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Spatio-temporal water quality assessment of the wetlands in the lower part of Gilgel Abay River Catchment, Ethiopia

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Abstract
This study was conducted in the wetlands of the lower Gilgel Abay River catchment, Ethiopia from 2017 to 2018. The objective of the study was to assess the impacts of human activities on the physicochemical parameters and habitat quality of the wetlands. The water quality parameters (temperature, pH, salinity, TDS, TSS, DO, turbidity, electrical conductivity and nutrients) were examined at six study sites during the wet and dry seasons. The significance of spatial and temporal variability of water quality parameters was evaluated using Kruskal-Wallis and Mann-Whitney U tests respectively. The result showed that most of the water quality parameters were significantly different among the sampling sites and between seasons ($p < 0.05$). The water quality parameter association using principal component analysis (PCA) indicated that the quality of water was influenced by human activities such as agricultural activities and urban effluent around the wetland. The study concluded that the wetlands have been polluted as a result of the human activities within the wetlands and their surrounding areas. It is recommended that the unsustainable human activities around the wetlands should be minimized to reduce further deterioration.

Keywords: Ecosystem, habitat quality, human disturbance, nutrient recycling, physicochemical

Introduction

Wetlands are among the most productive ecosystems on earth Mitsch and Gosselink (2000) [26] and provide many functions and services that are valuable to the environment and human wellbeing (Maltby, 2009) [22]. According to USEPA (2002) [33], these functions of wetlands include: nutrient recycling, carbon sequestration, flood control, groundwater recharge/discharge, nutrient removal and habitat provision for biodiversity. Fresh water wetlands of the world provide habitat for more than 7% (126,000) of the total number of described animal species on earth (1.8 million) (Dugan 1990; Zedler and Kercher, 2005) [10, 38]. Wetlands also provide socio-economic importance (Maltby, 2009) [22].

Despite their ecosystem functions and economic values, wetlands have been degraded rapidly during the last few decades due to destructive anthropogenic activities in their catchments (MEA, 2005) [25]. As a result, more than 50% of wetlands of the world have been lost since 1900 due to rapid expansion in human population and urbanization, land use changes; drainage to agricultural use; infrastructure development; pollution from industrial effluent and agricultural runoff; overexploitation of wetland resources, introduction of invasive alien species, climate change and variability (MEA, 2005) [25].

Ethiopia is endowed with a variety of wetland ecosystems in different regions and agro ecological zones (Abunie, 2003) [1]. With the exception of coastal and marine related wetlands and extensive swamp forest complexes, all forms of wetlands are present in Ethiopia (Dixon and wood, 2003) [9]. Major rivers and lake systems, together with their associated wetlands, are fundamental parts of life interwoven into the structure and welfare of societies and natural ecosystems (Afework and Tilahun, 2015) [2]. However, the rapid human population growth, economic developments and concomitant increases of human needs put undue pressure on wetland ecosystems, and the rate of degradation has increased over time across the country (Gebre Mariam, 2002; EPA, 2004) [15, 11]. In order to fulfill the increasing human needs, wetlands have drained and converted to farmlands, grazing land, settlement and waste disposal area (Gebre Mariam, 2002; Desta, 2003; EPA, 2004; Tewabe, 2014; Mequanent and Sisay, 2015) [15, 8, 11, 32, 23].

Gilgel Abay River (GAR), which is the source of the Blue Nile River in Ethiopia, is one of the largest rivers which drain into Lake Tana and contributes more than 40% of the lake's water (Sewnet, 2013). The lower part of the river is associated with large extents of floodplain wetlands. Similar to other wetlands of Ethiopia, these wetlands provide numerous ecosystem services and socioeconomic benefits to the community living around the wetlands (Wondie, 2018) [35]. They have also innumerable ecological role in the maintenance and sustenance of the lake through filtering out of pollutants and sediments. However, the ecological functions and services of the wetlands have not been appreciated by the local communities and the local administers as well. Rather wetlands in Ethiopia in general and in the study area in particular have been considered as waste lands and breeding sites for disease causing organisms like mosquito. Due to this erroneous view of wetlands coupled with the rapid increase in human population and high levels of poverty in the study watershed, large extents of wetlands drained and converted into farmlands and settlement areas (Sewnet, 2013) [31]. A great numbers of people are moving and settling in fragile wetland areas, in search of new means of livelihood. Consequently, wetland resources are increasingly being degraded through various consumptive uses (Afework and Tilahun, 2015) [2].

Compared to other ecosystems, limited studies have been conducted on the ecology of wetlands in Ethiopia (Abunie, 2003; Mereta *et al*., 2013) [2, 24]. Similarly, the ecological status and anthropogenic impacts on wetlands along the lower part of GAR have not been studied in detail and there are no conservation measures undertaken by the community and the government to safeguard their sustainability. Hence, there is no enough information about the overall wetland condition and its status to stakeholders. To conserve these valuable resources and to prevent further deterioration, there is a need for regular monitoring of these ecosystems. According to Ramachandran, *et al*. (2006) [28], water quality monitoring is the first step for the management and conservation of wetland ecosystems. Management of an aquatic ecosystem aims for the conservation of its habitat by suitably maintaining the physicochemical quality of water within acceptable levels (Garg *et al*., 2010) [14]. Therefore, the objective of this study was to evaluate the water quality parameters and anthropogenic impacts on wetlands along the lower part of the GAR catchment with the purpose of providing appropriate ecological data to the conservationist, managers, policy makers and other stakeholders.

