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Research article

Evaluation of the impacts of turbidity on Gilgel-Gibe I reservoir storage, Omo-Gibe River Basin, Ethiopia

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ABSTRACT

Quantity and quality of the water held in the reservoir fluctuates due to turbidity alterations. The influence of turbidity on the amount of the water held in a reservoir was described explicitly in this research. This study aimed to evaluate turbidity's impact on the Gilgel-Gibe I reservoir water. The samples were obtained by longitudinally stratifying the reservoir water throughout its course. Ten burrowed pools wrapped in transparent white plastic were used to retain water, for detection of the association between turbidity and surface water temperature, and to demonstrate the vertical variation in water temperature. The pan evaporation rate was measured using two Class A pans placed in the field to indicate the disparity in the amount of water evaporated from reservoir owing to reservoir turbidity variation. SPSS and MS Excel spreadsheet softwares were used to analyze the data. According to the results of this study, turbidity and water temperature have a significant direct relationship that is positive at 9:00 and 13:00 and negative at 17:00 observation hours. From the top layer of pool water to the bottom layer, the water temperature decreased vertically. Intensity of the light rays absorbed and scattered alters with turbidity variation and significant amounts of light rays was absorbed and scattered in the most turbid water. The reported water temperature differences between the top and bottom layers at 13:00 observation hour were 9.78 °C and 1.53 °C, for the most and least turbid pool water, respectively. Turbidity directly affects reservoir water by increasing both the water temperature and evaporation rates. Among all turbid-water samples, substantial quantity of water evaporated from the most turbid-water. For the most and least turbid water samples, the volume difference of the evaporated water from the reservoir was approximately 65.812 m^3. According to these findings, if the reservoir water turbidity increases, the amount of water held in the reservoir significantly reduced due to substantial water loss.

1. Introduction

It is crucial to assess how turbidity affects stored water in water bodies via evaporation, because it causes light rays to be scattered and absorbed more readily than travel through the water in a straight line and reduces the transparency of the water [1–3]. Due to the severe global climate change affecting the world, the exposure of more land surfaces and acceleration of soil erosion, along with the

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increased entry of soil particles into water bodies, it has become a major environmental concern worldwide. Owing to the nature of their surface area and their economic significance for the growth of a specific country, this change has significant effects on water bodies, particularly reservoirs. According to Ref. [3], the concentration of suspended sediment particles is directly correlated with the turbidity of water and inversely associated with the transparency of water.

Expanding and intensifying the cultivated area increases soil erosion, reservoir sedimentation, precipitation, and surface runoff changes. This is because, deforestation has taken place to expand and intensify farmland, which alters precipitation both temporally and spatially. This variation might lead to an increase in rainfall intensity, which would increase the surface runoff [4]. According to a study done by Refs. [5,6], overland water flow increases the concentration of suspended particles entering the reservoir. These suspended particles entering the reservoir increase reservoir water turbidity. To mitigate this issue, it is essential to manage and regulate the activities and events that causes it. Additionally, applying structural and non-structural methods and techniques can help control to the inflow of soil eroded from the upstream catchment of water bodies [7–9].

Turbidity causes the raise of water temperature, because suspended particles scatter and absorb solar energy that hits the water surface. The temperature of turbid water can be decreased by lowering the quantity of suspended particles in the water and eliminating plankton, which raises the turbidity of the water. Both turbidity and water temperature drop near the reservoir's surface along its longitudinal axis [3,10–12].

Statistical, deterministic, and stochastic models can be used to simulate water temperature, each with its benefits and drawbacks. They require information to analyze the water temperature for various water bodies [7,13–15]. In this study, parametric and non-parametric statistical models were exploited from the list of models above because of the availability of data.

A significant quantity of water has been lost from constructed lakes and reservoirs compared to other natural fresh water surfaces because, the large surface area in these two water bodies exposed to the atmosphere. Evaporation occurs when the number of moving water molecules that break from the water surface and escape into the air is larger than the number that re-enters the water surface from the air and becomes entrapped in the liquid [6,16]. Depending on the location, evaporative losses from the reservoir can exceed the consumptive water usage [13].

