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Modeling the impact of highland settlements on ecological disturbance of streams in Choke Mountain Catchment: Macroinvertebrate assemblages and water quality

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ABSTRACT

Human disturbances of waterways in Ethiopian highlands have increased throughout the last century due to population growth and increased land use. Despite this, there is a lack of knowledge on macroinvertebrate responses to human disturbances and the application of biological monitoring in tropical highland waterways in general. In this study, we have evaluated the human impact on the ecological integrity of the Chemoga River catchment in the Choke mountain watershed in the northwestern region of the Ethiopian Blue Nile highlands. During wet and dry seasons the water quality and macroinvertebrate assemblages were assessed. Multivariate statistics and Canonical Correspondence Analysis (CCA) were used to identify factors influencing macroinvertebrate community structures in highland streams in the northwest regions of Ethiopia. A total of 66 taxa of benthic macroinvertebrates were recorded, among which Diptera (38%) and Coleoptera (21%) were the most dominant. The results revealed a severe decrease in the ecological integrity of the Chemoga River in terms of macroinvertebrate composition at higher altitude. The ordination and cluster analysis clearly indicates extremely low macroinvertebrate diversity at sites where human impact is severe and a strong effect of altitude. These results highlight the need to protect the highland waterways of the Blue Nile area and that of similarly degraded watersheds in the Ethiopian highlands.

1. Introduction

The Ethiopian Highlands have been home to humans from the very dawn of the species. In the past decades, however, increasing population growth and the associated expansion of farming and grazing activities across nearly the entire highland landscape have led to high rates of environmental degradation (Vlek and Denich, 2012; Birhanu, 2014), testing the resilience of highland ecosystems to human-induced pressures. Environmental degradation is an ever-worsening problem (Aerts et al., 2007), with erosion and loss of soil fertility headwaters regions posing a particular threat (Zeleke and Hurni, 2001). Improper agricultural practices, over grazing and deforestation all contribute to the problem (Simane et al., 2012). In addition, the quantity and quality of surface water resources in such areas are highly affected. As a result of many years of improper land use, the majority of the Ethiopian highlands contain degraded ecosystems affecting the quality and quantity of surface water resources and diversity of aquatic organisms (Ambelu et al., 2010).

The Choke Mountain watershed are primary headwaters of the upper Blue Nile River (Teferi et al., 2010; Simane et al., 2012). However, human settlement in this area negatively affects the rivers and streams of the watershed. Human populations and their use of land have already threatened habitats and degraded most of the terrestrial and aquatic ecosystems in the area (Ellis, 2011). Land use modifications and small scale irrigation are the most common practices of farmers in the watershed. Such activities around drainage areas are one of the potential causes of pollution

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of the aquatic systems (Beyene et al., 2009; Ambelu et al., 2010). In addition, the current agricultural policy of Ethiopia encourages farmers to use fertilizers without any measure of preventing the washout water pollution. Similarly, stream diversion for irrigation purposes is becoming a common practice which leads to reduction of water level in the downstream watercourse (Ambelu, 2009). Such activities are common in Choke Mountain watershed for small scale irrigation activities. The reduction of stream flow in the natural watercourse limits macroinvertebrate habitats and causes elevated concentrations of pollutants, disturbs species interactions and reduces species richness (Poff et al., 1997; McIntosh et al., 2002; Niraula, 2012).

Highland streams also face non-point source discharges from domestic activities, grazing fields and agricultural runoff (Beyene et al., 2009; Ellis, 2011). In addition, due to high degree of elevation of the watershed, the water sources are highly exposed to sedimentation as a result of ecological degradation of the surrounding watershed. The presence, absence or composition of macroinvertebrate assemblages has been suggested as an index of human activity (Ambelu et al., 2010). Other studies conducted in some tropical highland African countries like Ndaruga et al. (2004), Kasangaki et al. (2008), Beyene et al. (2009) and Ambelu (2009) have shown that anthropogenic disturbances affect the presence or absence of aquatic macroinvertebrate species. However, no studies have been conducted in tropical African countries in general and East Africa in particular looking at the effect of human impacts on macroinvertebrate assemblages at higher altitudes. Therefore, a better understanding of the specific factors driving changes in water quality and the macroinvertebrate community structure along perturbation and settlement gradients is needed in order to generate knowledge and identify focus areas for sustainable environmental conservation approaches in highland watersheds. Similarly, effective environmental decision-making requires models that quantify species-environment interactions affecting macroinvertebrate communities in highland streams. Therefore, the main aim of the present study was to identify and evaluate the ecological disturbance of highland settlements on macroinvertebrate assemblages and water quality in a representative watershed of the Blue Nile highlands.

