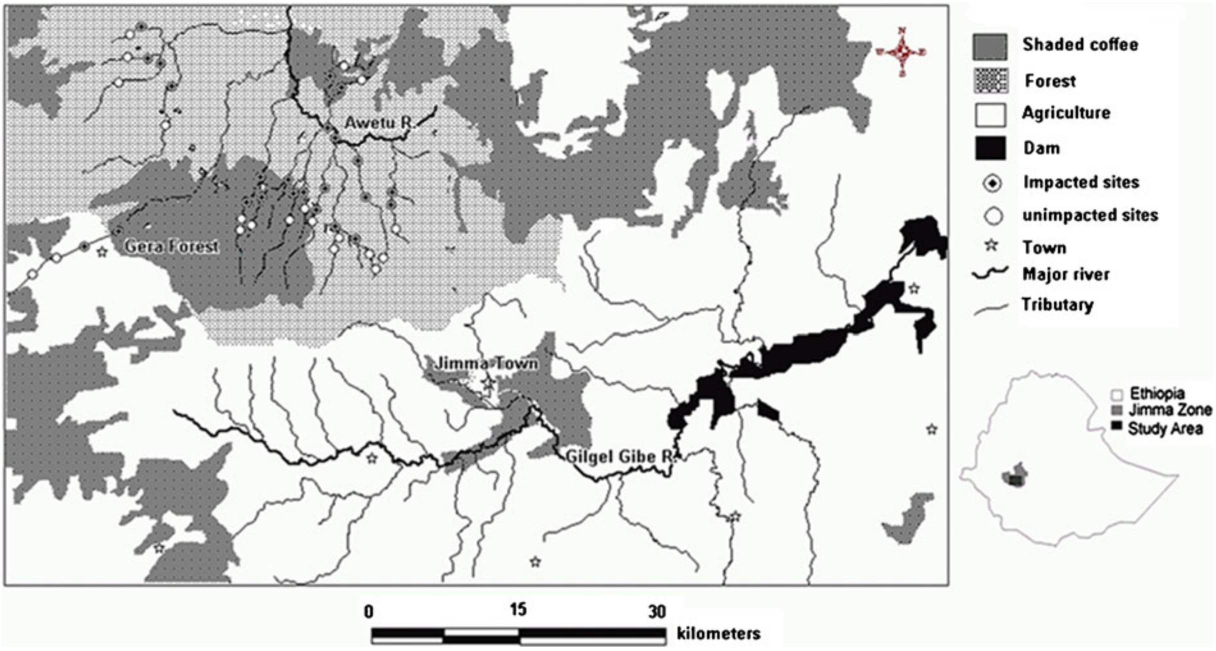

Fig. 1 Vegetation cover, land use, drainage, and sampling points of the studied area

common major ions in most natural waters. The major ions of Jimma Zone are characterized by $Ca(HCO_3)_2$ water type (unpublished data of the Ethiopian Ministry of Water Resources).

The rivers in Jimma zone that receive untreated coffee waste were included in this study. These include the headwaters of the Nile and Omo-Gibe Basins. It is impossible to select aquatic sampling sites in the field that are similar in all aspects and that can be divided into control and experimental groups, but this problem can be solved by choosing adjacent sites on the same streams or rivers that permit upstream and downstream comparisons. Based on this approach, an array of 20 sampling sites free from coffee waste impact was selected in the upstream site of the rivers, hereafter called unimpacted sites. The second group (24 sampling sites) which was affected directly or indirectly by coffee-processing waste is considered as impacted sites. Generally, riffle communities of streams are more diverse in invertebrate forms than pools (Beyene et al. 2009b). Based on these findings, we selected a total of 44 riffle sampling sites with a homogenous habitat for water and macroinvertebrate sampling. Two sampling sites were dry during the 2008 dry season sampling and were not sampled.

