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Seasonal and spatial variation of reservoir water quality in the southwest of Ethiopia

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Abstract This research investigated the spatiotemporal variation of water quality in the Gilgel Gibe reservoir, Ethiopia, using physicochemical water quality parameters. Nonparametric tests and multivariate statistical techniques were used to evaluate data sets measured during dry and rainy seasons. Electrical conductivity (EC), pH, biochemical oxygen demand (BOD_5), total phosphorus (TP), total nitrogen (TN), nitrate (NO_3^-), total dissolved solids (TDSs), and total suspended solids (TSSs) were all significantly different among seasons (Mann-Whitney *U* test, $p < 0.01$). In addition, principal component analysis distinguished dry season samples from wet season samples. The dry season was positively associated with EC, pH, TP, TN, NO_3^-, TDS, and TSS and negatively associated with BOD_5. The wet season was in contrast associated with high values of turbidity, soluble reactive phosphorus (SRP), water temperature, and dissolved oxygen (DO). Within the reservoir, spatial variation was observed for some of the water quality parameters, with significant difference at $p = < 0.05$. Overall, high nutrient concentrations suggest eutrophic conditions, likely due to high nutrient loading from the watershed. Levels of TSS, attributed to inputs from tributaries, have been excessive enough to inhibit light penetration and thus have a considerable impact on the aquatic food web. Our findings indicate that the reservoir is at high risk of eutrophication and siltation, and hence, urgent action should target the planning and implementation of integrated watershed management for this and similar reservoirs in the region.

Keywords Eutrophication · Gilgel Gibe · Physicochemical · Reservoir · Spatiotemporal variability

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Introduction

Reservoirs are artificial water bodies that have economic and ecological importance (Wetzel 2001). They play a pivotal role in freshwater resource accessibility in many regions throughout the world. Although many reservoirs were initially constructed with a single purpose (e.g., production of hydroelectric power), they commonly evolve towards provision of a multitude of services (Jorgensen et al. 2005). Reservoirs provide important ecological services (Atobatele and Ugwumba 2008), serving as rich ecological habitats (Menetrey et al. 2005) and hot spots of biodiversity, supporting abundant as well as unique and rare species (Williams 2003). Furthermore, reservoirs have diverse social and economic values like water management and serve as a source or sink for heat, sediments, and solutes that can

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cause severe effects far downstream from the dam (Wetzel 2001). Similarly, in Ethiopia, reservoirs often provide rural communities with an important source of dietary protein, consumable water for people and domesticated animals, irrigation water for horticulture, and income from fishing and eco-tourism (FAO 2008; Ndebele-Murisa et al. 2010).

Ethiopia, like many countries experiencing development, is undertaking large dam construction projects, primarily for the purpose of electric power generation and integrated irrigation development. The reservoirs are an important component of infrastructure expansion, as a part of a movement to improve quality of life for people in the region. Ethiopia has 12 major river basins, 12 large lakes (Berhanu et al. 2014), and numerous smaller ponds, lakes, rivers, reservoirs, and wetlands, particularly in the central, western, and south western parts of the country (Awulachew et al. 2007; Tessema et al. 2014). The major lakes and reservoirs cover 7334 and 275 km^2, respectively (FAO 2003), and are distributed throughout the country.

Reservoirs are vulnerable to water quality deterioration, because of the nature of their formation by damming of rivers to contain and accumulate surface water and the associated particulate and dissolved chemicals. Tropical reservoirs in regions undergoing economic development are particularly vulnerable, because increasing human activities in the reservoir's watershed can lead to nutrient loading and eutrophication (Chapman 1996). In Ethiopia for example, rapidly increasing population levels and subsequent land use changes (e.g., deforestation, agriculture) within a given watershed can result in degradation of reservoir water quality (Ebisa 2010). High sediment loads as well as chemicals and nutrients in runoff from agricultural land, manufacturing, and other related sources have been observed impacting Ethiopian reservoirs (Wolancho 2012). As a consequence, physical and chemical water quality degradation is among the most prevalent problems in Ethiopia (UNESCO 2004), and watershed activities may limit the ability of a given reservoir to deliver its effective functions (Mustapha 2009).

The Gilgel Gibe reservoir is one of the five major reservoirs in Ethiopia. Beside its primary purpose which is power generation, this 54-km^2 reservoir now provides food (fish) and a source of income, acts as a research and educational area, a source of water for the local residents, and a source of water for cattle during the dry season. In order to maintain the multiple uses of the reservoir, not only water availability but also water quality has taken on high importance. Water quality has become a topic of concern due to the many diverse uses of the reservoir (Chapman 1996; Jorgensen et al. 2005), particularly as actual and potential sources of food. Thus, it is a logical choice for a case study due to its economic and ecological significance and its vulnerability to pollution.

Reliable information on water quality is imperative to manage reservoirs sustainably, and to prevent and control water pollution. Because of its importance to the local community and its role as water source for Gilgel Gibe II and III hydroelectric power stations, Gilgel Gibe reservoir is a clear candidate for water quality research to inform natural resource managers and policy makers. Yet, currently, there is little known about the spatial and seasonal water physico-chemical quality characteristics in the reservoir. Although case studies have been conducted in the reservoir (Devi et al. 2008;Yewhalaw et al. 2009; Broothaerts et al. 2012; Ambelu et al. 2013), they have been limited in time and space, covering only the dry season and ignoring within-reservoir spatial variation, which may be important. Spatial and temporal variation in water quality is to be expected due to variation in edaphic factors, climatic conditions, source of water, land use type, seasonal hydrology, and density of fish stock (Aladesanmi et al. 2014). This spatio-temporal variation is known to be important for biological diversity and for the provision of resources from aquatic ecosystems (Venkatesharaju et al. 2010). Filling this knowledge gap will help regulate the health of this aquatic ecosystem, will support sustainable and economically beneficial use of resources by the local community (Makhlough 2008), and will inform management strategies for other similar reservoirs.

The goal of this study is to assess the spatio-temporal variation of physico-chemical water quality parameters within the Gilgel Gibe Reservoir. We hypothesized that during the dry season when the input of water is low, most water quality chemical parameters would have higher concentrations (as compared to the wet season) due to resuspension, absence of dilution, and increased evaporation. We also hypothesized that water quality would vary spatially throughout the reservoir, with the highest concentrations of terrestrially derived pollutants (like TN and TP) found near the mouths of the largest tributaries, which serve as the main sources.