2. Methods and materials

2.1. Study area

The Choke Mountain watershed is located in the Upper Blue Nile (Abay River) highlands of Ethiopia. The watershed span a significant elevation gradient, with the highest peaks reaching 4200 m above sea level and the lowest confluence with the Blue Nile located at approximately 800 m above sea level (Zaitchik et al., 2012). The agro-ecology of the watershed is extremely varied from *kola* (hot) to *wurch* (afro-alpine) and with the physiographic, ecology, agriculture, socio-cultural and climatic conditions being quite different in appearance at the different elevations. Choke Mountain serves as a water tower of the region and headwater source of the Upper Blue Nile (Abay) river basin. Many of the rivers and tributaries of the Upper Blue Nile originate from this mountain range. There are about 59 rivers and many springs that originate from Choke Mountain watershed (Teferi et al., 2010).

The Chemoga River catchment is one of the main mesoscale catchments in Choke Mountain watershed. This catchment is exposed to extreme land use pressure in which the ecology is being alarmingly threatened by direct human interference as a result of rapid population growth (Bewket, 2002; Simane et al., 2012; Zaitchik et al., 2012). The catchment is characterized by overexploitation and overgrazing resulting from a large number of human settlements (CSA, 2007), high livestock loads, low agricultural productivity, severe land degradation, decreasing quality and volume of surface water flow (Simane et al., 2012). Therefore, there is no longer a significant natural forest cover in this catchment. However, the top moorland area of the Chemoga catchment is sparsely covered with giant lobelias (*Lobelia synchopetala*), lady's mantle (*Alchemilla humania*), Guassa grass (*Festuca* spp.) and other grasses. Small areas of natural woody plant cover (*Erica arborea* and *Hypericum revolutum)* are found in patches. Bamboo (*Arundinaria alpine)* is found as homestead/farmstead plantation as well as part of the natural vegetation cover in the area, though it is very sparsely and under threat. *Eucalyptus globules* is extensively grown in plantation in the watershed (Teferi et al., 2010; Simane et al., 2013).

The Chemoga catchment includes all traditionally classified agro-ecological zones, which are *wurch, dega, woyna dega,* and *kola*. The rainfall in the watershed is associated with the movement of the Inter-tropical Convergence Zone (ITCZ) with high rainfall during the rainy season (May-October) (Zaitchik et al., 2012; Simane et al., 2013). The highest elevations of the Chemoga catchment fall into the *wurch* agro-ecosystem, characterized by cold, moist conditions, average rainfall in excess of 2200 mm/year and the average annual temperature is less than 11.5 °C. However, at lower elevation of the catchment, the temperature increases successively from *dega* to *woyna dega* and then to *Kola* with average annual temperature of 11.5–17.5 °C, 17.5–20.0 °C, and 20.0–27.5 °C respectively (Zaitchik et al., 2012).

The location of the Chemoga River within the Blue Nile River headwaters gives it a special relevance, both because of the well-known transboundary tensions associated with the Blue Nile River and because the Blue Nile basin is the home of the Grand Ethiopian Renaissance Dam (GERD). The GERD, which is currently under construction, is a major development priority for Ethiopia, and it has raised appreciation for the importance of biomonitoring studies and tools that can contribute to ecological river management and the sustainable use of water resources.

2.2. Data collection

Macroinvertebrates and environmental data were collected at 36 sampling sites in the streams of the Chemoga River in the Choke Mountain watershed during the wet and dry seasons from September 2014 through May 2015 (Fig. 1). Depending on sampling site, one to five samples were taken. Throughout this period, 118 samples were collected using the kick sampling method as described by Gabriels et al. (2010). In short a D-frame net having a mesh size of 300 μm diameter was used for collection during 5 min sampling period. Samples were collected from each meso-habitat such as boulders and vegetation within a 10 m stretch. Macroinvertebrates were then sorted alive onsite and preserved in 70% ethanol for subsequent identification at family level following Gerber and Gabriel (2002) and Bouchard (2004).

Physical features of the streams that could have a direct or indirect influence on the macroinvertebrate community and water quality were recorded at the sampling sites. The habitat of each sampling reach was characterized using the USEPA rapid physical habitat classification format (Barbour et al., 1999). At each sampling site, anthropogenic activities were carefully registered based on six main human activities: *tillage, irrigation, grazing, land slid, tree removal* and *other activities* (cloth washing, swimming, and sand dredging). Each human disturbance activity was quantified based on its intensity in the studied streams as indicated by Wang et al. (1998) and Mereta et al. (2013). A class of one was given for no or minimal disturbance, 2 for medium and 3 for high disturbance (Table 1). The overall disturbance index score is based on the scores of the six variables and hence the total disturbance score could potentially range from 1 to 18. The higher the score,

Table 1
Rating criteria for human disturbance variables used in the stream habitat index (Modified from Wang et al., 1998). The overall disturbance index score is based on the scores of the six variables. A score of 1 was awarded for no or minimal disturbance, 2 for moderate disturbance and 3 for high disturbance.