Sampling technique, variables, and their measurements

Both biological and water sampling was done immediately after the big rainy season in October 2007 and at the end of the dry season in March 2008. Sampling on rivers should, as a general rule, be established at places where the water is sufficiently mixed for only a single sample to be required. Sampling at 3–5 points is usually sufficient, and fewer points are needed for narrow and shallow rivers and streams (Bartram and Ballance 1996). Consequently, we employed a composite sampling technique to take water samples at three sampling points across the width of the rivers for chemical analysis. Both the filtered and unfiltered water samples were kept in a chilled ice chest during transport and refrigerated in the laboratory of the School of Environmental Health, Jimma University until they were analyzed. Environmental variables, ammonia, nitrate, soluble reactive phosphorous (SRP), biochemical oxygen demand (BOD), and total suspended solids (TSS) were measured using indophenol blue, cadmium reduction, ascorbic acid, iodometric titration, and gravimetric methods, respectively following APHA (2005). In situ measurements of total dissolved solids (TDS), dissolved oxygen (DO), and both water temperature and pH were measured using HACH Pocket Pal TDS Tester (Model 10-1990 TDS), dissolved oxygen meter (Model HI-9143), and pH/mV/thermometer (Model HI 8424NEW), respectively.

Although no one sampling method will provide enough information to reflect the actual biological community, which exists at the sampling site, the Kick-Net method can be used to obtain samples of the macroinvertebrates from riffle type habitat communities in shallow rivers (Hornig and Pollard 1978; Davies 2001; Ostermiller and Hawkins 2003; Beyene et al. 2009a; b). As described by Hornig and Pollard (1978), Davies (2001) and Beyene et al. (2009b), a 100-m stretch was representative of the rivers sampling in riffle area. These areas of the stream comprised of cobble/gravel substrate with fast current, shallow water (usually less than 8 in. in depth) and non-laminar flow were selected.

Collections of macroinvertebrates from more than one habitat type may introduce variation that can potentially mask water quality differences among sites (Ostermiller and Hawkins 2003; Beyene et al. 2009b). Therefore, to minimize this variation, all samples were collected from the same habitat types of riffle zones of streams in areas where there was the best canopy coverage and side bank macrovegetation. Macroinvertebrates were collected and processed using a standardized method devised by Ostermiller and Hawkins (2003) and strictly followed as described by Beyene et al. (2009b).

Data analysis

Relationships between the environmental data and taxa abundance or community metrics were assessed using canonical multivariate analysis. To explore the response of macroinvertebrates, a Detrended Correspondence Analysis (DCA) on the abundance data were performed. This preliminary analysis of the metric data indicated that the lengths of the gradients were long (i.e., >2 standard deviations). Taxa abundances exhibit unimodal responses to environmental gradients (Jongman et al. 1995); hence, we performed Canonical Correspondence Analysis (CCA) (ter Braak and Smilauer 2002). Environmental variables and macroinvertebrate abundance data were square root transformed prior to statistical analysis to normalize and stabilize the variance. The CANOCO software package, Version 4.5, the algorithm for CCA in CANOCO was used to standardize the environmental data to a mean of 0 and standard deviation of 1 to remove the effect of differences in measurement units among the environmental variables. Correlations of the environmental variables with the significant axes were carried out to determine those environmental variables that were significantly correlated with the axes (Jongman et al. 1995). BioDiversity Pro. (1997) NHM and SAMS, version 2 was used to calculate invertebrate indices. Mann–Whitney *U* test using STATISTICA StatSoft, Inc. 2007, version 8.0 was applied for both physicochemical variables and macroinvertebrate indices to test the difference between impacted and unimpacted sites.