Materials and methods

Study area

The Gilgel Gibe reservoir is situated in the Gibe-Omo River Basin in Oromiya regional state of Jimma zone, 260 km southwest of Addis Ababa (Fig. 1). The climate of the study area is classified as tropical humid and belongs to the high-altitude cool tropic area of the country. There is unimodal pattern of seasonal rainfall distribution where up to 60% of the rainfall falling during the rainy season (Demissie et al. 2013). According to unpublished data of Ethiopian National Meteorological Agency, from the year 1968–2015, the average annual rainfall in Jimma stations was 243 mm and minimum (43 mm) recorded in August and December, respectively. The maximum mean monthly rainfall (287 mm) was occurred during June. In terms of the rainfall variability of the country by river basins, the West-flowing rivers (Abay, Baro-Akobo, Omo-Gibe, and Tekeze) receive much rainfall (Berhanu et al. 2014).

The selection of the study area was based on its importance for power generation, its economic importance to the local community, and its accessibility. The reservoir was built on the Gilgel Gibe River in 1998, with a primary purpose of hydroelectric power production. The reservoir is characterized by a large 40-m-high dam, with a storage capacity of 839 Mm^3 covering more

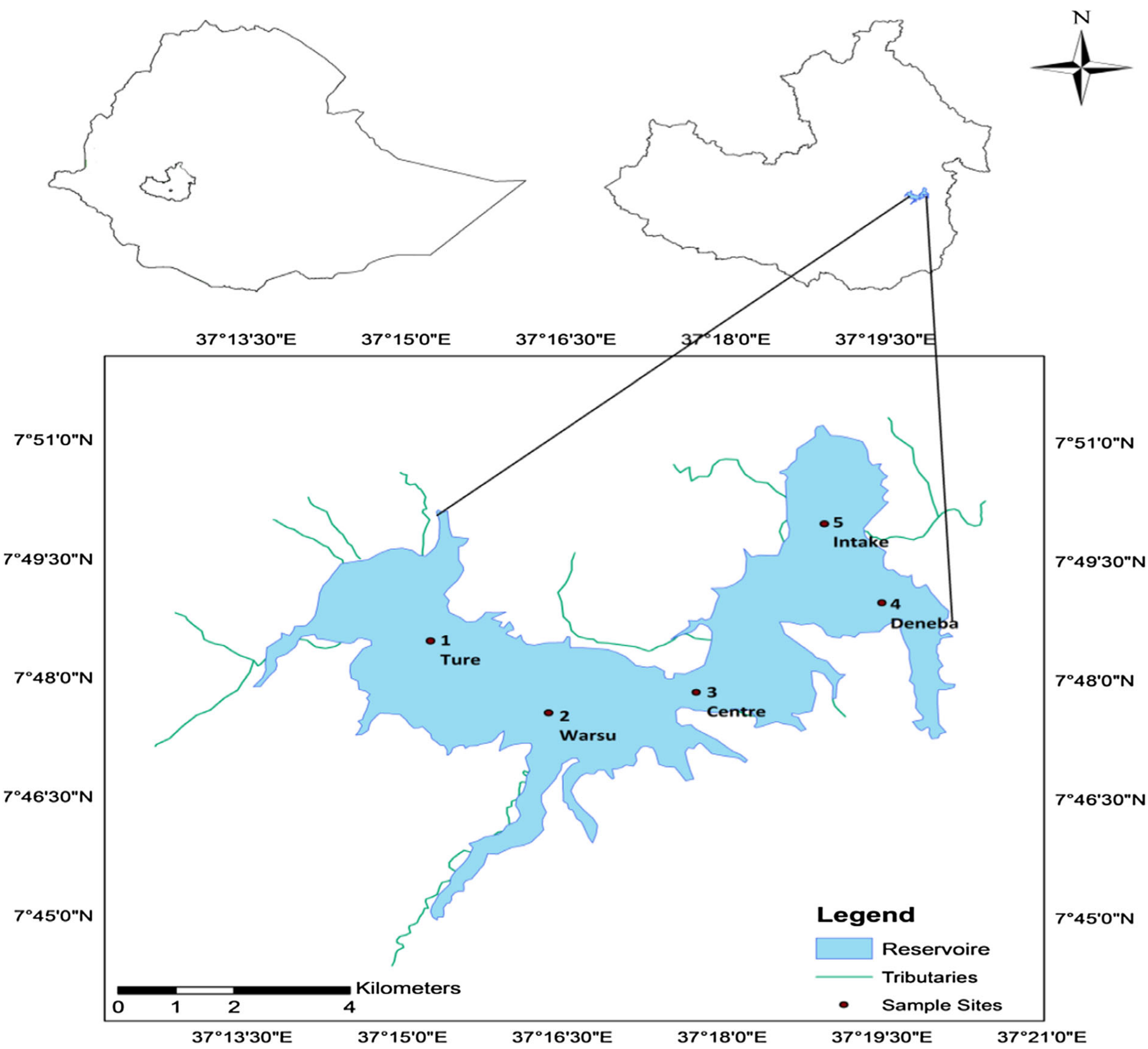

Fig. 1 Location of Gilgel Gibe reservoir and sampling stations in south west Ethiopia

than 54 km^2 of land at its full supply level and with a conveyance system of tunnels and an underground power house consisting of three 61.3-MW generating units (EEPCO 2011). The site began operation in 2004 and is currently generating 184 MW at its full capacity, with annual average flow of 50.4 m^3/s, reservoir live storage of 657 million m^3, and reservoir dead storage of 182 million m^3. Based on unpublished data of Ethiopian National Meteorological Agency, from the year 2005/2006–2014/2015, the minimum reservoir water level was 1654 m a.s.l and the maximum was 1671.2 m a.s.l., with maximum and minimum depths of 35 and 2 m, respectively, and an average depth of 20 m. The reservoir receives water from the surrounding tributaries, namely, the Nadaguda, Nedi, Yedi, and Gilgel Gibe Rivers. The total catchment area is 4225 km^2, and the watershed is highly agricultural, serving as an important food source for the region (Wakjira et al. 2016).