Disturbances	Low (score 1)	Medium (score 2)	High (score 3)
Tillage	No tillage or farming at >50 m from the stream	Farming in a distance of <50 m from the stream	Farming including buffer of the streams
Grazing	Minimal grazing <10%	Medium grazing 10–50%	Intensive grazing, >50%
Tree removal	Less tree removal, <10%	Medium tree removal, 10–50%	High tree removal, >50%
Irrigation	No or minimal irrigation >100 m from sampling site	Irrigation within 10–50 m from the sampling site	Irrigation within <10 m distance from sampling site
Landslide	No or minimal land slide	Landslide within <50m	Landslide within streams and <10m
Other activities	Minimal or less cloth washing, bathing and sand dredging <10%	Medium activities of cloth washing, bathing and sand dredging 10–50%	Intensive use of cloth washing, bathing and sand dredging >50%

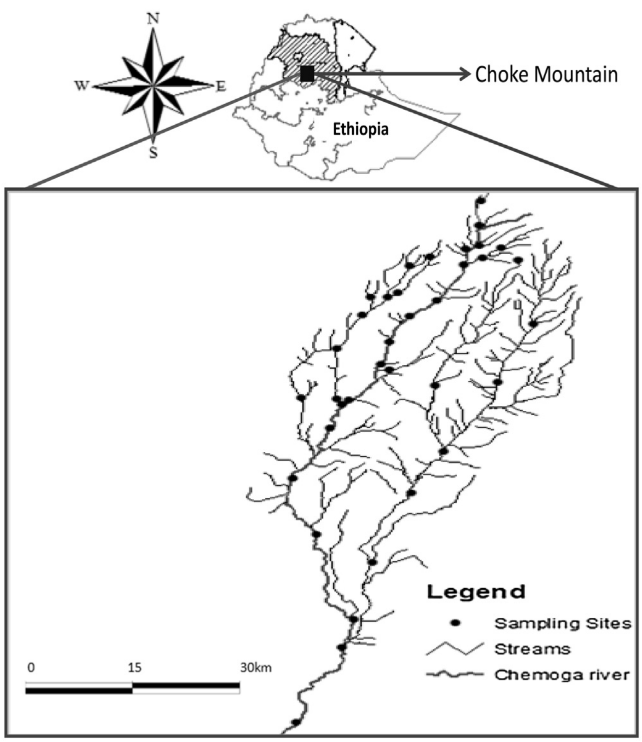

Fig. 1. Location of sampling sites in the Chemoga river Choke Mountain watershed, Ethiopia.

the greater was the anthropogenic disturbance of the sample site. Settlement density data were also collected at each sampling site based on counting of the number of houses within 300 m radius in both stream banks to measure the magnitude of the indirect effects of settlement on the macroinvertebrate assemblages and water quality.

Physicochemical parameters measurements were performed either onsite during sampling or in the laboratory. The electrical conductivity of the water, dissolved oxygen, pH, turbidity and water temperature at the respective sites were measured onsite using HACH multi-meter handheld probe, model HQ40D. In addition, 2 l water samples were collected from each site and stored in a refrigerator at 4°C and transported to the laboratory in an insulated box containing ice packs. Subsequently, nitrate, total nitrogen, total phosphate and orthophosphate were measured in the laboratory according to standard methods (APHA, AWWA, WEF, 1999). The distance between the sampling sites was calculated using GIS and altitude was measured using the Global Positioning System (Magellan ®, SporTrak Pro). In total, 14 different river characteristics were recorded (Table 2).

Table 2
Input physicochemical and environmental variables collected from each sampling site: mean values, standard deviation and range values.

Variables	Unit	Mean	Standard deviation	Range
Stream depth	M	0.25	0.14	0.01–0.65
Stream width	M	2.29	1.70	0.18–6.5
Velocity	m/s	0.10	0.17	0.008–1.07
Discharge	m^3/s	0.21	0.27	0.001–1.34
Chanel depth	M	1.73	0.91	0.45–4.5
Chanel width	M	4.48	2.18	1.15–10
Ambient Temperature	°C	19.71	3.80	12–26
Water Temperature	°C	13.86	3.49	7.2–26
Altitude	M	2907.88	387.56	2418–3642
Electrical conductivity	μS/cm	74.31	19.71	48.1–250
Dissolved oxygen	mg/l	7.05	0.31	4.77–9.59
pH	–	6.49	1.62	5.55–9.11
Turbidity	NTU	149.03	206.57	2.45–640
Total Nitrogen	mg/l	1.83	1.07	0.64–4.4
Nitrate	mg/l	0.41	0.25	0.13–0.96
Total Phosphorous	mg/l	1.22	0.71	0.06–3.3
O-Phosphate	mg/l	0.40	0.23	0.02–1.1