Results

Physicochemical characteristics of the rivers

Although the physicochemical parameters varied among the rivers, the major difference was observed between impacted and unimpacted sites (Table 1). The minimum BOD (0.5 mg/l) and the maximum BOD (1,900 mg/l) were respectively measured at upstream sites which are free from coffee waste impact and downstream sites receiving coffee effluent in the 2007 sampling campaign (Table 1). Consequently, DO was depleted below 0.01 mg/l at the impacted sites (Table 1). Based on the average values, a significant improvement was observed at all impacted sites as we compared the peak coffee-processing season in 2007 and with off season in 2008. For instance, 24-fold reduction in BOD values were measured. A similar trend was also observed for DO but at two sampling sites free from coffee waste inside the Gera Forest, DO<5.0 mg/l was measured in both sampling seasons (Table 1). The other most important parameter associated with coffee waste was nitrate, which showed similar trend with BOD at the impacted sites and had higher nitrate content than unimpacted sites. Nitrate was significantly elevated during the off season in 2008 than peak coffee-processing season in 2007 (Table 1).

The major processes affecting the amount of DO in streams and rivers in the study area as a result of rampant dumping of untreated coffee wastes is presented in a conceptual model (Fig. 2). During peak coffee-processing season, the disposed untreated coffee waste consumed DO as result of high decomposition, which created anoxic condition and curtailed nitrification. During off season, oxygen started to recuperate and augmented nitrification (Table 1).

Coffee waste is known to lower the pH, and acidic waters (pH=4.5) were recorded during the peak coffee-processing season in 2007 (Table 1). TSS, TDS, and SRP were also significantly higher ($p<0.05$) at impacted sites than unimpacted sites. Based on the average values presented in Table 1, nitrate, ammonia, pH, and TDS were within the range of the permissible limits to protect aquatic life only at

Table 1 The range and average values (brackets) of the physicochemical characteristics for sampling sites impacted by coffee-processing waste versus unimpacted sites during 2007 and 2008 sampling periods

	Sampling in 2007 (wet season)			Sampling in 2008 (dry season)			
Parameter	Unimpacted	Impacted	*P* value	Unimpacted	Impacted	*P* value	MPL
BOD (mg/l)	0.5–270 (31)	2–1,900 (436)	0.000	0.9–170 (13)	1–150 (18)	0.194	<3.0
DO (mg/l)	5.0–7.2 (6.2)	<0.01–7.0 (5.2)	0.047	4.4–7.8 (6.3)	5.0–7.0 (6.2)	0.548	>7.0
TDS (mg/l)	50–195 (117)	50–315 (170)	0.119	15–145 (101)	40–280 (120)	0.381	<500
TSS (mg/l)	16–600 (192)	142–970 (598)	0.002	30–482 (152)	60–314 (158)	0.525	<80
pH	6.6–7.3 (7.0)	4.6–7.4 (6.2)	0.251	6.5–8.0 (7.2)	6.0–8.0 (7.1)	0.559	6.5–9.0
Nitrate (mg/l)	0.9–2.5 (1.5)	6.1–12.4 (6.8)	0.006	1.6–4.2 (3.1)	10.0–26.1 (14)	0.000	<10.0
Ammonia (mg/l)	0.2–0.5 (0.3)	5.0–30.0 (11)	0.000	0.001–0.15 (0.03)	0.1–19.0 (4.0)	0.000	<1.0
SRP (μg/l)	6–26 (14)	2–48 (19)	0.380	71–338 (145)	46–998 (261)	0.022	<50

The maximum permissible limits (MPL) to protect aquatic life in rivers were compiled from Chave (2001) and EPA (1986). Below detection limit (DO<0.01 mg/l) and in this case, the value 0.01 mg/l was used for the statistical test