Sample collection

Five sampling sites (stations) were identified (Ture (St. 1), Warsu (St. 2), Centre (St. 3), Deneba (St. 4), and Intake (St. 5)). Sample site determination was made on the relative proximity of the pelagic zone towards the tributaries; hence, St. 1, St. 2, St. 4, and St. 5 sites were comparatively near to Gibe, Nadaguda, Yedi, and Nedhi river inflows while the sampling site St. 3 was chosen as an approximately central point. Samples were taken during wet season from November 18, 2014 to November 26, 2014 and dry season from March 21, 2015 to March 28, 2015. During each season, 15 water samples for laboratory analysis (three from each location) were taken from different sampling sites of the reservoir using a Van Dorn Sampler, and collected in clean 250-mL polyethylene bottles after pre-rinsing with sample water. The average values were calculated for analysis in this study (Gu et al. 2016). All samples were collected in cold boxes and transported to the laboratory. For analysis of nitrate, total suspended solid (TSS) and total dissolved solid (TDS) samples were sifted by Whatman filter paper with a pore size of 0.45 μm using the standard method (APHA 1999).

Water quality analyses

Twelve physico-chemical water quality parameters were analyzed on-site and in the laboratory. Onsite measurement of temperature, pH, conductivity, and dissolved oxygen was done using a HACH, HQ40d portable multi-meter, and turbidity was measured using Wag tech turbidity meter with a model number of wag-WT 3020. Other physico-chemical parameters including 5-day biochemical oxygen demand (BOD_5), TSS, total nitrogen (TN), TDS, nitrate (NO_3^-), total phosphorus (TP), and soluble reactive phosphorus (SRP) were investigated in the laboratory of Environmental Health Science and Technology at Jimma University.

BOD_5 is the difference between the concentration of dissolved oxygen (DO) in water sample taken instantaneously and concentration of DO that has been incubated for 5 days at 20 °C in the dark. TSS and TDS were determined using the gravimetric method (APHA 1999). For TSS, water samples are filtered through a pre-weighed glass fiber filter paper, and are placed into a 105 °C drying oven to remove any remaining water, then removed from the oven, and placed in a desiccator to cool to room temperature, and the difference in weight is calculated as TSS. For TDS, the filtrate was evaporated to dryness in a pre-weighed dish and dried to a constant weight at 180 °C. The increase in the weight of the dish after drying represents the total dissolved solids.

TP was analyzed by the ascorbic acid method with direct reading on a spectrophotometer following persulfate oxidation. In this method, water sample undergo a digestion process to convert combined phosphate in to orthophosphate which then reacts with ammonium molybdate and potassium antimonyl tartrate in an acid medium to form a heteropoly acid—phosphomolybdic acid; this reaction can be reduced by ascorbic acid to form highly colored molybdenum blue (APHA 1999). Nitrate was analyzed using a kit LCK 138 that covers a concentration range of 1–16 mg/L. Inorganically and organically bounded nitrogen compounds are oxidized to nitrate by processing with peroxo disulfate, and finally determined by reading on a spectrophotometer.

Statistical methods

Concentration differences for each water quality variable between the wet and dry season were examined using the Mann-Whitney *U* test, and differences among sites were examined using one way ANOVA, both at a significance level of $p < 0.05$. Spearman rank-order correlations (Spearman *R* coefficient) were used to study the correlation structure between variables as datasets had a non-normal distribution of water quality parameters. The box plot analysis was used to assess temporal variability in water quality parameter concentrations based on the median, minimum, maximum, and 25th and 75th percentile values (Dou et al. 2016). The reservoir water quality variables were also subjected to multivariate statistical techniques using principal component analysis (PCA), which is one of the most commonly used multivariate statistical techniques (Quinn and Keough 2002). Data analyses were performed with PAST, Statistica 8 software, and SPSS version 20.

Results

Spatial and seasonal water quality variation

The physico-chemical parameters under study are given in Table 1 (wet season) and Table 2 (dry season). The concentrations of EC, pH, BOD_5, TP, TN, NO_3^-, TDS, and TSS were significantly different among seasons (Mann-Whitney *U* test, $p < 0.01$), while other parameters remained the same during the dry and wet seasons.

Spatial descriptive statistics result of the analyzed parameters showed that there are parameters that express significant changes during the study period, indicating spatial variability of chemical composition among sampling sites (Tables 1 and 2) for wet and dry seasons, respectively.

Water temperature

Water temperature varied from 22.2 to 22.87 °C in the wet season and 22.49 to 25 °C in the dry season (Tables 1 and 2) with higher temperatures in the dry season (Fig. 2). Spatially, the concentration was highest at St. 2 sampling sites for both wet and dry seasons (Tables 1 and 2). The temperature during the study period was within the range of 20–30 °C (Tables 1 and 2), which is suitable to sustain warm-water aquatic life. The observed maximum dry season temperature is most likely associated with increased temperature of surface water as a result of higher air temperature.

pH

Overall, the pH values ranged from 6.5 to 8.1 (Fig. 2b). It was higher in the dry season than the wet season, which may be due to the low water level during the dry season causing a concentration of base cations, or an

Table 1 The mean and standard deviation values of water quality parameters among five sites at Gilgel Gibe Reservoir, during the wet season

WQ parameters	St. 1 Mean ± SD	St. 2 Mean ± SD	St. 3 Mean ± SD	St. 4 Mean ± SD	St. 5 Mean ± SD
DO	5.28 (0.4) ^{a}	3.94 (1.75) ^{a}	3.85 (1.69) ^{a}	4.38 (1.38) ^{a}	4.58 (2.6) ^{a}
EC	80.27 (0.57) ^{a}	87.1 (3.68) ^{b}	83.2 (1.75) ^{ab}	80.27 (0.57) ^{a}	81 (1.6) ^{a}
WT	22.8 (1.39) ^{a}	22.87 (1.34) ^{a}	22.8 (1.06) ^{a}	22.8 (1.39) ^{a}	22.2 (0.7) ^{a}
pH	6.46 (0.16) ^{a}	6.72 (0.2) ^{a}	6.8 (0.36) ^{a}	6.46 (0.16) ^{a}	7.05 (0.67) ^{a}
BOD	17 (0.99) ^{a}	21.79 (2.98) ^{a}	21.8 (2.76) ^{a}	15.78 (12.4) ^{a}	24.75 (5) ^{a}
TP	0.17 (0.01) ^{a}	0.11 (0.02) ^{a}	0.24 (0.8) ^{a}	0.17 (0.01) ^{a}	0.23 (0.08) ^{a}
SRP	0.01 (0) ^{a}	0.04 (0.02) ^{bc}	0.05 (0.01) ^{bc}	0.01 (0) ^{a}	0.01 (0) ^{a}
TN	1.19 (0.76) ^{a}	1.52 (0.16) ^{a}	2.2 (0.06) ^{a}	1.19 (0.76) ^{a}	1.93 (0.7) ^{a}
NO_3^-	0.69 (0.28) ^{a}	0.66 (0.29) ^{a}	0.62 (0.1) ^{a}	0.69 (0.28) ^{a}	0.64 (0.12) ^{a}
TDS	64.7 (0.58) ^{a}	68.67 (2.08) ^{b}	66.3 (1.25) ^{a}	64.67 (0.58) ^{a}	65 (1) ^{a}
TSS	30 (20) ^{a}	120 (52.9) ^{b}	51.8 (25.1) ^{a}	30 (20) ^{ac}	86.67 (15.3) ^{a}
TURB	53.57 (12.7)	47.07 (8.24)	95.3 (59.45)	53.57 (12.68)	77.7 (60.9)