The quantity of water evaporating from the surface of the reservoir determines the amount of water in the air. Reservoir evaporation physical drivers primarily control the magnitude of the vapor pressure difference between the water surface and the air above it. The water surface temperature, the degree of turbulent air mixing, and the atmosphere absolute humidity all influence this gradient [11,18–21].

Because a significant amount of water is lost by evaporation, reservoir storage is reduced, reservoir efficiency decreases, and has impacts on the nation's economic development by limiting the reservoir production capacity [17,22,23]. Using geoengineering and smart location, reducing reservoir evaporation is a potential solution for water conservation at the source. Therefore, estimating the amount of water that evaporates from reservoirs is crucial for achieving the intended purpose of a dam [18].

Numerous reservoirs in Ethiopia have accumulated more sediment than normal. Gilgel Gibe I is one of these reservoirs in the critical phase. Owing to rapid sedimentation, the volume of this reservoir was reduced by half within 12 years, with a 70-years serving period. If prompt corrective action is not performed, the reservoir will be completely filled with sediment within 24 years [19]. The build-up of

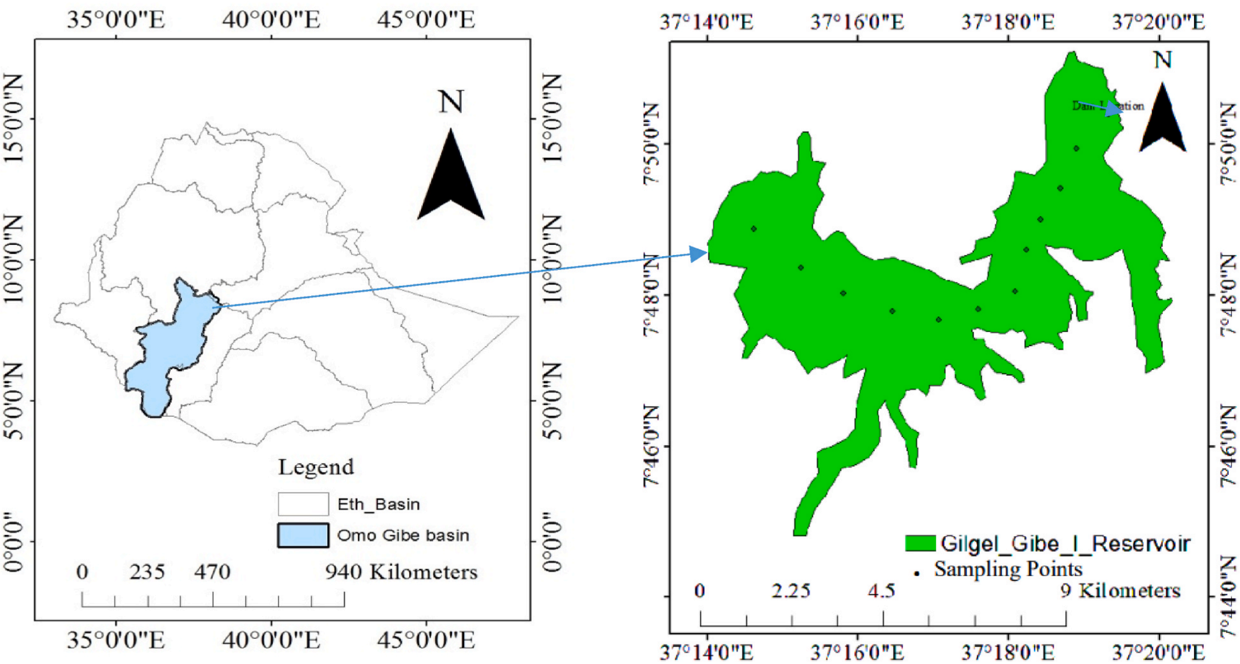

Fig. 1. Location of Gilgel-Gibe I reservoir with sampling points.

suspended particles increased the turbidity of the reservoir. Turbidity has affected the Gilgel-Gibe I reservoir as a result of significant sedimentation in this reservoir. Turbidity increases the water temperature and accelerates the evaporation rate, which decreases the amount of water in the reservoir [8]. The main purpose of this research was to provide concise and vibrant information about the impact of turbidity on reservoir storage, particularly in the Gilgel-Gibe I reservoir, and it was acquired. Increasing the knowledge and providing up-to-date information about the impact of turbidity on reservoir storage of Gilgel Gibe I, serving as a working document for policymakers, power planners, and suppliers, and adopting as a baseline data for any further investigations were the significance of this research. Hence, this study's primary objective is to evaluate turbidity's impacts on reservoir storage of the Gilgel-Gibe I.