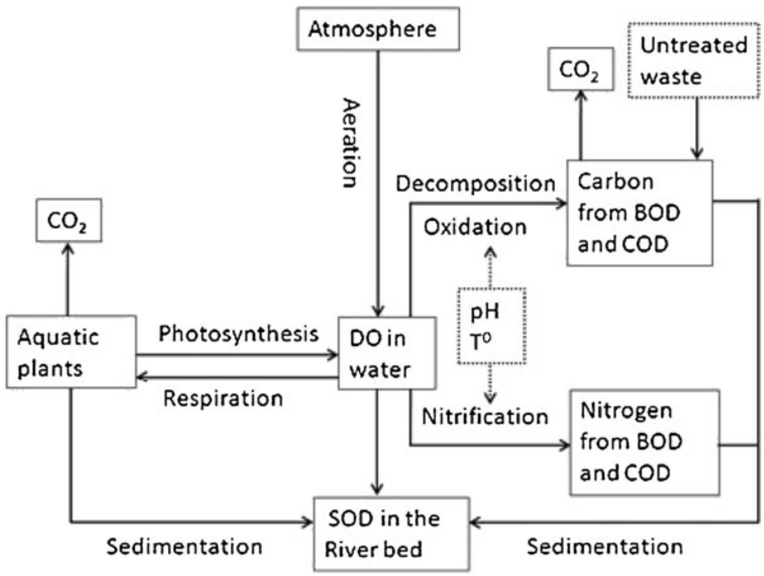

Fig. 2 A conceptual model of the major processes affecting the amount of DO as a results of disposing untreated coffee waste emanated from traditional coffee processing to the nearby rivers modified from Cox (2003)

unimpacted sites during both seasons. BOD, DO, SRP, and TSS were beyond the range of permissible limits to protect aquatic life in coffee waste impacted and unimpacted sites during both seasons. Physicochemical results below the permissible limit (Table 1) were also observed at two impacted sites, which have large size pits to contain all the waste and located at a reasonable far distance (>200 m) from the rivers. Water temperature was not significantly different between impacted and unimpacted sites for both seasons. The mean average value of water temperature for all sites in the wet season in 2007 was 18°C and ranged from 15°C to 19°C, whereas in the dry season in 2008, its average and range were 19°C and 16°C to 23°C, respectively.

Biological characteristics of the rivers

A total of 8,532 macroinvertebrate individuals representing 46 families were collected and identified from all sampling sites. The mean abundance of individuals in the Chironomidae family was 16 times higher at impacted than unimpacted upstream sites. All the three diversity indices (Shannon, Alpha, and Simpson) showed that macrofaunal diversity was significantly reduced ($p<0.05$) in the impacted sites during the peak coffee-processing season in 2007 (Table 2). Diversity indices were not significantly different between impacted and unimpacted sites during the low coffee-processing season in 2008. However, the ratio of pollution-sensitive (Ephemeroptera, Plecoptera, and

Table 2 Mann–Whitney *U* test for the different macroinvertebrate indices between two independent groups (impacted and unimpacted)

	Sampling in 2007 (wet season)					Sampling in 2008 (dry season)				
	Rank sum of sites					Rank sum of sites				
Indices	Impacted (n=24)	Unimpacted (n=20)	U	Z	P value	Impacted (n=23)	Unimpacted (n=19)	U	Z	P value
Shannon (H')	516	474	68	3.8	0.000	436	467	191	0.7	0.495
Alpha	476	514	108	2.8	0.005	382	521	192	−0.7	0.511
Simpsons (D)	224	767	88	−3.3	0.001	386	518	196	−0.6	0.570
d%	218	772	82	−3.5	0.001	364	539	174	−1.1	0.266
EPT/PT	441	463	85	3.1	0.002	553	350	740	3.6	0.000

d% Berger–Parker dominance, *EPT* Ephemeroptera, Plecoptera, and Trichoptera, *PT* pollution tolerant

Trichoptera (EPT) to pollution-tolerant (PT) taxa indicated a significant difference ($p<0.05$) between the groups during both sampling seasons (Table 2).