Except for EC (μS/cm), WT (°C), pH, and TURB (NTU), the rest are in mg/L. The different superscript letters indicate statistical difference among sites at $p < 0.05$

WQ water quality, *St.* station, *WT* water temperature, *DO* dissolved oxygen, *EC* electrical conductivity, pH, *BOD* biological oxygen demand, *TP* total phosphate, *SRP* soluble reactive phosphorus, *TN* total nitrogen, NO_3^- nitrate, *TDS* total dissolved, *TSS* total suspended solids, *TURB* turbidity

Table 2 The mean and standard deviation values of water quality parameters among five sites at Gilgel Gibe Reservoir, during the dry season

WQ parameters	St. 1 Mean ± SD	St. 2 Mean ± SD	St. 3 Mean ± SD	St. 4 Mean ± SD	St. 5 Mean ± SD
DO	4.58 (1.36)	3.06 (1.2)	6.38 (0.86)	3.52 (2.5)	3.86 (2.18)
EC	111.8 (4.99) [a]	106.5 (0.05) [ac]	103.5 (2.89) [bc]	97.4 (1.69) [b]	98 (1.65) [b]
WT	23.87 (0.65) [a]	25 (1.4) [a]	22.8 (1.3) [a]	23.7 (1.7) [a]	22.49 (0.77) [a]
pH	7.55 (0.15) [a]	7.14 (0.3) [a]	7.54 (1.37) [a]	8.09 (0.3) [a]	7.4 (0.75) [a]
BOD	1.63 (1.03) [a]	4.04 (0.12) [a]	1.05 (1.4) [a]	2.14 (2.32) [a]	1.45 (0.89) [a]
TP	0.49 (0.2) [a]	0.32 (0.02) [a]	0.28 (0.06) [a]	0.32 (0.07) [a]	0.27 (0.03) [a]
SRP	0.01 (0) [a]	0.04 (0.02) [a]	0.04 (0.03) [a]	0.06 (0.05) [a]	0.07 (0.05) [a]
TN	10.6 (1.5) [a]	4.3 (2.79) [a]	8.58 (5.67) [a]	11.63 (1.8) [a]	11.26 (0.45) [a]
NO_3^-	1.68 (0.55) [a]	1.18 (0.19) [a]	1.14 (0.67) [a]	1.45 (0.22) [a]	1.06 (0) [a]
TDS	84.7 (3.06) [a]	81 (0) ac	79.5 (2.2) [bc]	75.7 (1.5) [b]	76 (1) [bc]
TSS	450 (26.38) [a]	330 (160) [a]	485 (482) [a]	372 (196) [a]	383 (255) [a]
TURB	77.6 (26.38) [a]	48.57 (4.8) [a]	6.38 (0.86) b	49 (5.97) [a]	50.06 (2.9) [a]

Variable names are the same as in Table 1. The different superscript letters indicate statistical difference among sites at $p < 0.05$

excess of primary productivity over respiration during that season, consuming CO_2 and reducing H^+. Spatially, the highest concentration value of pH was recorded at St. 5 and St. 4 sites during the wet and dry seasons, respectively (Tables 1 and 2).

Dissolved oxygen

There was no significant difference between the seasons in median DO (Mann-Whitney U test, $p > 0.05$) (Fig. 2c). The concentration of DO varied from 3.85 to 5.28 mg/L during the wet season and 3.06 to 6.38 mg/L in dry season (Tables 1 and 2). However, the dry season PCA analysis revealed that the DO is among the variables that characterizes PC2 (Fig. 5b).

Biochemical oxygen demand

The BOD_5 gives an estimate of the amount of biochemically degradable organic matter present in a sample. BOD_5 varied seasonally ($p < 0.05$); the value ranges from 15.78 to 24.75 mg/L in the wet season and from 1.05 to 4.04 mg/L in the dry season (Tables 1 and 2). The wet season values exceed the guideline ambient environment standards for Ethiopia (≤ 5 mg/L). During the wet season, BOD_5 was positively correlated with pH ($r = 0.98$, $p < 0.01$) and the highest BOD_5 mean value was recorded at St. 5 in wet season and at St. 2 in the dry season (Tables 1 and 2). The dry season PCA (Fig. 5b) has showed that BOD_5 is among the variables that explained 36% of variability in PC2.

Electrical conductivity and TDS

Conductivity ranged from 80.27 to 87.1 μS/cm in the wet season and 97.4 to 111.8 μS/cm in the dry season. The EC mean values were observed to be statistically highest in wet season for sampling sites 2 and 3, while in dry season, highest values were recorded at sites 1 and 2 (Tables 1 and 2). Seasonally, conductivity varied significantly ($p < 0.01$). The first quartile of EC in the dry season is higher than the fourth quartile of the wet season (Fig. 3a). The highest concentration values results were recorded in St. 2 and St. 1 during the wet and dry seasons, respectively (Tables 1 and 2). EC is the variable most strongly associated with PC2 of wet and PC1 of the dry season (Fig. 5a, b).

EC and TDS were common for both wet and dry seasons to vary statistically in sampling sites (Tables 1 and 2). There was a highly significant positive correlation of TDS with EC both in the wet season ($r = 0.976$ at $p < 0 .01$) and in the dry season ($r = 0.972$ at $p < 0.01$). TDS also explained PC2 and PC1 of the wet and dry seasons, respectively (Fig. 5a, b).