2. Materials and methods

2.1. Description of study area

The research area, which has an approximate total catchment area of 4218 km^2, is situated in the Omo-Gibe River Basin in the Oromia regional state of the Jimma zone (Fig. 1). The latitude and longitude of the catchment area are 7°19′07.15″ to 8°12′09.49″N and 36°31′42.60″ to 37°25′16.05″ E, respectively. The study area is situated in a humid tropical high-altitude zone of the country. The distribution of seasonal rainfall showed a unimodal pattern, with up to 60 % of the total amount falling during the rainy season. The Ethiopian National Meteorological Agency's unpublished data from 1968 to 2015 indicate that the Jimma meteorological institute had an average annual rainfall of 243 mm, with a low rainfall of 43 mm reported in August and December, respectively. The largest mean monthly rainfall in June was 287 mm [20].

In 1998, a reservoir on the Gilgel-Gibe River was constructed primarily for the production of hydroelectric power. At full supply level, it encompasses approximately 54 km^2 area and is distinguished by a massive 40 m high dam with an 839 Mm^3 storage capacity. At the maximum capacity, the plant generates 184 MW and has been in operation since 2004. Its capacity is 657 million m^3 for active storage and 182 million m^3 for dead storage, with an average yearly flow of 50.4 m^3/s. There was an average depth of 20 m, with records of the maximum and minimum depths of 35 m and 2 m, respectively. The Nadaguda, Nedi, Yedi, and Gilgel Gibe river are among the nearby streams that feed water into the reservoir [20].

2.2. Experimental setup

Water samples with various turbidity values were collected from the Gilgel Gibe I reservoir and used as input data for this research. The sampling duration covered 128 days in total (May 1 to September 5, 2020) but, effective sampling days were solely 72 days, because the samples were taken only following rainfall events. This sampling time was chosen since it is a time during which a prominent quantity of suspended particles enters the reservoir. Samples were collected from the reservoir using a wooden boat which has been used for fishing by others near the reservoir and plastic cans during several rainstorms (Fig. 2a). The total number of samples collected were 72 and they were collected from 12 points following the longitudinal axis of the reservoir. Each sample was then stored in several blue plastic tankers and stored in the room provided to store them (Fig. 2b). The size of each tanker in which the water sample was stored measures 90 L. The amount of water stored in the tankers ranges from 80 to 90 L. All water stored in tankers were transported to the laboratory room and field by car. A turbidimeter was used to measure the turbidity of the water samples, and the measured samples were then brought to the field to measure the temperatures of the pools water and the rate at which water evaporates from the pans.

Among all water samples taken from the reservoir during different rainfall events, only ten samples were adopted to execute the field experiment. The selection of the samples relied on the difference in magnitude of turbidity values measured in the laboratory. A laboratory experiment was conducted in the Environmental Health Science and Engineering Department Laboratory room of Jimma University to measure the turbidity of all water samples. During turbidity measurement in the laboratory, the readings of some samples

(a) (b) (c) (d)

Fig. 2. Materials and equipment used:(a) sample taking using wooden boat and plastic cans; (b) Blue plastic tankers used to store samples; (c) burrowed pool used to store water for water temperature measurement at different levels; and (d) evaporation pan installed and adjusted on the field for evaporation rates measurement.

overlapped, and the other's readings were close to each other. Only one was selected among the overlapped readings, and readings far from each other were also considered for the field experiment. Thermometers (shorter and longer length) and evaporation pans were adopted to measure the pools water temperature at different layers and pan evaporation rates. The impact of turbidity on the storage of the Gilgel Gibe I reservoir was examined using recorded water temperature and evaporation data.