2.3. Data analysis

Relationships between the environmental data and macroinvertebrate community metrics were assessed using canonical multivariate analysis. Detrended Correspondence Analysis (DCA) was applied using CANOCO 4.5 (ter Braak and Smilauer, 2002) to examine whether Redundancy Analysis (RDA) or Canonical Correspondence Analysis (CCA) would be appropriate (Ter Braak, 1994) to analyze the data. The DCA yielded gradient lengths that were higher than three standard deviations, therefore CCA was used. Environmental variables except pH and macroinvertebrate abundance data were log(x + 1) and square root transformed prior to statistical analysis to normalize the distributions and homogenize the variance. The statistical significance of eigenvalues and species-environment correlations generated by the CCA were tested using Monte Carlo permutations and correlations of the environmental variables and the significant axes were calculated to determine those environmental variables that were significantly correlated with the axes (Jongman et al., 1996). Hierarchical cluster analysis using constrained Ward's method was performed to assess clustering in PAST software version 2. The clusters were checked to which category of the three habitat classes (poor, marginal and suboptimal) with the three human impact classes (less, medium and high) in wet and dry season classes belonged to.

Multiple regression analysis was performed to analyze the existence of linear relationship between biological data (macroinvertebrate communities) and the environmental variables by stepwise forward selection method using STATISTICA® Software package version 7. The standard errors for the regression coefficients were calculated automatically in the Statistica software. It uses traditional for multiple leaner regression method based on error mean square ($s\hat{2}$) and variance covariance matrix of the predictors (X'X). The error mean square is calculated as: yp * (I – H) * y/(n − (k + 1)), where yp is a vector with predicted y-values, y is a vector with measured y-values, I is the identity matrix, H is the hat matrix ($H = X(X'X)^{-1}X'$), n is number of rows (measurements) and k is a number of predictors (X-variables). The variance-covariance matrix of estimated regression coefficients can be obtained by $C = s\hat{2} * (X'X)^{-1}$. The diagonal element of the matrix is corresponding to the squared standard errors (variance) of the coefficients.

In addition, we used Global Sensitivity and Uncertainty Analysis model to evaluate output uncertainty and factor importance (Yang, 2011; Convertino et al., 2014). Considering all the data inputs as uncertain variables, we took the average frequency for each selected factor (Fig. S4). Stepwise multiple regression analysis was used to see the ranges of variability and to determine the important predictors. Evaluation of uncertainty is essentially important for both assessing the reliability of the species richness and controlling the species distribution in relation to management plans as explained by Saltelli (1999) and Convertino et al. (2014).

Global sensitivity and uncertainty analysis is in general, a nonlinearity set of models that evaluate the propagation of uncertainty from inputs to outputs of any model. The uncertainty analysis (UA) component of Global Sensitivity and Uncertainty Analysis determines all uncertainties in the model outputs due to the uncertainty in the model inputs. UA focuses on exploring all potential outputs of a model given all uncertainties of input factors (Convertino et al., 2014). Sensitivity analysis (SA) on the other hand is focused on how variation of the output of a regression model can be assigned to different sources of variation or input and determines the contribution of each uncertain input factor to the uncertainty of a given output (DeJonge et al., 2012; Convertino et al., 2014) and measures the changes in the model output. The final selections of input variables were based on their importance and interaction for the variability of predicted model output. This was done by plotting the selected variables (Table 2; Fig. S4) considering the total values encountered at each sampling site.

3. Results

3.1. Human disturbance and habitat description

The human disturbance score and status of habitat conditions differed significantly among study sites. The total sum of disturbance scores ranged from 1 to 18 where the lower threshold (minimum score of 1) represented the less impacted condition, and the upper threshold (maximum score of 18) represents highly impacted condition. The scores were divided into three quality classes (Table 1) (1, 2 and 3 classes for: 1–6 = less impacted, 6–12 = medium impacted and 12–18 = high impacted conditions, respectively). Most of the study sites were scored as class 3 (disturbance score 12–18), showing severe disturbance by human activities. The majority of such sites are located at higher altitudes (altitude >2,950 m.a.s.l) of the Chemoga River catchment (Fig. S1). Only a few sampling sites belonged to class 1 (human disturbance score < 6), and they were found at altitudes below 2,550m.a.s.l. The remaining sampling sites were scored as class 2 (disturbance score 6–12). The results of correlation coefficients confirmed that there was a strong negative correlation between macroinvertebrate richness and human disturbance gradient ($p < 0.05$).

3.2. Physicochemical characteristics of the streams at the sampling sites

The average values of the physicochemical variables of the samples collected in both wet and dry seasons are shown in Table 2. They differed considerably across the study sites. The PCA bi-plot of the wet season (Fig. 2a) clearly shows that environmental variables, mainly DO, nitrate, pH and human disturbance like tillage, small scale irrigation/stream diversion and tree removal were positively correlated with sites at higher altitude where high number of settlement is found in the watershed, water temperature, conductivity and turbidity were positively correlated with sites at lower altitude in the study area. The PCA bi-plot results of dry season (Fig. 2b) also showed that tillage, stream diversion for irrigation, and riparian vegetation clearance were positively correlated with altitude while water temperature, conductivity, nitrate, pH, DO and turbidity were positively correlated with sites at lower altitude in the study area. The practice of small scale irrigation/stream diversion is more common in the catchment in the dry season. This contributes to the fact that there was no flow of water in the natural river/stream channel in the dry season at some sampling sites and as a result of this we failed to get water and macroinvertebrate samples from sites 8, 9, 33, 34 and 35.