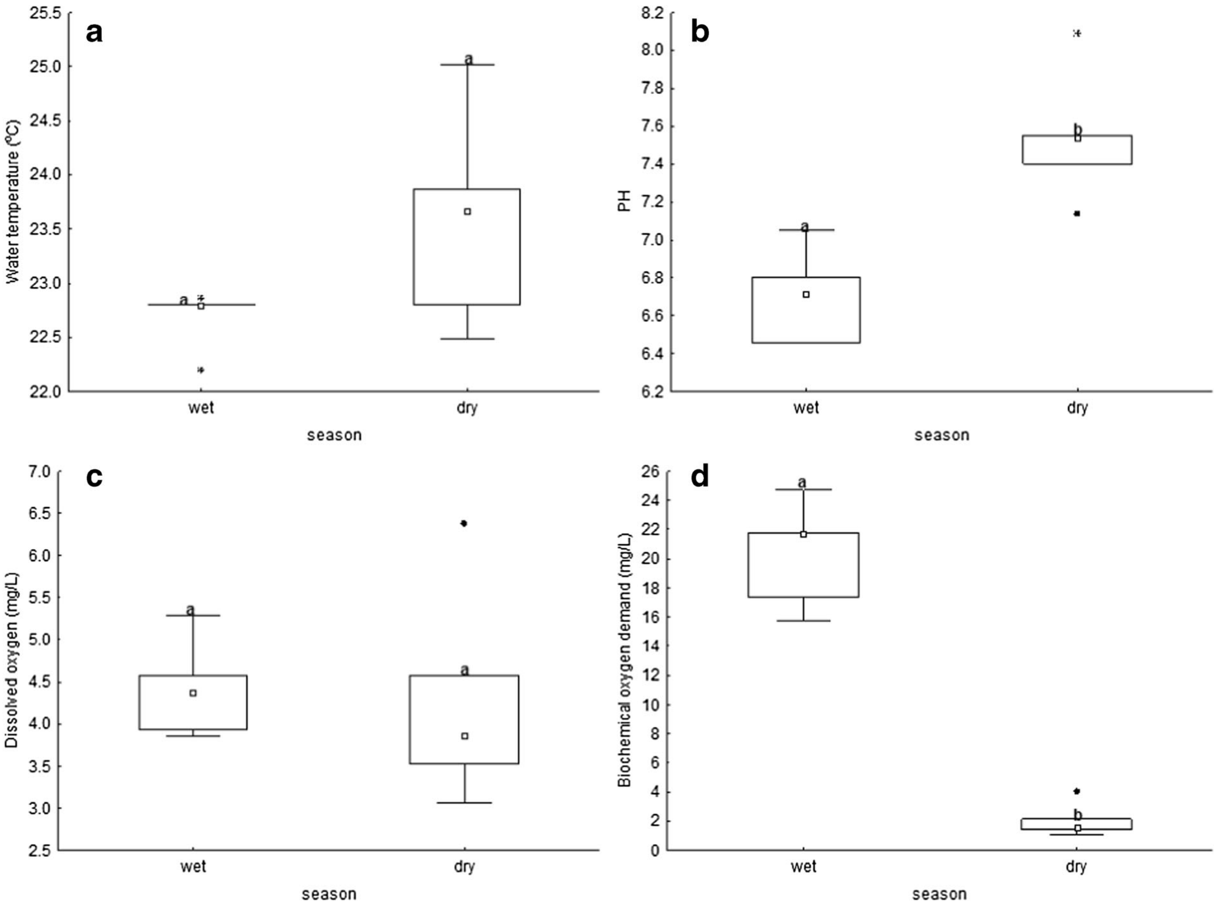

Fig. 2 Box and whisker plot of seasonal variation of water quality parameters. Water temperature (**a**), pH (**b**), DO (**c**), and BOD_5 (**d**). Small white squares represent the median values, boxes represent the interquartile range, plus signs represent the extremes, small black dots represent the outliers, and range bars show the maximum and minimum values. Different letters (*a* and *b*) over box plots indicate a significant difference (Mann-Whitney *U* test, $p < 0.05$)

Turbidity and TSS

The value of turbidity ranged from 47.07 to 95.3 NTU during the wet season and 48.57 to 77.6 NTU during the dry season (Tables 1 and 2), with no significant difference between seasons (Fig. 3c). The highest mean concentration values of turbidity were observed at site 3 (95.3 mg/L) during the wet season and 77.6 mg/L at site 1 in dry season (Tables 1 and 2). Turbidity is one of the variables associated with PC1 of the wet season PCA analysis (Fig. 5a).

TSS values obtained at sampling sites in wet season vary between 30 and 120 mg/L, and in dry season, it varies between 330 and 450 mg/L (Tables 1 and 2). The dry season had a significantly higher TSS concentration value than the wet season (Mann-Whitney *U* test) (Fig. 3d). Elevated values of TSS were recorded at St. 2 sampling site during the wet season (Table 1), while all sites had high TSS during the dry season comparing the wet season. TSS is among the variable that characterizes the PC2 of both wet and dry seasons (Fig. 5a, b).

Nutrients

The dry season inter-quartile range of TN and NO_3^- was found to be high, indicating a higher variability in their concentration as compared to the wet season (Fig. 4c, d). The seasonal Mann-Whitney *U* test for the concentration of total phosphorus, total nitrogen, and nitrate showed a significant difference at $p < 0.01$, and these nutrients have higher concentration during the dry