Materials and Methods

Study area

This study was conducted in GAR catchment which is located in West Gojjam Zone of Amhara Regional State, Ethiopia. The catchment is situated at latitudes between 10°57′–11°54′N and longitudes 36°38′–37°23′E. The altitude of the area ranged from 1780 m to 3528 m above sea level. The total area coverage of the catchment is 3779.16 km^2. The river originates from the highland spring of Gish-Abay town and terminates into Lake Tana. This catchment contributes more than 40% of the volume of the Lake's water (Sewnet, 2013) [31]. The study area has an average annual rainfall of 1407 mm and mean temperature of 27 ºC (National Meteorological Agency 2019). Large extents of flood plain and palustrine wetlands are distributed in the lower part of the catchment which have a great ecological role in the maintenance of the river and Lake Tana. Six wetlands (Chimba Abay, Estumit, Ras Abay1, Ras Abay2, Debremariam and Semaitat) were included in this study (Figure 1). These wetlands were selected in a targeted manner based on the surrounding land use, exposure to anthropogenic activities and accessibility to quantitative study as recommended by (USEPA, 2002).

Chimba Abay and Estumit wetlands were located close to agricultural areas. These sites experienced a high level of anthropogenic activities such as farming, grazing, macrophyte harvesting and water abstraction. Debremariam and Semaitat wetlands were near to Bahir Dar city. The major human activities on these sites include grazing, waste dumping, water abstraction, tree plantation, washing and bathing. RA1 and RA2 were located relatively far from human settlements and agricultural practices; hence they are relatively less impacted by anthropogenic activities. The study wetlands were selected based on a preliminary study conducted during January, 2017.

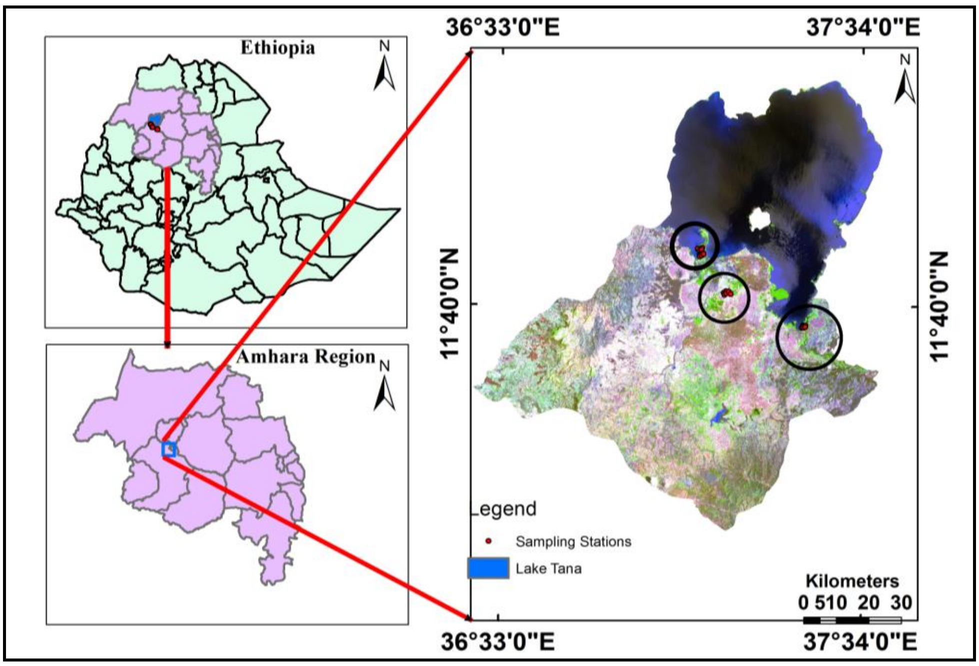

Fig 1: Map of the study area

Sampling Design

Based on the size of the study wetlands, 3 to 6 permanent sampling segments (stations) were selected from each wetland with the smallest wetlands having a lower number of sampling stations. The sampling stations were selected within each wetland along a gradient of visible anthropogenic disturbance including both least impaired and highly impaired sites (eg. presence of hydrological modification, habitat alteration, grazing, farming, etc.). The accessibility of the wetland was also taken into consideration. A total of 24 sampling stations was fixed in the six study wetlands. Ecological data (habitat quality, physicochemical parameters, macrophytes and macroinvertebrates) were assessed from each sampling stations of the study area during the wet season (August to October, 2017) and the dry season (February to March, 2018).