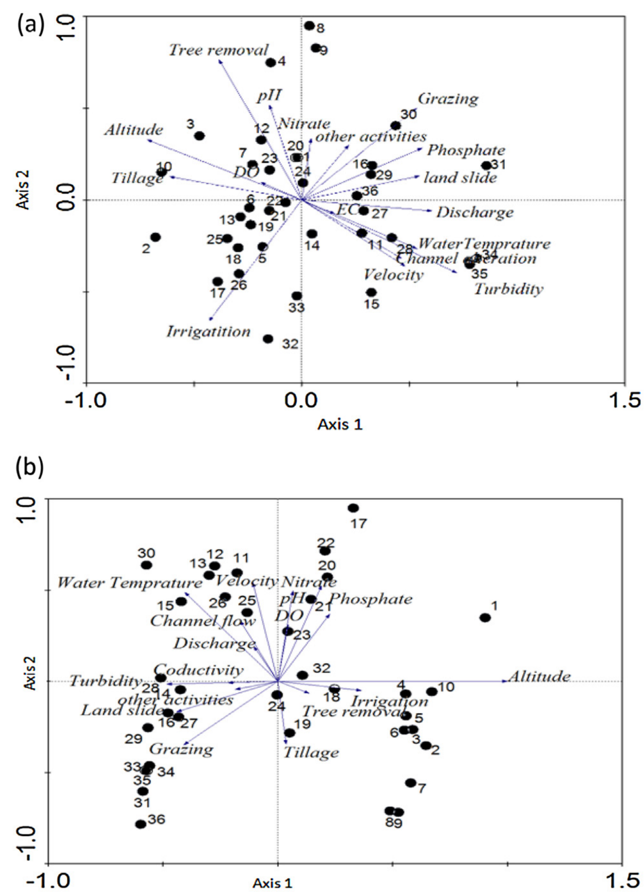

Fig. 2. PCA bi-plot of a) wet and b) dry season environmental variables with their corresponding sampling sites at the Chemoga River in the Choke Mountain watershed 2015 (The numbers are representing the sites).

3.3. Macroinvertebrate communities

A total of 7856 individual macroinvertebrates, grouped into 23 orders and 66 families, one identified at class level and three unidentified were collected from all representative habitats throughout the 36 sampling sites in both the wet and dry seasons. The most abundant orders were *Diptera* (3000; 38.18%) followed by *Coleoptera* (1721; 21.9%). In addition, *Hemiptera* (862; 10.98%), *Odonata* (792; 10.08%), *Ephemeroptera* (745; 9.48%) and *Trichoptera* (284; 3.61%) were dominant orders at the study sites. These orders were represented by 51 families and accounted more than 94.24% of the overall macroinvertebrate samples.