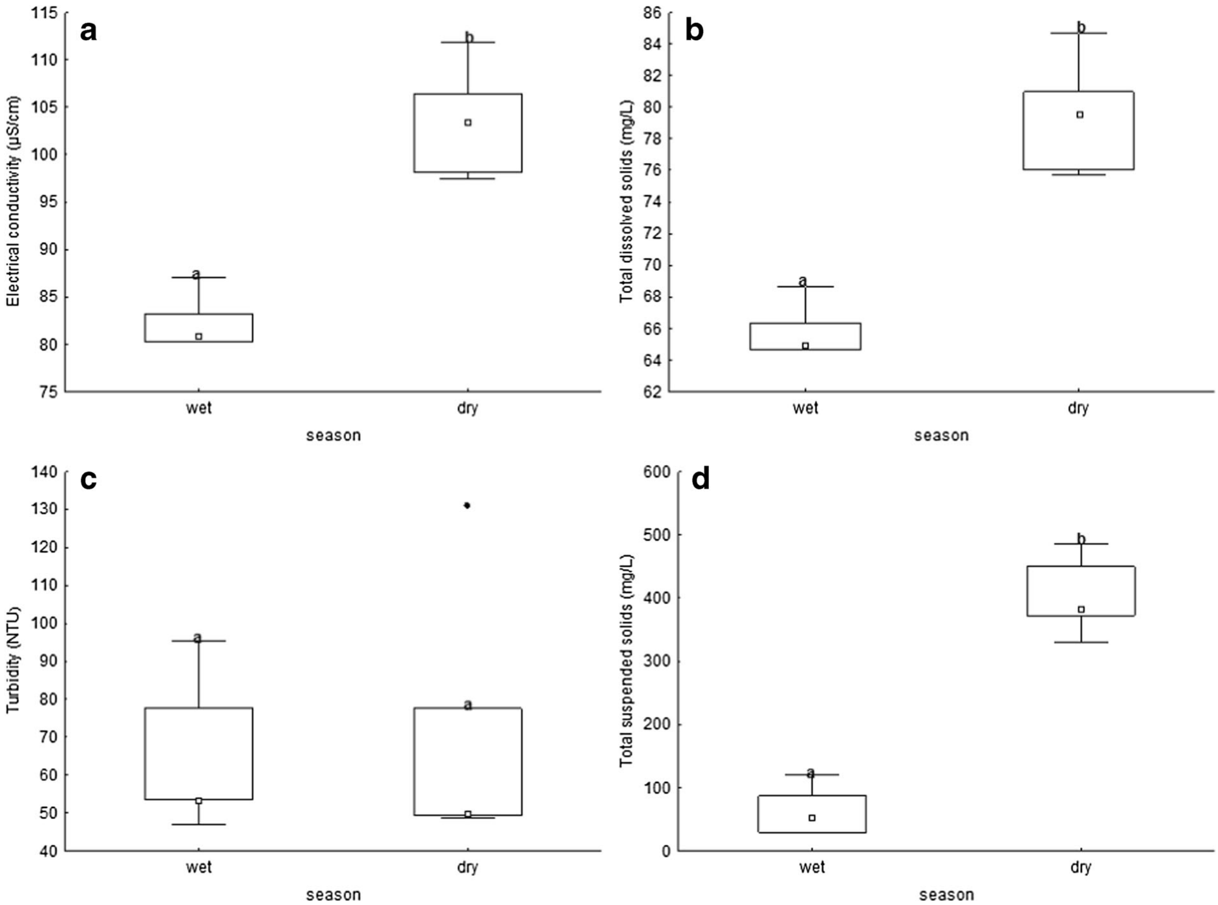

Fig. 3 Box and whisker plot of seasonal variation of water quality parameters. EC (**a**), TDS (**b**), turbidity (**c**), and TSS (**d**). Small white squares represent the median value, box represents the interquartile range (25–75 percentages), small black dot represents the outliers, and range bar shows the maximum and minimum values. Statistically significant differences (Mann-Whitney *U* test, $p < 0.05$) are represented by *a* and *b*

season (Fig. 4a, c, d). The mean concentrations of available forms of nutrients, namely, NO_3^- (1.68 mg/L) and SRP (0.07 mg/L), were higher during dry than wet seasons (Table 2 and Fig. 4).

Nitrate is one of the characteristic variables of PC1 (Fig. 5b). The highest concentration of NO_3^- was recorded at St. 1 sampling site and for SRP was at St. 5 sampling sites during the dry season (Table 2). In the wet season, highest value for SRP was observed at St. 2 and St. 3 sampling sites (Table 1).

TN and TP were positively correlated with the PC1 that explains 62% of the total variability (Fig. 2). The mean value of total nitrogen varied from 1.19 to 2.2 mg/L during the wet season and 4.3 mg/L to 11.6 mg/L in dry season (Tables 1 and 2), and it is among the variables that associate with PC2 of the dry season while the rest (TP, SRP, and nitrate) associated with PC1 (Fig. 5b). High TN mean value was observed at St. 3 sites during the wet season (Table 1) and at St. 4 sampling site during the dry season (Table 2).

The concentration of total phosphorus was higher in the dry season, ranging from 0.27 to 0.49 mg/L (Table 2). The highest concentration of TP (0.24 mg/L) was recorded during the wet season at St. 3 sampling site and 0.49 mg/L at St. 1 sampling site in the dry season (Table 2). During the wet season, TN and SRP were associated positively with PC1, and nitrate correlated negatively to PC1, explaining a total of 51% of PC1 (Fig. 5a).

Principal component analysis for each season showed that the wet season PCA extracted 84% of the variance of that season's data (Fig. 5a). Of this, the first factor (PC1) extracted 51% of the variance, while PC2