Table 1: Geographical description of sampling sites

Wetlands	Vicinity	Category	Wetland type	Coordinates		
				Latitude	Longitude	Altitude
Chimb Abay	Chimba	Agricultural	Marsh	1294425	301297	1820
Estumit	Estumit	Agricultural	Marsh	1306435	293992	1810
Rasa Abay 1	Estumit	Reference	Marsh	1307598	294229	1800
Ras Abay 2	Estumit	Reference	Marsh	1308008	294164	1790
Debremariam	Bahir-Dar town	Urban	Marsh	1284080	326003	1785
Sematat	Bahir-Dar town	Urban	Marsh	1283497	325689	1780

Data Collection

Physical habitat quality assessments

At each sampling station, habitat quality characteristics were evaluated based on the USEPA wetland habitat assessment protocol (Gernes and Helgen, 2002) [16]. The degree of human disturbance was obtained by assessing several habitat attributes including habitat alteration (tree removal, tree plantation and grazing), hydrological modifications (drainage, ditching and filling) and land use patterns such as waste dumping and farming, which were assigned numerical scores along a gradient of optimal to poor based on visual inspection according to Hruby (2004) [17] which was modified by (Mereta *et al*., 2013) [24].

An estimate of the relative degree of human disturbance was obtained by qualitatively scoring the level of impact of each activity or development at each site. A score of 1 was assigned to no or minimal disturbance, 2 to moderate and 3 to highly disturbed sites. The overall disturbance score for each site was determined by adding the partial values given to each individual factor (nine different factors in total). The study site with a high score on this portion of the assessment likely indicates more human interference and lower habitat quality, whereas a low score indicates higher habitat quality. The overall human disturbance score ranges from 9 to 27. The scores indicate the degree of disturbance of the sampling sites and were used to classify sampling sites as low human impact (reference) or severe human impact (degraded). The criteria used for designating reference and impaired wetland sites based on the qualitative scoring of human activities are shown in table 2.

Table 2: Criteria used for designating reference and impaired (degraded) wetland sites (Mereta *et al*., 2013) [24]. A score of 1 was awarded for no or minimal disturbance, 2 for moderate disturbance and 3 for high disturbance.

Disturbance		Score = 1	Score = 2	Score = 3
Habitat alteration	Grazing	Minimal grazing	Moderate grazing	Intensive grazing
	Vegetation removal	<10% vegetation removal	10-50 of vegetation removal	> 50% vegetation removal
	Tree plantation	no tree plantation	tree plantation at <50 m but not in the wetland	tree plantation in the wetland
Land Use	Farming	farming > 50 m from the wetland	farming in a distance of < 50m from the wetland	farming in the wetland
	Waste dumping	no waste dumping	waste dumping near the wetland	waste dumping in the wetland
	Settlement	no settlements	Settlements in a distance of > 50 m from the wetland	Settlements in a distance of < 50 m from the wetland
Hydrological modification	Draining and ditching	no draining and ditching	draining nearby < 50 m	draining in the wetland
	Filling	no filling	filling near the wetland	filling in the wetland
	Water abstraction	no dewatering	dewatering near the wetland	dewatering in the wetland

In-situ measurement of physicochemical parameters

In situ measurements were taken for water temperature, dissolved oxygen (DO), electric conductivity (EC), total dissolved solids (TDS), Biological oxygen demand (BOD), turbidity (TU), salinity, pH and wetland depth before mid day during wet and dry seasons in all of the study sites. The measurements of BOD and DO were taken using a HACH portable multimeter (Model HI98193). Water temperature, salinity, TDS and conductivity were measured using a combined portable professional serious multimeter (Model Pro 30) while, turbidity and pH were measured using a separate turbidity and pH meters respectively. In addition, the depth of the wetlands and their longitude, latitude and altitude were measured at each sampling site using a meter stick and Garmin GPS. The water quality parameter values were then summarized as mean and standard deviation for each parameter at each site.

Water samples were collected from each sampling site for the analysis of total suspended solid and nutrients (nitrate, nitrite, ammonia, ammonium ion and phosphate) by using one litter acid washed plastic sampling bottles. During sampling, the bottles were rinsed three times with wetland water at each sampling point prior to taking the water sample. All of the water quality parameters were measured and collected in the morning hours (9:00-12:00) at a depth of 10 cm from the water surface. The collected samples were packed in ice cooled boxes in the field and transported to the water laboratory of Amhara Design and Supervision Enterprise in Ethiopia for chemical water quality analysis.

Laboratory analysis of water quality parameters

Laboratory analysis of water, nitrate, nitrite, Ammonia, Ammonium ion, phosphate and total suspended solids (TSS) was conducted based on the procedures detailed in Palintest water analysis techniques. The analysis of phosphate and nitrate were based on Palintest Phosphate LR method and the Palintest Nitratest method respectively, using a water analysis instrument (Photometer 7100) whereas TSS was done by using the aluminum reductase method. All water quality measurements were averaged for the samples collected from each wetland.