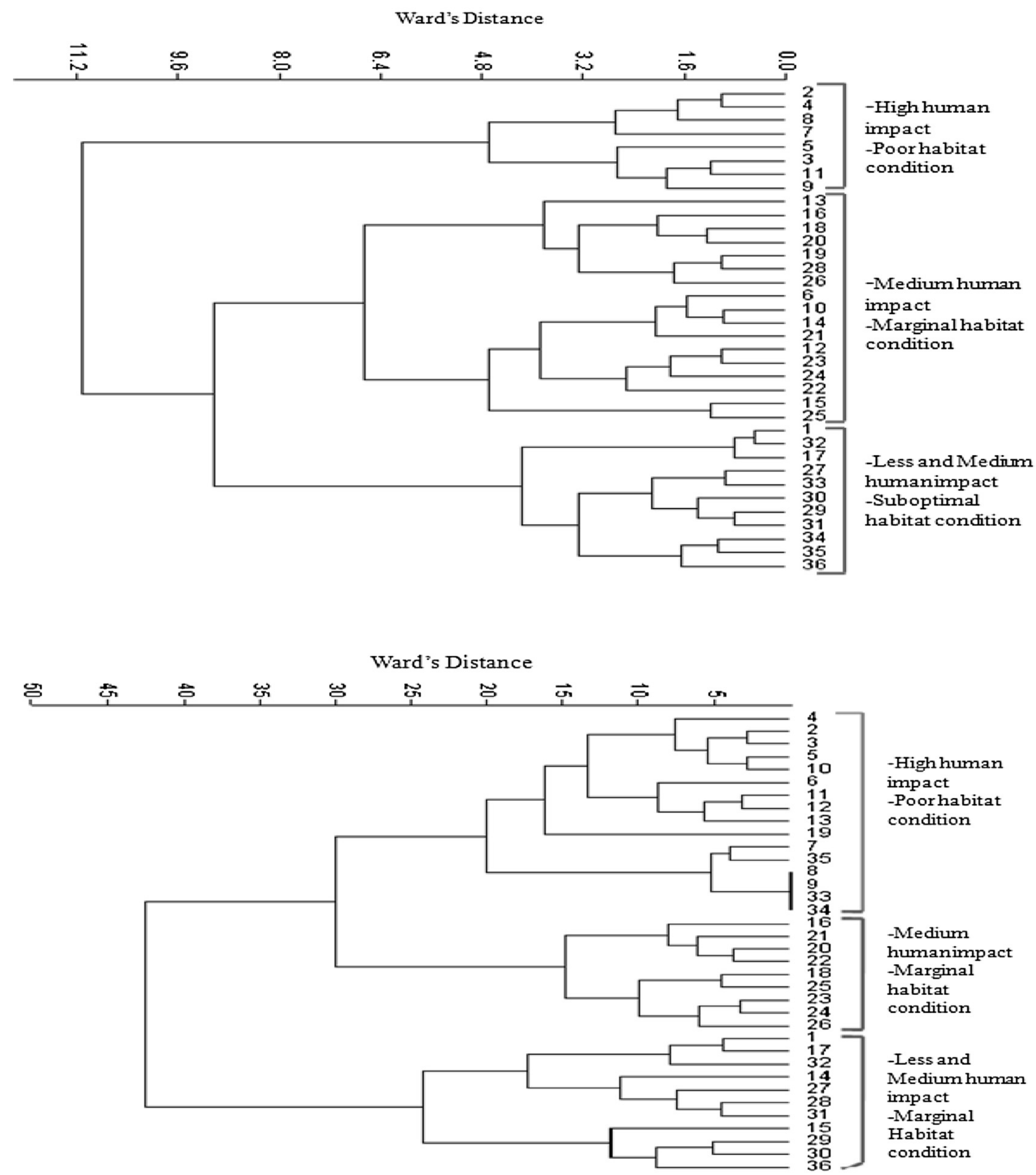

Fig. 3. Dendrogram of hierarchical cluster analysis based on Ward's method using square root transformed macroinvertebrate data obtained during a) the wet and b) dry season from the Chemoga River, Choke Mountain watershed, Ethiopia 2015.

Hierarchal cluster analysis of wet and dry season macroinvertebrate (Fig. 3a and 3b) showed that samples could be clustered into several groups. Sites with high human impact and poor habitat conditions grouped together. The second groups were sites with mixed (less and medium) human impact with suboptimal habitat conditions. Sites with medium human impact with marginal habitat conditions were the third group.

The multivariate classification of the sampling sites based on the biological data for the wet and dry season sampling (Fig. 4) shows significant variation among sites. The first and the second canonical axes explained 48.7% (eigenvalue of 0.197) and 28.6% (eigenvalue of 0.139) of the variation in the species data, respectively. The cumulative percentage variance of the species-environmental relation explained by both axes is 63%. This clearly demonstrates that species richness was significantly affected ($p < 0.05$) by altitude, human impact (tillage, small scale irrigation/stream diversion, tree removal, grazing, channel alteration, clothes washing and bathing) and settlement (Figs. S2 and S3, Table 3). The correlation test demonstrates that there is a significant correlation between species richness and each of the variables ($p < 0.05$).

4. Discussion

Physical habitat survey showed that substrate particle size, channel alteration, and embeddedness varied considerably across sites in the study area. Riparian vegetation cover was low or absent except for a few study sites upstream of the Chemoga River, and upstream of the Temzeg and Shegeza streams (large tributaries to the Chemoga River). High population settlement, poor farming practices, diverting of streams for irrigation, overgrazing and deforestation in the study area are the major factors contributing to land degradation. Residents are using streams for clothes washing, bathing, and as drinking water with no further treatment. Stone dredging, sand mining and open waste dumping into the streams

Table 3
Regression summary of macroinvertebrate richness using environmental predictors in Chemoga river Choke Mountain watershed, Ethiopia, 2015.

N = 72	Beta	Std. Error of Beta	B	Std. Error of B	t(60)	p-level
Intercept			24.85	6.03	4.11	0.00
Ambient temp.	0.52	0.21	0.44	0.18	2.42	0.01
Settlement	−0.26	0.08	−0.15	0.04	−3.11	0.00
Human impact	−0.32	0.08	−0.36	0.09	−3.70	0.00
pH	−0.12	0.21	−0.35	0.61	−0.57	0.56
Channel width	−0.29	0.10	−0.69	0.24	−2.84	0.01
Turbidity	0.10	0.08	0.003	0.002	1.25	0.21
Altitude	−0.43	0.14	−0.005	0.001	−3.00	0.00
Water Temp.	−0.47	0.18	−0.44	0.17	−2.51	0.01
DO	0.74	0.33	2.04	0.90	2.26	0.02
EC	0.12	0.08	0.01	0.01	1.56	0.12
Nitrate	−0.08	0.08	−0.42	0.41	−1.03	0.30

*Adjusted R^2=0.71799593 F (11, 60) = 17.581 p < 0.00000 Std. Error of estimate: 2.8150, N = 36 sites*2 seasons.