In the Canonical Correspondence Analysis (CCA), we selected environmental variables based on their marginal and conditional effects as well as the significance level of the effect as obtained in a Monte Carlo permutation test under null model with 999 permutations. As a result, BOD, DO, and nitrate with both relatively better marginal and conditional effects were selected for the ordination (Table 3). In the CCA ordination plot (Fig. 3), the first two eigenvalues are 0.129 and 0.086. The total inertia is 2.943 where as the sum of all CCA eigenvalues is 0.328. Therefore, Fig. 3 displays the sum of eigenvalues of the first two axes divided by the total inertia and multiplied by 100 which is 7.3% of the total inertia, indicating that it is not coherent in displaying the observed abundance, but it is consistent in displaying the fitted abundance values, weighted averages and class totals, as it was calculated from the sum of eigenvalues of the first two axes divided by the sum of all CCA eigenvalues and multiplied by 100, accounting for 65.6% of the variance in the weighted average and relative class totals of the data.

The synthetic pollution gradient along the first axis (Fig. 3) depicts rich in dissolved oxygen towards the left and high organic load and rich in nitrate to the right. Accordingly, sites polluted with coffee waste are distributed to the right of the second axis and diminished in number towards the left (Fig. 3). The two sampling seasons, peak coffee processing during October 2007 and March 2008 with no coffee processing

Table 3 Ranking of environmental variables in importance based on their marginal and conditional effects on the macroinvertebrate families

Marginal effects		Conditional effects		
Variable	λ_1	λ_A	*P*	*F*
DO[a]	0.09	0.09	0.028	2.79
Nitrate[a]	0.07	0.07	0.008	2.09
BOD[a]	0.05	0.07	0.058	1.93
TDS	0.08	0.05	0.078	1.58
pH	0.04	0.03	0.51	0.85
SRP	0.03	0.02	0.876	0.57

[a] Indicates the variables, which were selected for CCA ordination

were distributed along the high organic pollution load measured as BOD with longer gradient and rich in nitrate with short gradient, respectively (Fig. 3). A shift from high organic load (BOD) and reduced DO in the wet season to high nitrate in the dry season was the determining factor for the macroinvertbrate community structure (Fig. 3). According to the centroid principle as described by ter Braak and Verdonschot (1995), species are distributed at the centroid of the points for sites in which they occur, thus most pollution-tolerant macroinvertebrate families Ceratopogenidae (CER), Chaoboridae (CHA), Chironomidae (CHR), and Oligocheata (OLI) were significantly abundant in the impacted sites (Fig. 3). These pollution-tolerant taxa also constituted 83.3% of the mean total abundance observed at all sites in both seasons (Table 4).

Discussion

Self purification of streams and rivers requires both biological and chemical processes. Oxygen is one of several dissolved gases vital for aquatic life, and it is the single most important elements of rivers for self-purification by both biological (aerobic respiration) and chemical (oxidation) processes. Primary sources of oxygen in surface water are photosynthesis by aquatic plants and diffusion of atmospheric oxygen across the air/water interface (Cox 2003). In this study, as it is partied in the conceptual model, oxygen is removed from the river water as organic materials are oxidized by chemical processes (COD) and biological activities of aquatic organisms (BOD). Sediment or benthic oxygen demand (SOD), which results from organic matter being deposited and incorporated in the channel bed, is another major cause for DO deficiency in rivers (Cox 2003; Lehman et al. 2004). Ammonia, produced by decaying organic waste, is oxidized to less toxic nitrates by *Nitrosomonas* and *Nitrobacter* bacteria, a process that also consumes a large amount of oxygen (Lehman et al. 2004). Decomposition and nitrification were the major processes that diminish the levels of DO in rivers that are impacted by the coffee waste. Consequently, low levels of DO reduce the self-purification capacity of these rivers to recover from the coffee waste impact during off season. DO concentrations below 5 mg/l may also adversely affect the functioning and survival of biological communities