Data analysis

Prior to conducting statistical analysis, the data were tested for normality using the Shapiro-Wilk test to determine the test statistics. Since the data were not normally distributed, non parametric test (Kruskal-Wallis and Mann-Whitney U tests) were applied. Basic statistical measurement was carried out and results were expressed as mean ± SD. Comparison for variations ($p< 0.05$) in physicochemical and habitat quality parameters among the six sampling sites were done using non parametric Kruskal-Wallis test. When water and habitat quality variables were significantly different, Dunn's non parametric multiple comparison *post hoc* test was used to indicate sites that differed. Mann-Whitney U test was used to evaluate whether the physico-chemical parameters significantly vary ($p< 0.05$) between seasons. Principal component analysis (PCA) was performed on the correlation matrix of means of normalized environmental parameters by site (16 parameters × 6 sampling sites) to reduce the dimensions of the original data sets and to identify latent factors affecting water quality. The number of significant principal components (PCs) was determined based on both scree plot and Eigen value one criterion. The Eigen value one criterion indicates that PCs with Eigen values greater than one are regarded as significant when the correlation matrix is used in the analysis (Yidana *et al*., 2008). Varimax rotation was performed on extracted PC axes to improve the interpretation of PCA, as it increased the absolute values of larger loadings and reduced the absolute values of smaller loadings within each component. Liu *et al.* (2003) classified the factor loadings as strong, moderate and weak corresponding to absolute loading values of >0.75, 0.75- 0.5, and 0.5 - 0.3, respectively. Tables and graphs were used to visualize differences in physicochemical and habitat quality parameters among the study sites as well as the wet and dry seasons. All statistical analyses were performed using the SPSS statistical software Version 20 (SPSS Inc, 2016), PAST statistical software Version 3.2 and Excel spreadsheet, 2007.

Results

Wetland physical habitat quality assessments

The results of site characterization on the basis of notable human activities such as habitat alteration, hydrological modification and land use pattern occurring within the wetlands and their surrounding areas are presented in table 3. Based on these parameters the level of human disturbance on each site was determined. The mean human disturbance scores (HDS) were significantly vary among the sampling sites (F = 119.6; $p< 0.05$). The highest HDS was recorded at DM and SEM sampling sites with a score of 23 each while the lowest was recorded at RA1 and RA2 with a score of 9.

Table 3: Physical habitat quality measured at the sites (numbers in the brackets are SDV)

	Sampling sites					
Parameters	**CA (n =6)**	**EST (n =6)**	**RA1 (n =3)**	**RA2 (n =3)**	**DM (n=3)**	**SEM (n =3)**
GR	2.5 (0.5)	2.5(0.5)	1	1	2	2
VR	3 (0)	2.5(0.5)	1	1	3	3
TP	1.5(0.5)	1.5(0.5)	1	1	2	2
FR	2.5(0.5)	2.5(0.5)	1	1	2	2
WD	1(0)	1(0)	1	1	3	3
ST	1(0)	1.5(0.5)	1	1	3	3
DD	2.5 (0.5)	1(0)	1	1	3	3
FL	1(0)	1(0)	1	1	2	2
WA	2.5(0.5)	2.5(0.5)	1	1	3	3
HDS	17.5 (2.7)	16 (3.3)	9 (0)	9 (0)	23 (0)	23 (0)

NB: GR, Grazing; VR, Vegetation removal; TP, Tree plantation; FR, Farming; WD, waste damping; ST, settlement; DD, Draining and ditching; FL, filling; WA, water abstraction, n = number of sampling stations

Physicochemical variables

The average values of environmental variables recorded during the study period are presented in table 4. The examined environmental variables except nitrite, DO, TSS, salinity and BOD showed a significant variation between seasons (Z- test, $p< 0.05$). The higher mean values of nitrate, phosphate, ammonia, ammonium, depth and TU were recorded during the wet season, whereas EC, TDS and water temperature values increased during the dry season. All environmental variables except nitrite also showed a statistical significant difference among sampling sites (Chi-square, $p< 0.05$). The highest mean value of DO and lowest mean values of EC, TDS, TU, temperature, BOD, phosphate and ammonium were recorded at RA1 and RA2 sampling sites. On the other hand EC, TSS, TDS, TU, phosphate and nitrate concentrations were highest at Chimba Abay and Semaitat sampling sites. High values of ammonium and BOD and low value of DO were recorded at Sematat, Debre Mariam and Estumit sampling sites.

Table 4: Mean values ± standard deviation of physicochemical variables of the study sites used in the analysis, where F is the test statistics and P is the level of significance for testing differences of each variable among stations