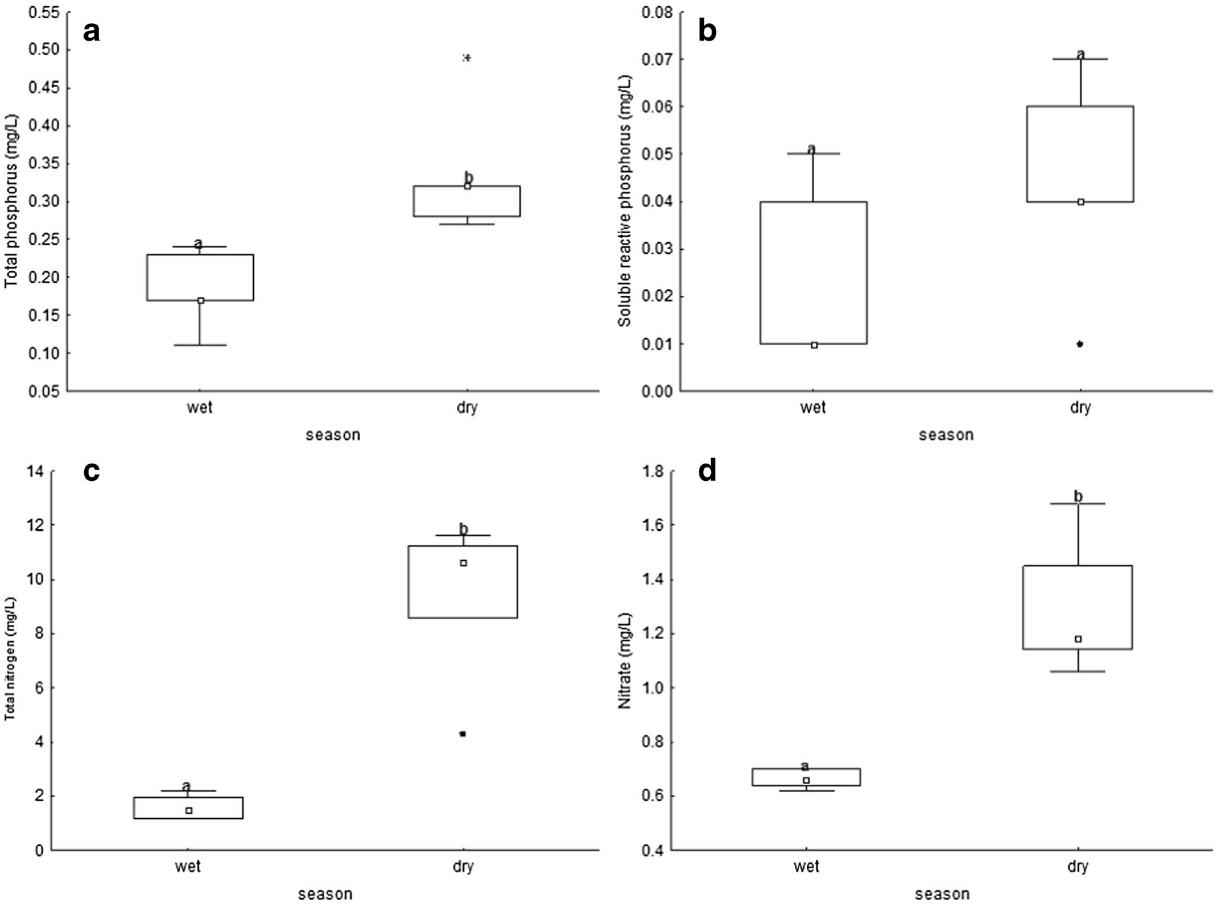

Fig. 4 Box and whisker plot of seasonal variation of water quality parameters. TP (**a**), SRP (**b**), TN (**c**), and nitrate (**d**). Small black squares represent the median value, box represents the interquartile range (25–75 percentages), plus sign represent the extremes, small black dot represents the outliers, and range bar shows the maximum and minimum values. Statistically significant differences (Mann-Whitney *U* test, $p < 0.05$) are indicated by *a* and *b*

explained 32% of the variance. The dry season PCA (Fig. 5b) extracted 76% of the variance of that season. Of this, PC1explained 40% and was correlated positively with TDS, EC, TP, temperature, and NO_3^- and negatively with SRP. PC2 explained 36% and was positively correlated with TN, pH, TSS, turbidity, and DO and negatively correlated with BOD_5 (Figs. 5b).

Discussion

We found that there was a distinct seasonal pattern in water quality of the Gilgel Gibe reservoir, with most parameters higher during the dry season (EC, pH, TP, TN, $NO3^-$, TDS, and TSS) in contrast to BOD_5, which was higher during the wet season. The high pH value during the dry season could be due to low water level, while the decreased pH value in wet season may be due to the effect of lower pH in rain and runoff water from the tributaries. Similar results for seasonal variability in pH were reported in lakes in Nigeria (Araoye 2009; Irenosen et al. 2012), and in the Pahuj Reservoir of central India (Khan and Parveen 2012). The pH range of the study was within the range of good water quality (6.5 to 8.5), which is typical of most major drainage basins of the world (Carr and Neary 2008). It is also within the range of the guideline ambient environment standards for Ethiopia (6–9 mg/L) (EPA and UNIDO 2003).

DO values of the Gilgel Gibe reservoir ranged from 3.06 to 6.38 mg/L, where the higher end (6.38 mg/L) is within the range of other reservoirs in the region, and relative to earlier measurements in Gilgel Gibe. For instance, the Geray reservoir in the northern highlands

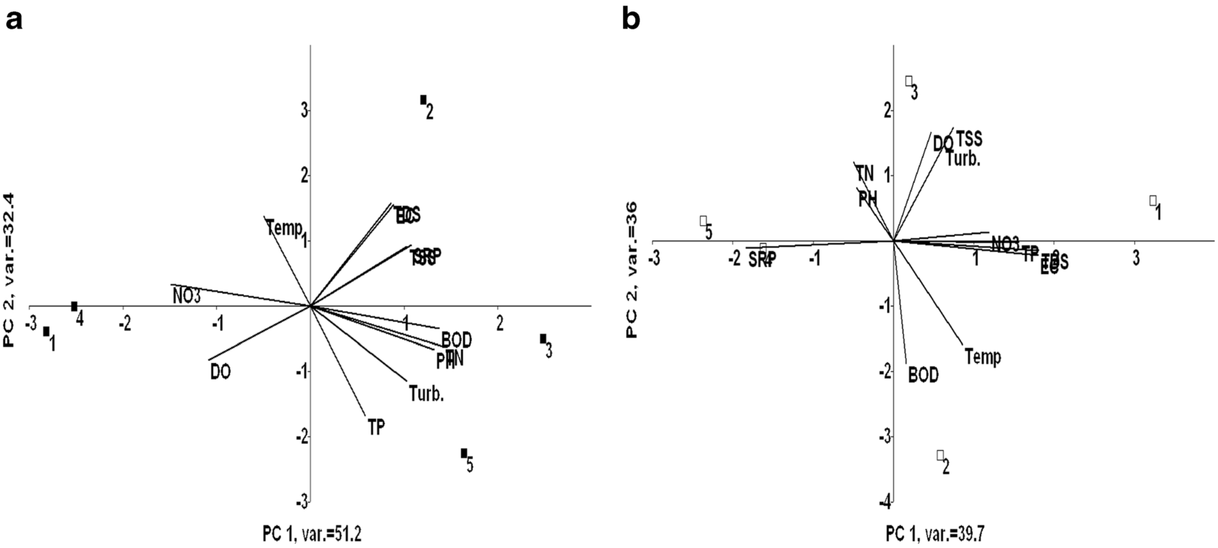

Fig. 5 Wet (**a**) and dry (**b**) season PCA analysis of Gilgel Gibe reservoir water quality parameters. Filled and Open squares are sampling sites during wet and dry season respectively

of Ethiopia had DO values ranging from 3.9 to 10.4 mg/L (Goshu 2007), and summary statistics of water quality parameters for Gilgel Gibe reservoir from 2006 to 2008 revealed DO ranging from 5 to 8.2 mg/L (Ambelu et al. 2013). This reduction in the current study of the concentration of DO may be associated with turnover or the release of anoxic bottom water from the deep reservoir (DWAF 1996) or the decomposition of organic material input through runoff (Makhlough 2008). In terms of potential biological effects, about half of our measurements were below the recommended minimum threshold of 5.0 mg/L DO for functioning and survival of biological communities, though no sites averaged DO below 2 mg/L, where death of most fish may occur (Chapman 1996). In this study, DO and temperature had a positive relationship, where a similar pattern with a positive relationship between dissolved oxygen and temperature was seen in North Central Nigeria (Meme et al. 2014).