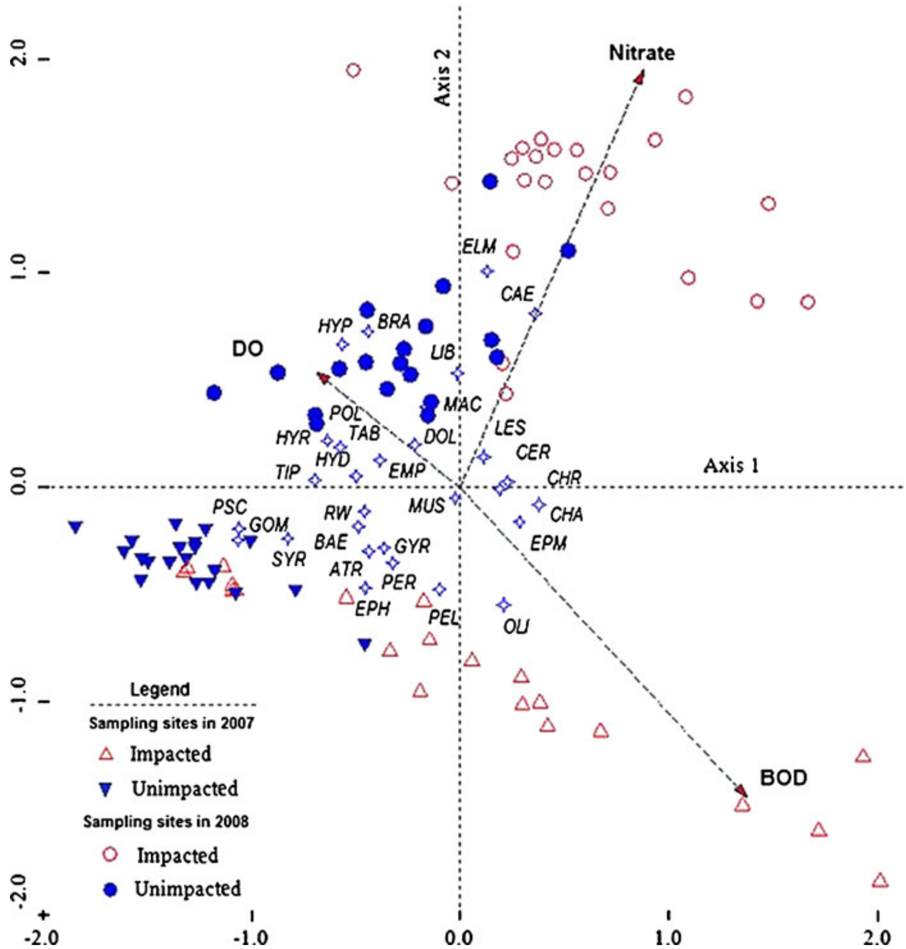

Fig. 3 CCA triplot of samples, macroinvertebrates, and environmental variables for the first two axes of the ordination represented by *circles* and *triangles*, *stars* and *arrows*, respectively. See full names of family codes in Table 4

(US-EPA 1986) and hence all pollution-sensitive taxa failed to retrieve.

While coffee industries in some countries, including Kenya, are reported to practice waste minimization and reuse of wastewater, this was not observed in Jimma Zone. Pulping alone consumed 6–7 m^3 of water per ton of fresh coffee cherries processed in Kenya, whereas reuse of water reduced this volume up to 50% (Mwaura and Mburu 1998). These figures indicate that the quantity of water consumed for coffee processing is huge in Jimma Zone, which produces more than 32,000 t of processed coffee every year (unpublished data of Jimma Agricultural Research Center, Ethiopia). In addition, the pits that are intended to serve as wastewater stabilization were neither properly constructed nor were they of the right dimension to accommodate the generated waste during peak processing, leading to overflow of raw effluents into natural watercourses. Thus, the polluting potential of the factories is enormous as shown by the high BOD content of coffee effluent reaching 1,900 mg/l even after stabilization in a pit, leading to severe depletion of DO (0.01 mg/l). This figure underestimates the actual BOD concentration of the effluent because these samples were taken after overflowing from a pit that had been designed to affect stabilization of the organic wastewater and immediately before it disperses into the rivers. Similar samples taken from an effluent overflowing from a pit into the nearby rivers reached on average a level of 2,200 mg/l of BOD. This observation highlights the fact that poorly designed and constructed pits do not prevent pollution of water bodies and the resulting threat to aquatic life unless well-designed waste treatment technologies are provided for the coffee waste in addition to adopting sound environmental practices. This finding is in agreement with a study conducted on the effects of coffee waste on nearby rivers in Ethiopia (Haddis and