Variables		**Sampling sites**						**Season**	
	Unit	**EST**	**RA1**	**RA2**	**CH**	**DM**	**SEM**	**Wet**	**Dry**
Depth	Meter	0.82±0.3	0.77±0.26	0.80±0.53	0.62±0.23	0.82±0.26	0.47±0.5	0.83±0.2^{a}	0.61±0.3^{b}
Temp	^{o}C	20.29±1.0	19.0±0.6	19.37±0.8	21.14±2.04	22.9±1.2	19.3±2.2	19.70±2^{a}	21.16±1.9^{b}
pH	-	8.07±0.3	7.59±0.2	8.05±0.14	8.09±0.31	7.76±0.06	8.43±0.4	7.94±0.4^{a}	8.10±0.3^{b}
EC	mS cm^{-1}	194.31±7	100.0±27.6	135.83±2.1	340.94±165.3	136.67±5.2	285.18±2	184.85±90^{a}	273.57±1^{b}
DO	mg/L	3.99±0.3	4.13±0.28	4.18±0.19	3.68±0.17	2.77±1.03	2.83±0.81	3.70±0.5^{a}	3.61±0.8^{a}
TU	NTU	13.04±4.8	7.57±1.65	14.17±1.9	56.16±46.98	8.79±4.3	21.4±3.99	34.53±39^{a}	13.05±5.5^{b}
TDS	mg/L	140.92±9	85..33±18.3	182.4±16.2	240.25±220.2	98± 5.1	212.43±15	122.32±5^{a}	209.42±2^{b}
TSS	mg/L	0.24±0.3	0.16±0.05	0.25±0.03	0.14±0.08	0.16±0.08	0.43±0.1	0.16±0.2^{a}	0.17±0.1^{a}
BOD	mg/L	3.94±0.3	3.23±1.5	3.92±0.1	3.52±1.11	4.13±0.62	4.72±0.3	3.79±0.92^{a}	3.93±0.86^{a}
SAL	mg/L	0.10±0.04	0.10±00	0.10±00	0.10±0.01	0.10±0.03	0.14±0.02	0.11±0.02^{a}	0.10±0.03^{a}
Ammonia	mg/L	0.04±0.04	0.02±0.04	0.02±0.1	0.32±0.37	0.02±0.02	0.12±0.06	0.20±0.29^{a}	0.03±0.04^{b}
Nitrate	mg/L	1.70±0.7	1.45±0.41	1.97 ±0.4	3.20±1.25	1.77±0.62	2.03±0.66	2.31±1.10^{a}	1.69±1.01^{b}
Nitrite	mg/L	0.04±0.04	0.04±0.01	0.02±0.02	0.07±0.06	0.06±0.12	0.08±0.12	0.07±0.09^{a}	0.03±0.03^{a}
Ammonium	mg/L	0.09±0.09	0.03±0.04	0.03±0.02	0.03±0.03	0.03±0.03	0.64±0.15	0.10±0.1^{a}	0.02±0.02^{b}
Phosphate	mg/L	0.33±0.35	0.05±0.06	0.19±0.18	0.68±0.59	0.51±0.26	0.53±0.20	0.48±0.1^{a}	0.23±0.04^{b}
HDS	-	16 ± 3.5	9±0	9±0	17.5 ±2.5	23±0	23±0		

NB: EST; Estumit, RA1; Ras Abay1, RA2: Ras Abay2, CA: Chimba Abay, DM; Debre Mariam, SEM: Semaitat, EC; Electrical conductivity, DO; Dissolved oxygen, TDS; total dissolved solid, TSS; total suspended solid, TU; turbidity, BOD; biological oxygen demand, SAL; salinity

Multivariate Analysis (PCA)

In this study, PCA extracted two significant PCs with Eigen values > 1, explaining about 80.8% of the total variation in the entire data set. The first PC accounted for 53.4% of the total variation between the sampling sites, had strong positive loadings on: EC, TU, TDS, ammonia, nitrate and strong negative loadings on depth. pH, phosphate, nitrite and salinity loaded moderately in this component. The second PC explained 27.4% of the total variation between sampling sites and strongly loadings on: DO, temperature, ammonium and HDS. (Table 5).

Table 5: Principal Component loading matrix indicating loadings of Physico-chemical parameters on significant Principal Components (PCs)

	Rotated Components	
Environmental variables	**PC1**	**PC 2**
EC	0.975	0.148
TU	0.966	0.037
TDS	0.944	-0.049
Ammonia	0.921	0.175
Nitrate	0.847	0.299
Depth	-0.817	0.09
pH	0.726	-0.063
Phosphate	0.725	0.683
DO	-0.019	-0.97
Temp	0.234	0.968
Ammonium	-0.285	0.952
HDS	0.278	0.941
Nitrite	0.558	0.666
TSS	-0.188	-0.303
BOD	-0.118	0.657
SAL	-0.617	-0.083
Eigenvalue	8.55	4.38
% of total variance	0.534	0.274
% Cumulative variance	0.534	0.808

The bi-plot of the first two significant principal components as indicated by figure 2 showed that turbidity was closely associated with TDS, EC, pH, ammonia and nitrate and showed inversely related to depth and TSS. These parameters mainly attributed to Chimba Abay sampling site. DM and SEM samplingsites distinctiveness were attributed to mainly nitrite, phosphate, temperature, Ammonium, HDS and BOD. The parameters influencing the distinction in EST were depth, salinity and TSS while, RA1 and RA2 were associated with dissolved oxygen.