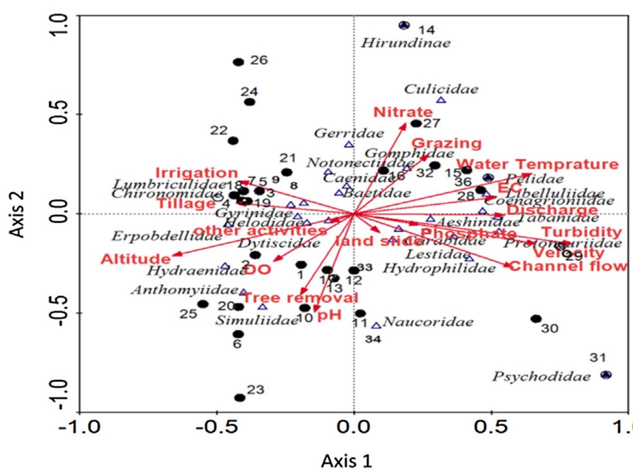

Fig. 4. Canonical correspondence analysis (CCA) of macroinvertebrate taxa and environmental variables in the Chemoga River in the Choke Mountain watershed (environmental variables are explained in Table 1and the numbers are representing the sites of collection).

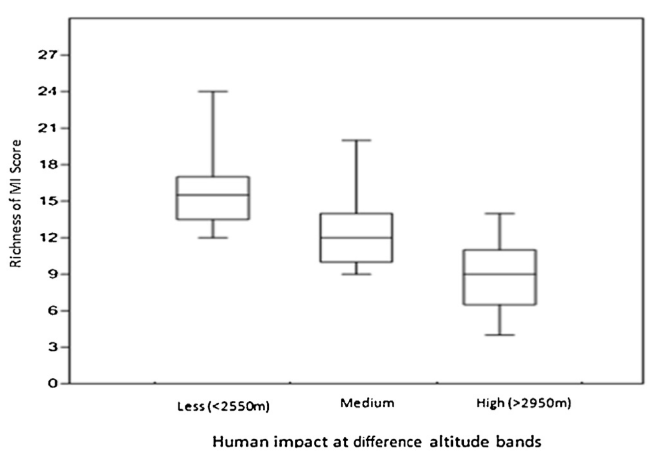

Fig. 5. Box plot of human disturbance on macroinvertebrate richness at different altitude bands in the Chemoga river Choke mountain watershed, Ethiopia, 2015. MI = macroinvertebrate.

are common practices which have a direct impact on the water quality and diversity of aquatic macroinvertebrates.

Water quality, macroinvertebrate richness and habitat conditions were all affected by human activities and hence a drastic decline of ecological integrity was observed in the studied highland streams. Human disturbance classes (low, medium and high) were plotted against macroinvertebrate richness using box plot (Fig. 5) at different altitude levels showed that richness was affected at all altitude levels but more at higher altitudes. Therefore, human disturbance is a significant predictor of macroinvetebrate richness even when altitude is taken into account. Regression analysis (Table 3) confirms that the relationship between human disturbance and richness is not an artifact of the correlation between human disturbance and altitude. The consequent effects of high population pressure/settlement like, cloth washing, household untreated solid and liquid waste dumping into the streams, intensive agricultural land use, surface runoff, landslides, small scale irrigation and overgrazing in the Chemoga River catchments are the multiple scale of environmental stressors that have been reported to alter the environmental variables in other Ethiopian rivers and streams (Ambelu, 2009; Beyene et al., 2009; Teferi et al., 2013; De Troyer et al., 2016). CCA bi-plot analysis (Fig. 4) established that many of these environmental stressors were found to have a significant impact on the macroinvertebrate richness of the Chemoga River and its tributaries.

The regression coefficients obtained from the model (Table 3) varied significantly among the input variables (Fig. S4). Human impact, settlement and altitude were used as predictor variables as these were the most important input variables selected by the model (Table 3) because sensitivity analysis is performed only for the most important input factors (Convertino et al., 2014). The analysis pointed out that the macroinvertebrate richness (Table 3 and Figs. S2 and S3) significantly decreasing with increasing human impact, altitude and settlement.

We observed high physicochemical variability across sites, and the changes in physicochemical parameter affected the diversity of macroinvertebrates in the Chemoga River. The most important physicochemical parameter affecting the assemblage of macroinvertebrate communities is pH (Table 3), and it is considerably higher in the dry season (Table 2). During the dry season, higher water temperatures were recorded and hence gases like CO_2 might be released, as a result of which the pH of the water could increase (Hoko, 2008; Ambelu, 2009). Conductivity also shows considerable variability and it was very high in dry season. But during rainy season conductivity decreases, possibly due to dilution of dissolved solids (Ambelu, 2009). High turbidity and Dissolved oxygen (DO) concentrations were recorded in the wet season samples, likely because of high rainfall, high runoff, and turbulent stream flow (Ambelu, 2009; Boets et al., 2010; Gabriels et al., 2010; Mereta et al., 2012). The mean concentration of physicochemical variables like total nitrogen and total phosphorus were beyond the surface water standards in both seasons (Table 2). This also might be associated with the high pressure of anthropogenic activities, including the use of irrigation, bathing, sand dredging, and cloth washing, open household waste dumping, fertilizers, livestock husbandry and riparian vegetation clearance.