Table 4 Average percent relative abundance (% RA) of macroinvertebrate taxa that were indentified and counted during two seasons

Order	Family	Code	%RA	Order	Family	Code	%RA
Coleoptera	Dytiscidae	DYT	0.02	Hemiptera	Corixidae	COX	0.01
	Elmide	ELM	0.20		Gerridae	GER	0.02
	Gyrinidae	GYR	0.04		Notonectidae	NON	0.01
	Hydrophilidae	HYR	0.14	Megaloptera	Sialidae	SIL	0.01
Diptera	Athericidae	ATR	0.46		Corydalidae	COR	0.02
	Ceratopogonidae	CER	11.11	Odonata	Aeshnidae	AES	0.04
	Chaoboridae	CHA	6.01		Corduliidae	COD	0.04
	Chironomidae	CHR	64.36		Gomphidae	GOM	0.21
	Culicidae	CUL	0.01		Lasiocampidae	HEL	0.01
	Dolichopodidae	DOL	0.59		Lestidae	LES	0.19
	Empididae	EMP	0.68		Libellulidae	LIB	0.54
	Muscidae	MUC	0.56		Macromiidae	MAC	0.86
	Psychodidae	PSY	0.03	Oligochaeta	Tubificidae and		
	Simulidae	SIM	0.03		Lumbriculidae	Oli	2.40
	Syrphidae	SYR	0.24	Plecoptera	Perlodidae	PER	0.14
	Tabanidae	TAB	1.65		Perlidae	PEL	0.03
	Tipulidae	TIP	0.21		Brachycentridae	BRA	0.16
Ephemeroptera	Baetidae	BAE	4.30		Hydropsychidae	HYD	1.90
	Caenidae	CAE	0.29		Hydropsychidae	HYD	1.28
	Ephemeridae	EPH	0.16		Hydroptilidae	HYP	0.15
	Ephemerllidae	EPM	0.48		Leptoceridae	LEP	0.01
	Heptageniidae	HEP	0.02		Polycentropodae	POL	0.23
Hemiptera	Belostomidae	BEL	0.01		Psychomiidae	PSC	0.14

Devi 2008), but the amount of BOD measured both from the effluent and the receiving water bodies differs probably due to the inherent differences in seasonal sampling results and annual variations. Joshi and Sukumaran (1991) also reported complete dearth of DO in the River Tungabhadra in India as a result of disposing untreated coffee waste into this river.

As coffee processing is one of the seasonal agricultural activities performed immediately after the big rainy season during the months of September to December, its impact on nearby freshwaters is assumed to be also seasonal. Consequently, most of the receiving rivers in 2008 showed a remarkable recovery, such as an overall 24-fold BOD reduction. Lower nitrate and higher ammonia during the peak coffee-processing season in 2007 than 2008 might be due to the fact that the anoxic conditions in 2007 might have suppressed the production of nitrate while producing high levels of ammonia as a result of fermentation and decomposition of coffee mucilage. The elevated physicochemical parameters above the permissible limit at unimpacted sites might be attributed to non-point pollution from other agricultural activities in the study area.