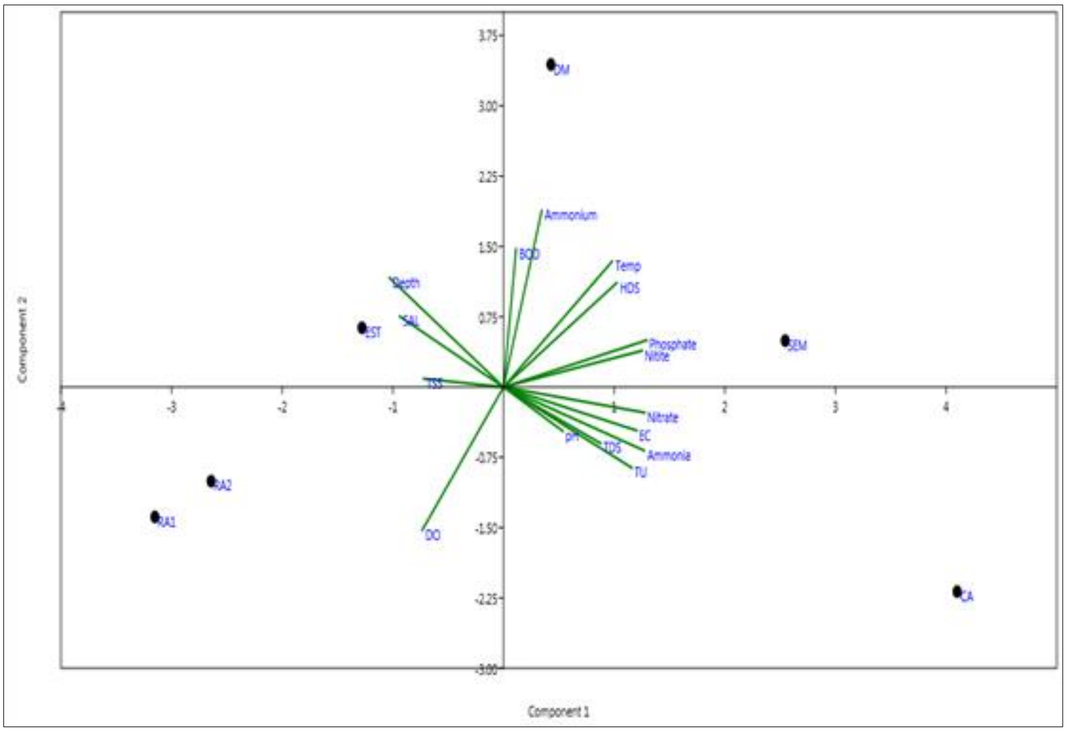

Fig 2: Principal Component Analysis (PCA) ordination diagram of environmental factors at the study sites.

Discussion

Spatial and temporal variability of water quality parameters

The quality of water is determined by its physical, chemical and biological properties which are influenced by a host of natural and human factors (Zedler and Kercher, 2005; Maltby, 2009) [38, 22]. The natural factors are geological, hydrological and climatological while human factors include polluting activities such as discharges of agricultural activities, domestic, industrial, urban and other waste waters and the disposal of chemicals into drainage basins (Maltby, 2009; Keddy, 2010) [22, 18]. In this study, pH, temperature, DO, BOD, EC, turbidity, TSS and TDS of water sampled from the six wetlands of CA, EST, RA1, RA2, SEM and DM on the lower part of GAR catchment were determined.

Water temperature was found to vary across the sampling sites and seasons of the study area. The lowest average water temperature was recorded in Ras Abay1 and Ras Abay2 sampling sites where there were dense macrophyte vegetation and relatively less anthropogenic activities. The lowest average temperature recorded at these sites was probably due to the shading effect of the macrophyte canopy. On the other hand, relatively high temperature was recorded in Chimba Abay, Estumit, Debre Mariam and Semaitat sampling sites, in which there were high anthropogenic pressure and sparse macrophytes. This could be attributed to direct penetration of sunlight into the wetland and the highest turbidity and TSS. A similar observation was made by the findings of (Deborde *et al*. 2016) [7]. Analysis of seasonal differences in water temperature revealed higher levels in the dry season than in the wet season in all study sites of the present study. Mereta *et al*. (2013) [22] have reported similar seasonal variation in water temperature of wetlands in Ethiopia. The seasonal variation of temperature in the present study is related to seasonal variation in atmospheric temperature and lighting conditions.

The pH values in the wetlands of this study were generally on the alkaline side (pH >7) at all study sites and sampling periods. The values were varied among sampling sites which range between 7.5 and 8.7 pH units. The maximum value of 8.7 pH units was recorded on Semaitat sampling site during the wet season and the minimum value 7.5 pH units was recorded at RA1 during the dry season. The high level of pH recorded at the Semaitat sampling site could be associated with increased use of alkaline detergent wastes from Bahir-Dar town and alkaline material from wastewater in industrial areas, pesticides and fertilizers from agricultural activities (Chang, 2008; Alavaisha *et al*., 2019) [5, 4]. The observed values except the Semaitat sampling site of the present study show a relative agreement with pH values of surface water, which lie within the range of 6.5 to 8.5 pH units (Chapman, 1996; BIS, 2003; Fajardo *et al*., 2015) [6, 4, 12]. The pH value at Semaitat sampling site (8.7) was a slight variation from the normal range of freshwater and requires due attention. The greater the deviation from the normal range, the less life the water can support. Maintaining a stable, moderate pH is very important for wetlands because they serve as a habitat of biological diversity.