To accomplish this research goal, both laboratory and field tests were conducted. A laboratory experiment was carried out in the Jimma University Environmental Health Science and Engineering Department laboratory room to measure the turbidity of the water samples taken from the reservoir. This laboratory was equipped with all the materials and instruments needed to carry out an experiment. A turbidimeter was used to measure the turbidity of the water samples and prior to each result being observed, the device was calibrated to a predefined standard. The calibration was done using the reference standard solution (formazin polymer) and the two turbidimeter knobs. Out of the three knobs on an instrument, the bottom knob was used to set the instrument zero. After preparing the formazin polymer and distilled (turbidity-free) water, the sample cell was filled with distilled water up to the horizontal mark and gently wiped with soft tissue to remove any moisture from its outer part. After cleaning the sample cell, which was filled with distilled water, was placed in a turbidimeter. It was then pushed down until the vertical mark on the cell was lined up with a horizontal mark on the turbidimeter (Fig. 3). The cell was cleaned to enhance the amount of light that could pass through it and turbid water inside it. A cell cap seal was used to cover the sample cell, and a set zero knob was exploited to set the device to zero. After the instrument was set to zero, the standard solution prepared according to our need was added to the sample cell up to the horizontal mark. The instrument displayed turbidity values of the standard solution, and the procedure was repeated twice to ensure the accuracy of the recorded data.

Once the instrument was reset to zero and the turbidity of the prepared standard solution was recorded, turbidity of each sample was measured. It was possible to measure the turbidity of the water samples by comparing the intensity of the light rays dispersed by the turbid water samples and the standard solution. The collected results demonstrated a strong direct correlation between scattered light rays and the turbidity of the water samples. For the most turbid water sample, there was a considerable dispersion of light rays released. Indian Standard technique (IS) 3025, which was reaffirmed in 2002, was used to measure the turbidity of the water samples, and the results were displayed in nephelometric turbidity units [26,27]. The outcomes of laboratory experiments were adopted as input data for field experiments to gauge the temperature of pools water at different layers and the evaporation of pan water to estimate the rates of reservoir evaporation. All selected turbid water were adopted to measure the water temperature at different layers in various pools water and among all the measured turbid water the most and the least turbid water were used to measure pan evaporation to estimate reservoir evaporation.

Field experiments were conducted to measure water temperature in various pools with varying turbidity values and pans water evaporation for the estimation of reservoir water temperature and reservoir water evaporation to illustrate the impact of turbidity on the Gilgel Gibe I reservoir storage. We decided to adopt the field for the execution of all field experiments owing to the unsuitability of the reservoir surface in creating a model and setting of the instrument exploited during the tests. Among all the meteorological institutes (stations) in the reservoir's catchment area, only one institute was selected. The choice of location for conducting field tests is influenced by a number of factors, such as the reservoir's proximity to the meteorological institute, the availability of an instrument used for the tests, and the accessibility of the area for developing the model. Jimma Meteorological Institute was chosen as the best institution in the catchment area of the Gilgel Gibe I reservoir, since it met all the criteria listed above.

By creating a reservoir model after digging test holes or pools, water temperature was measured at various levels in different pools. To avoid the insolation of incoming solar radiation, the experimental field was cleaned prior to the digging of the pools. The pools were spaced out over the experimental area and were made by excavating holes with 0.45 m in diameter, 0.2 m depth, and 3 m apart (Fig. 2c). The opted pool dimensions are ideal for illustrating the correlation between turbidity and water temperature in the pool, as well as for displaying the vertical variation of water temperature at various layers within the pool. Each of these pools was excavated by hand, and thin metal rings held the white transparent plastic lining in place. The plastic was pressed tightly against the soil to

Fig. 3. Measuring water turbidity in laboratory using turbidimeter for different water samples.

maximize soil-plastic contact (Fig. 4a). This white translucent material served as a barrier to prevent pool water from seeping into the soil and groundwater from the nearby soil from entering the pools. Each pit held turbid water varying in suspended particle concentration up to 12 mm below the edge of the pool. The purpose of adopting the white transparent plastic was to counteract the effects of solar radiation absorption, which could release additional energy into the pool water and increase the temperature of the water.

Using two portable digital thermometers, the temperature of the water at different pools levels was determined [23]. The temperature of the water at the top level of the pool (Fig. 4b) was measured using a shorter thermometer, and the temperature of the water at the mid-depth and bottom layer of the pool (Fig. 4c) was measured using a longer thermometer. Water temperature data were logged for 15 days from September 10 to 24 2020. The amount of water lost to evaporation was replaced within a 24-h period prior to data collection, in order to maintain the water level at the same level and reduce the impact of water level reductions on pool water temperature. Pools were filled at 8:00 a.m. throughout all the experimental periods. The turbidity of all selected samples (10) needed to replace the water evaporated from each pool was measured before the commencement of field tests in the laboratory and was stored in the room provided for storing them.