Diversity indices (Simpson, Alpha, and Shannon) and total EPT taxa were significantly reduced ($p<0.05$) at the impacted sites only during the peak coffee-processing season. In the dry season, there was less difference in macroinvertebrate diversity between impacted and unimpacted sites but a significant difference was observed in the ratio of sensitive to pollution-tolerant taxa, which remain depreciated on longer term. The greatest criticism of diversity indices is their inability to detect ecological impairment and accurately assess the water quality of streams and rivers (Davis and Simon 1995). The abundance of Chironomidae taxa, revealed by a 16-fold increase (accounting 64.36% of the total relative abundance) and significant reduction ($p<0.05$) of EPT/PT ratio at the impacted sites further substantiate the severity of the impact not only during peak coffee waste generation periods but also in the dryer months following the coffee waste disposal into the rivers. Thus, unlike the diversity indices, EPT to PT ratio was robust in detecting ecological impairment during both seasons.

The biological assemblage at sampling sites also revealed the impact of wet coffee processing on the biotic environment following untreated coffee waste disposal or discharge. Multivariate analysis based on macroinvertebrate composition of the sites was effective in discriminating impacted and unimpacted sites. The CCA ordination was efficient in detecting the pollution gradient from unimpacted to impacted sites and separating the two sampling seasons based on the organic load measured as BOD and nitrate concentration during high and low coffee-processing seasons, respectively. During peak coffee-processing season, the disposed untreated organic coffee waste consumed DO as result of high decomposition, which created anoxic condition and curtailed nitrification. During off season, oxygen started to recuperate and augmented nitrification. As a result, a shift from high organic load (BOD) and reduced DO in wet season to high nitrate in dry season was the determining factor for the macroinvertbrate community structure. Such severe surface water quality impairments as a result of human impact were reported in Kebana and Borkena rivers in the Ethiopian highland (Beyene et al. 2009a; b).

The comparison between upstream and downstream sites demonstrated the deterioration of river water quality and longer-term effects on aquatic life as a result of being a dumping site for untreated coffee waste. Our finding revealed that the placement of coffee-processing stations and large size pit for the containment of all coffee pulp and coffee wastewater at a far distance in some of the rivers reduced pollution levels. On the other hand, construction of small size pits, which cannot accommodate all wastes near rivers did not significantly reduce pollution. Pollution of surface waters in different countries has been tackled by modifying the production process to reduce water consumption and using coffee waste as an animal feed, compost for natural fertilizers, biogas production for energy and using its slurry as natural fertilizer (e.g., Mburu and Mwaura 1996). Recently, coffee waste was also found to become a potential new resource of biodiesel fuel (Kondamudi et al. 2008). None of these mitigating measures (sound environmental practices) have been considered so far in Ethiopia.

Conclusion

Both physicochemical and biological results revealed ecological impairment of downstream sites due to direct discharge of high organic waste from coffee-processing industries into nearby rivers. BOD measurements showed that the concentrations of oxidizable organic materials from coffee waste caused nearly complete deoxygenation of the rivers and swept out the pollution-sensitive taxa for a longer period. Although coffee processing is one of the seasonal agricultural activities performed immediately after the big rainy season during the months of September to December, its impact on nearby fresh waters was more persistent. This disproves what is indicated in the results of macroinvertebrates, which show a longer-term effect. The diversity indices were able to capture water quality impairment during the peak coffee-processing season. EPT/PT ratio, on the other hand, was found to be robust in detecting impairment in both seasons. In the dry season, macroinvertebrate diversity was not significantly different between impacted and unimpacted sites but the ratio of sensitive to pollution-tolerant taxa remain depreciated on the longer term. Our findings highlight that poorly designed and constructed pits do not prevent pollution of water bodies and the resulting longer-term threat to aquatic life, human health, and wildlife unless well-designed treatment technologies for coffee waste are used and sound environmental practices are adopted and promoted in the coffee-growing regions of Ethiopia. Local authorities need to take urgent measures to improve the ecological quality of these rivers as part of the efforts to restore their ecology and relieve public health risks.

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