Measures of electrical conductivity and Total dissolved solids were significantly different among the sampling sites and between seasons in this study. Electrical conductivity is a measure of the concentration of dissolved ionized substances in the wetland water column (Razmkhah *et al*., 2010) [28]. The higher the content of dissolved solids in the water, the greater the amount of ions and, therefore, the higher the electrical conductivity (Chapman and Kimstach, 1996) [6]. It is not surprising that CA and SEM sampling sites had the highest mean values, as these wetlands are located in urbanized and agricultural areas that deliver large volumes of urban run-off and fertilizer runoff that contain elevated concentrations of inorganic dissolved solids. Therefore, the higher EC and TDS is attributed to the high degree of anthropogenic activities such as waste disposal and agricultural runoff. On the other hand, the lowest level of EC and TDS were recorded from RA1 and RA2 sampling sites in which relatively low anthropogenic activities within the wetlands and their surrounding area. Furthermore, the low EC values recorded on these sites could be attributed to the removal of ions from the water either through uptake of ions by macrophytes, through the process of sedimentation or adsorption process by wetland sediments. The lower EC and TDS recorded during the wet season is probably due to the dilution effects of high volume of rainwater.

The high turbidity values were recorded during the wet season and low in the dry season due to the influx of maximum rainfall from the different catchment areas carried large amounts of suspended mater that increase the water turbidity in the wet season. This same trend of turbidity was reported by (Najar *et al*., 2017) [27]. The maximum level of turbidity recorded from CA sampling site (96.3 NTU) than the others could be due to higher sediment load through surface runoff that carried soil particles from the nearby farmlands. On the other hand, the lowest mean turbidity recorded at RA1 and RA2 (6.7 NTU) probably due to the filtering out and settlements of sediments by dense wetland macrophytes.

Biochemical Oxygen Demand (BOD) was significantly different among the sampling sites of the study area. BOD is usually defined as the amount of oxygen required by bacteria in stabilizing the decomposable organic matter. It provides an idea of the quantity of biodegradable organic materials present in wetland systems, which is subjected to aerobic decomposition by microorganisms (Saha *et al*., 2017) [29]. The biodegradation of organic materials exerts oxygen tension in the water and increases the biochemical oxygen demand (Desta, 2003) [8]. BOD is an important parameter for determining the level of pollution in water bodies. In the current study the highest mean values of BOD were 4.73 and 4.33 mg/L in Semaitat and Debre Mariam sampling sites respectively which were significantly higher than the other sites. On the other hand, the lowest mean value 2.63 mg/L was recorded on Ras Abay1 sampling site during the dry season. The highest concentrations of BOD in Semaitat and Debre Mariam sampling sites may have been due to disposal of solid and liquid waste materials from Bahir-Dar town. As stated by Sawyer *et al*. (1994) [30], the effluents disposed by domestic and industries into the surface water contaminate the quality of the water which can be assessed by BOD determination. According to Kumar *et al*. (2011) [19], the BOD of unpolluted water is less than 1 mg/L, moderately polluted water 2 to 9 mg/L while heavily polluted water has BOD more than 10 mg/L. Based on these standards, all study sites of this study fall under moderately polluted category.

The levels of DO recorded at different sampling sites were ranged from 2.8 to 4.3±0.17 which is below the permissible limits of 5 to 14.2 mg/l set by (Chapman and Kimstach 1996) [6]. Relatively highest DO value 4.3 mg/l was recorded at RA2 and the lowest DO value 2.23 mg/l mg was recorded at SEM which is not suitable for aquatic organisms. DO is crucial for wetland organisms dependent on aerobic respiration (Mitsch and Gosselink, 2000) [26]. Decomposition of decaying organic matter by bacteria, removes dissolved oxygen from water to the detriment of other aquatic organisms. As oxygen gets depleted, species composition of the wetlands may change dramatically or die off or leave the area altogether and hence, low oxygen tolerant organisms may prevail in the same area. About half of oxygen demanding pollutants come from non-point sources (Keddy, 2010) [18].