The BOD_5 at Gilgel Gibe reservoir ranged from 1.05 to 24.75 mg/L, and was very high during the wet season. This seasonal pattern was consistent with the work of Irenosen et al. (2012) in Nigeria. Higher BOD_5 values indicate high consumption of oxygen, presumably resulting from the oxidation of a high organic pollution load. This might be a result of organic load through runoff from the surrounding land use in the study area, as suggested by Saxena and Saksena (2012). BOD_5 values of 2 mg/L or less imply healthy waters while BOD_5 values of 10 mg/L or more are typical of water bodies receiving wastewaters (Chapman 1996). In terms of impact on ecosystem services, a BOD_5 range of 0–4 mg/L is recommended for sensitive species such as salmonid fish, and for other beneficial uses (EPA and UNIDO 2003). In Gilgel Gibe, the mean BOD_5 for all sites falls within the desired range during the dry season, but greatly exceeds the 4-mg/L threshold during the wet season, indicating that organic pollution and resulting oxygen consumption is a major concern during that season.

The studied conductivity values (80.27–111.8 μS/cm) were similar to the work of Ambelu et al. (2013), which was 70–110 μS/cm, and lower than the conductivity values of Bira dam (394–402 μS/cm), Tekeze dam (260–300 μS/cm), and Tendaho reservoir (569 μS/cm) (Tessema et al. 2014). This difference may be due to the different geological characteristics of these watersheds. The observed values at Gilgel Gibe are also in the low range of conductivity of most natural freshwaters values proposed by Chapman (1996), which ranges from 10 to 1000 μS/cm. This range of EC is not of particular environmental or ecological concern. During the dry season, the increased concentration of EC and TDS, similar with findings of Zinabu (2002), may be associated with evaporation and the absence of a dilution effect, while the lower values during the wet season are hypothesized to be due to dilution from the tributaries.

The measured turbidity values in Gilgel Gibe (ranging from 47.07 to 95.3 NTU) were also proximate to 40–155 NTU measured by Ambelu et al. (2013) of the same reservoir, and it is within the range of the stated normal values by Chapman (1996), which ranges from 1 to 1000 NTU. The range of turbidity and EC during the dry season were similar to those found in the Upper Lake of Bhopal of India (Parashar et al. 2006) and the Bibi Lake in India (Umerfaruq and Solanki 2015). The concentration of TSS in Gilgel Gibe reservoir is much higher than the maximum value of the guideline ambient environment standards for Ethiopia (50 mg/L) (EPA and UNIDO 2003); this may be related to the anthropogenic action (e.g., boating for fishing activity; personal observation).

Total nutrient concentrations were higher in the dry season than the wet season, and both TN and TP were high enough to suggest eutrophication. Similar seasonal patterns in nutrient concentration were observed by Zinabu (2002) from Lake Chamo in the rift-valley lakes of Ethiopia and Garg et al. (2010) in Ramsagar reservoir of India. A high dry season mean value of TP was also reported by Ibrahim et al. (2009), which could be due to the increased concentration effect of reduced water volume. The concentration of available forms nitrate and soluble reactive phosphorus in Gilgel Gibe were also highest during the dry season, though the seasonal difference in SRP was not significant at the $p < 0.05$ level. Similar seasonal variation has been observed for nitrate and orthophosphate in a river in Bangladesh (Alam et al. 2012).

However, according to Chapman (1996), concentrations in excess of 0.2 mg/L of nitrate will be liable to stimulate algal growth and indicate possible eutrophic conditions. The values of total nitrogen were in the range of eutrophic conditions (2.5–10 mg/L). Eutrophication is often connected with low species diversity, high productivity, harmful growth of aquatic plants, and blooms of cyanobacteria that can be toxic to humans and other animals, including livestock and wildlife (DWAF 1996). A concentration of SRP above about 0.025 mg/L is typically taken as an indication of eutrophic conditions (DWAF 1996), and based on the Redfield ration N:P value was also greater than 20, which indicate P limitation. So, Gilgel Gibe also exceeds that threshold. Shen (2002) stated that the number of algae increased when total phosphorus in the water was 0.1 to 0.75 mg/L, encompassing the range that this study found in Gilgel Gibe. Based on these observations, the concentration of TN and TP of the water in the Gilgel Gibe reservoir is high enough to support growth of cyanobacteria, and blooms of cyanobacteria have indeed been observed during the study period.

Spatially, there was significant variation at $p < 0.05$ among the five sampling sites for EC, SRP, TDS, and TSS during the wet season and EC, TDS, and turbidity in dry season (Tables 1 and 2), which may be caused by pollution sources and/or climatic factors(Palma et al. 2014).

Conclusion

In this study, we assessed the spatial and seasonal variabilities of Gilgel Gibe reservoir water physicochemical properties. The measured parameters showed a seasonal fluctuation, with predominantly higher concentrations during the dry season than the wet season. Parameters like pH, EC, and nitrate have values within the range of the standards for water quality, and below the level at which they are harmful. Whereas others like DO and BOD_5, are fluctuating beyond the allowable level, suggesting a problem with low oxygen levels at times; BOD_5 was particularly high during the wet season, for instance. The values of TN and TP in the Gilgel Gibe reservoir suggest a eutrophic condition, and this is of major concern. High concentrations of nutrients, and variation among reservoir sampling sites, may reflect the effect of anthropogenic activity in the watershed and tributary system. We tried to explore simple and inexpensive water quality monitoring as in the developing nations where resource is limited with a short duration of sampling, and found major water quality changes. Further detailed studies which include other seasonal or monthly water quality trend analysis and land use changes in the watershed to relate it with tributary water quality in order to characterize reservoir water quality change is needed. This will help to identify which tributary is primarily responsible for eutrophication and resulting impairment, and will ultimately allow for corrective action to be taken (e.g., Carpenter et al. 1998).

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