In this study, it was observed that the most important input variables affecting macroinvertebrate communities were human disturbance and the consequent effects of settlement ($p < 0.05$). Human activities like tillage, small scale irrigation/stream diversion, waste dumping in the stream systems, cloth washing, bathing, and the alteration of natural habitat of the streams like channel modification and vegetation clearance affect macroinvertebrate richness (Kyriakeas and Watzin, 2006; Chakona and Marshall, 2008; Kasangaki et al., 2008). Water temperature and channel width were also the important input variables affecting macroinvertebrate richness ($p < 0.05$). In addition to stream diversions for irrigation activity, the occurrence of drought in the study area affects the flow of water in the natural river bank of some sampling sites during dry season. Indeed, an absence of stream flow made it impossible to collect biological and environmental samples from sites 8, 9, 33, 34, and 35. Reduction of stream flow significantly affects the existence of macroinvertebrate within the ecosystem. The cumulative effect of the reduction of water flow on the natural stream bank could be the main cause of shifting of macroinvertebrate compositions, prey-predator interactions, alterations of functional feeding groups, life history characteristics, reproductive activity and morphological characteristics (McIntosh et al., 2002).

As expected, water temperature decreased with altitude in both wet and dry seasons. Our finding that macroinvertebrate richness also decreased significantly with altitude is consistent with studies in other regions (e.g. Jacobsen et al., 1997; Jacobsen, 2003, 2004; Henriques-Oliveira and Nessimian, 2010). Richness of macroinvertebrate have shown a negatively correlated ($p < 0.05$) with increasing of altitude (Table 3 and Fig. S2).

In addition, human settlement pressure is substantial and increasing at higher altitudes of the Choke Mountain watersheds (Teferi et al., 2010; Simane et al., 2012, 2013; Zaitchik et al., 2012). The results of the regression model confirmed that there was a strong negative relationship between the macroinvertebrate richness and settlement ($p < 0.05$, Fig. S4, Table 3). Importantly, settlement is a significant predictor of macroinvertebrate richness even when elevation is taken into account (Table 3), confirming that the relationship between settlement and richness is not simply an artifact of the correlation between settlement and altitude. The unvariate correlation was also confirmed that there was a negative relationship between richness and settlement ($p < 0.05$, $R^2 = 0.58$, Fig. S3). Seasonal variations were also considered to be an important variable to influence macroinvertebrate distribution in Chemoga River, as greater macroinvertebrate abundance and diversity was observed during the wet season than the dry season.

The dendrogram of hierarchical cluster analysis for macroinvertebrate in wet and dry season (Fig. 3a and b) respectively showed that the sampling sites grouped into three. This grouping was found to coincide with levels of human impact on the stream habitat studied. According to Barbour et al. (1999), the macroinvertebrate communities are plotted against the four habitat classes as poor, marginal, suboptimal and optimal with the status of high, medium, and less human impacts. However, in this study there were very few sites that could be categorized as "less impacted," such that the habitat classes of Chemoga River could be generalized into three classes: poor, marginal and suboptimal. These cluster analysis clearly show that low and medium human impacted sites, and marginal and suboptimal habitat conditions hold more biological diversity than high impacted and poor habitat conditions. The classification of the sampling sites based on the biological data for the wet and dry season clearly demonstrated that the less and medium impacted sites contained more diversity among sampling sites in both seasons. In the high impacted and poor habitat condition sites *Chironomidae* and some *Diptera* groups were the most abundant macroinvertebrates followed by pollution tolerant *Coleoptera* at higher altitude study sites.

5. Conclusions

In summary, the results of the sensitivity analysis of the present study showed that species composition and richness in macroinvertebrate communities of streams within the Chemoga River catchment, of the Blue Nile Highlands of Ethiopia, were mainly determined by human impact, altitude and high settlement. Study sites at higher altitude with high human impact and settlement showed low macroinvertebrate richness and deteriorated water quality. Major activities which have affected the streams are tillage, irrigation, grazing, vegetation clearance, waste dumping and other activities like clothes washing and sand dredging. Both physico-chemical and macroinvertebrate data confirmed that the ecological integrity of the streams was more affected in the dry season compared to the wet season. The results may form the basis for a quality monitoring framework that can provide sound ecological information for management purposes in the river catchment. Further studies of the Chemoga River and other Ethiopian river systems may help to develop scientific monitoring systems and in developing effective and feasible remedial measures.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ecolind.2016.10.019.

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