Pools water temperature was measured at different hours of the day. The chosen observation hours for pools water temperature at the surfaces were 9:00, 11:00, 13:00, 15:00, and 17:00 to investigate the linkage between turbidity and surface water temperature. Water temperature at mid-depths and bottom layers of the pools was measured at 9:00, 13:00, and 17:00 to identify downward vertical variations in water temperature within a pool and among the pools. Among the data gathered at five selected observation hours (9:00,11:00, 13:00, 15:00, and 17:00), the data taken at 9:00, 13:00, and 17:00 were used to determine the relationship between turbidity and surface water temperature. The differences in surface water temperature logged in successive observation hours were insignificant. Hence, data logged at only three non-consecutive observation hours were adopted among the data recorded at five different observation hours. Among the water temperature data recorded at three observation hours at different layers, the data obtained at 13:00 were used to depict how the water temperature altered vertically downward within a pool and water temperature differences at the same level in different pools. The average values of all recorded water temperatures over the course of the observation period were used to analyze the data for all selected observation hours. SPSS version 20 software and Microsoft Excel 2016 spreadsheet software were used to analyze the recorded results.

Class A evaporation pan was used to measure the evaporation rate for the two water samples (most and least turbid water) obtained from the reservoir. According to Ref. [12], the pan used has the following measurements: 1.207 m diameter, 0.254 m depth, and it is situated on a wooden platform around 15 cm above the ground. On the wooden platform the pans were properly positioned (Fig. 2d), so that the water poured into them (Fig. 5a) was kept at the same level across the pan's perimeter. Pan evaporation data could be recorded within a 24-h interval in depth (mm) using a vertical rod in the stilling well located at the center of the pan [24].

The evaporation data for both the most turbid (Fig. 5c) and least turbid (Fig. 5b) water samples were collected using two pans for 40 days from September 11 to October 20 (inclusive). For other samples, interpolation was used to compute the pan evaporation values for a given water turbidity values. Since it shouldn't have to fall below the pan's full supply level by more than 50 mm, water lost to evaporation was replaced as soon as the water level dropped by 30 mm. To estimate the daily pan evaporation intensity, data gathered during the course of the investigation were averaged. To determine amount of the water evaporated from the reservoir, the pan evaporation and pan coefficient were employed.

(a) (b) (c)

Fig. 4. Measuring water temperature: (a) white translucent plastic sheet used to cover the pool; (b) shorter thermometer used to measure water surface temperature; and (c) longer thermometer exploited to measure water temperature at the mid-depth and bottom layer of the pool.