Significant variations were recorded in the concentration of nutrients (Nitrate, Nitrite, Ammonia, Ammonium ion and Phosphate) among sampling sites and sampling seasons in the study wetlands. The highest level of nutrient concentration was recorded from wetlands in which high anthropogenic activities are carried out within the wetlands and their surrounding area such as Chimba Abay, Estumit, Debre Mariam and Semaitat. This could be attributed to a high concentration of nutrients discharged from the surrounding farmlands and sewage discharge from Bahir-Dar town. Similarly, Mereta *et al*., (2013) [24], found the highest concentration of nutrients in highly disturbed wetlands than less disturbed wetlands. Discharge of sewerage and agricultural activities through excess application of inorganic fertilizers and manure are sources of nitrates in water (Chapman and Kimstach, 1996; Vega *et al*., 1988) [6, 34]. Metabolic waste, excretory products and decaying organic matter oxidized by nitrifying bacteria also contribute to increase in nitrate levels in water bodies (Vega *et al*., 1988) [34]. On the other hand, the relatively low level of nutrients recorded from RA1 and RA2 was possibly due to the assimilation of nutrients by the dense macrophytes. According to Mitsch and Gosselink (2000) [26], wetland vegetation plays a vital role in water quality improvement in wetlands as they physically trap sediments and assimilate nutrients such as nitrogen and phosphorous species in biomass. The higher nutrients levels recorded during the wet season could be attributed to additional discharge from the catchment area such as sewage discharge from Bahir-Dar town as well as runoff from informal settlements and the surrounding farmlands as a result of heavy rainfall. The Seasonal influx of allochthonous organic and inorganic materials during the rainy season is a characteristic feature of most tropical wetlands. The concentration of nitrate and phosphate recorded in this study was much higher than the standard limits set by (Chapman and Kimstach, 1996) [6]. Nitrates, in low concentration, are important nutrients for wetland flora. However, in high concentrations, nitrates are considered to be a pollutant. High nitrate levels, such as those caused by sewage, support high bacteria concentrations which consume oxygen from the water. This oxygen depletion results in the loss of many of the wetland biota (Mitsch and Gosselink, 2000) [26].

The physical habitat quality of wetlands

Great variations in Human Disturbance Scores (HDS) were recorded among the sampling sites of the present study area. A relatively highest level of HDS was recorded from DM, SEM and CA sampling sites. The relatively high level of HDS recorded from these sampling sites could be attributed to the high anthropogenic activities within the wetlands and their surrounding area, including farming, draining, filling, livestock grazing, vegetation removal, tree plantation and sewage discharge. Sice these sites are adjacent to urban and agricultural areas, they have exposed to a wide range of anthropogenic disturbance. Similar observations have been reported by (Yimer and Mengistou, 2009; Mereta *et al*., 2013; Wondie, 2018) [37, 24, 35]. They found that, high HDS for the wetlands, which were exposed to high anthropogenic activities. On the other hand, the lowest HDS were recorded from RA1 and RA2. This could be due to relatively low anthropogenic disturbances within the wetlands and their surrounding area. These sites are located in a rural area, which is far from human settlements and also inaccessible to human activities because the sites are surrounded other water bodies.

The result of Principal Component Analysis (PCA) indicated that RA1 and RA2 were correlated with dissolved oxygen. These sites were also characterized by relatively low HDS, conductivity, turbidity and nutrient concentration compared to the other sites. The relatively low nutrient, conductivity and turbidity level and high dissolved oxygen concentration recorded from these sampling sites might be due to a relatively low anthropogenic impact on the wetlands and the surrounding area. Similar findings have been reported by (Mereta *et al*., 2013; Wondie, 2018; Fierro *et al*., 2018) [24, 35, 13]. In their study, lower concentration of nutrients, TDS and EC and higher concentration of DO were obtained at least impaired (reference) wetlands than impaired wetlands.

CA and EST sampling sites were located where agricultural activity dominates. Thus, these sites likely influenced by external discharge which consists of runoff from agricultural activities in the catchments. In addition to agricultural runoff, these sites are degraded by draining, overgrazing, vegetation removal and tree plantation. PCA indicated that, these sites are strongly associated with nitrate, ammonia, TDS, TU, EC, pH and TSS. The strong association of these variables can be explained by the extensive agricultural activities and other anthropogenic disturbances within and the surrounding areas of the sites which is sources of the above variables. Li, *et al*. (2008) [20]; Wondie (2018) [35], have also found a close association of these variables with agricultural activities.

DM and SEM sampling sites are located in adjacent to Bahir-dear town. As indicated by PCA these sites are strongly correlated with organic pollutants, including BOD, ammonium and phosphate. The organic and inorganic matter inputs from domestic wastewater, municipal sewage and industry discharges could be the possible contributing factors for the recorded high pollutant concentrations at these sites (Wondie, 2018) [35]. Furthermore, these sites are degraded by draining, filling, tree plantation, vegetation removal, and grazing. Generally, agricultural and urban impacted sites were characterized by high levels of nutrients, EC, TDS, BOD, HDS and low concentration of DO. These could be attributed to the intensive anthropogenic pressure on the wetlands and the surrounding area.

Conclusion

Most of the water quality parameters such as nutrients, BOD, conductivity, TDS, TSS and DO were significantly vary among the sampling sites and season. The underlined reasons for such spatial variations of water quality parameters were unsustainable anthropogenic activities such as agricultural activities, urbanization, grazing, over exploitation of wetland resources and others. Those sampling sites adjacent to agricultural and urban areas were highly disturbed (polluted) than other sites as reveled by PCA. Most of the water quality parameters in the disturbed sites have revealed that the wetlands are degrading and requires undue attention. In order to prevent further deterioration of the wetlands, the unsustainable anthropogenic activities should be minimized.

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