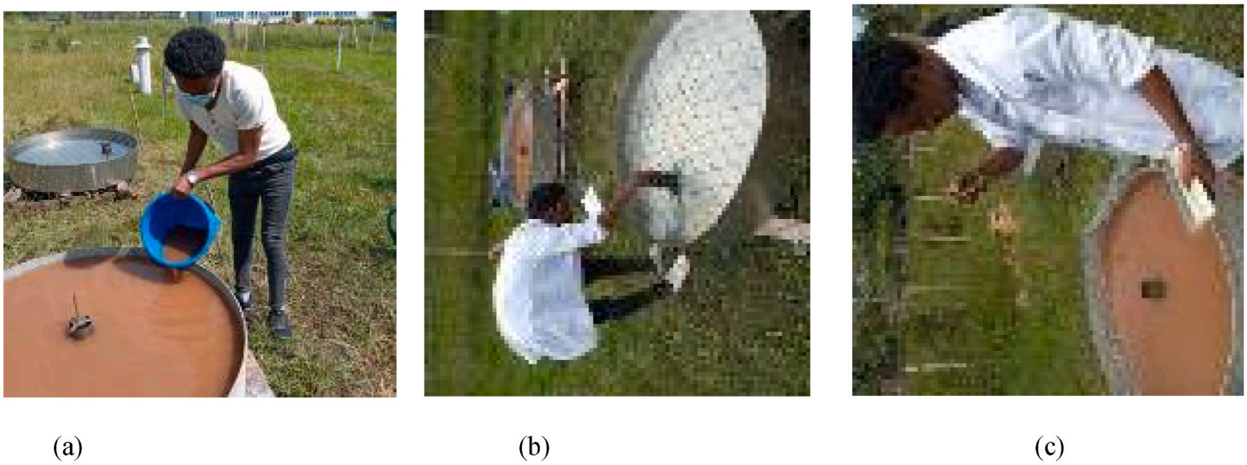

Fig. 5. Measuring pans evaporation: (a) filling the pan with the most turbid water; (b) looking for water level after evaporation; and (c) reading depth of pan water after evaporation.

3. Results and discussions

3.1. Reservoir water turbidity

The laboratory test results showed that during the intense rainstorm, the turbidity of the water in the Gilgel Gibe I reservoir altered significantly. The intensity of rainfall and activities occurring in the reservoir upstream catchment area affected the reservoir turbidity. A substantial number of suspended particles were deposited in the reservoir during times of intense rainfall as a result of significant soil erosion from the reservoir upstream catchment area.

The Gilgel Gibe I reservoir water had a high reported value of 75.33 mg/L of total suspended solid particles during the research period. Because, most of an area upstream of the reservoir is utilized for farming, a significant amount of sediment particles entered the reservoir during this season. The Gilgel Gibe I reservoir obtained noticeably high water turbidity during the intense rainy season, which ran from early June to late August. As shown in Table 1 above, the measured turbidity in water samples taken from the reservoir varied from 43.7 to 226 NTU. Spatial variation of the reservoir water turbidity occurred along the longitudinal axis of a reservoir due to the deposition of suspended particles on the reservoir bed. High turbidity values were observed when farming activity and high rainfall intensity overlapped (late May to mid-July). The samples collected and measured revealed the existence of temporal variability of reservoir water turbidity. When the amount of rainfall much less often, and most of the reservoir upstream area was covered with grasses and plants (after mid-July to early September), the lowest water turbidity value was measured.

3.2. Surface water temperature

Surface water temperatures of ten pools water was measured in the field using thermometer (shorter). This surface water temperature of each pool water was collected at different time of a day throughout the experimental period and the average values were listed in the underneath Table 2.

According to field test results depicted in the above Table 2, the average surface water temperature of pools changed as a result of changes in both water turbidity and the amount of net solar radiation that hit the surface of the water. Data on the surface water temperature were gathered every day at 9:00, 11:00, 13:00, 15:00, and 17:00 for fifteen days from September 10–24 (inclusive). Only three of the five measured data points were adopted to determine the association between turbidity and surface water temperature

Table 1
Measured reservoir water turbidity.

Chosen sample number	Recorded reservoir water turbidity in nephelometric turbidity unit (NTU)
1	226
2	203
3	194
4	166
5	115
6	89.3
7	74.72
8	68.2
9	50.3
10	43.7

Table 2
Measured average daily surface water temperature for different turbid water samples.

Observation hours	Turbid-water samples (NTU) and their respective recorded pools water surface temperature (°C)									
	226	203	194	166	115	89.3	74.72	68.2	50.3	43.7
9:00	23.52	22.92	22.65	22.33	21.95	21.75	21.53	21.37	21.06	20.87
11:00	27.48	26.84	26.60	26.21	25.82	25.51	25.28	25.15	24.85	24.70
13:00	33.29	30.69	30.31	29.79	29.23	29.02	28.84	28.72	28.52	28.45
15:00	29.34	28.44	28.21	27.69	27.01	26.76	26.54	26.41	26.11	25.96
17:00	22.19	22.85	23.15	23.43	23.73	23.94	24.21	24.53	24.91	25.10

because, the variation of surface water temperature for a successive observation hours were low. The average surface water temperature increased throughout both observation hours, except at 17:00, as the water turbidity increased, according to the results revealed in Table 2 above.

To investigate the relationship between turbidity and surface water temperature, data that were gathered at 9:00, 13:00, and 17:00 were assessed. At these three observational hours, there is a noticeable variation in the surface water temperatures among the pools. For this reason, they were used to examine the relationship between turbidity and surface water temperature. The results of this

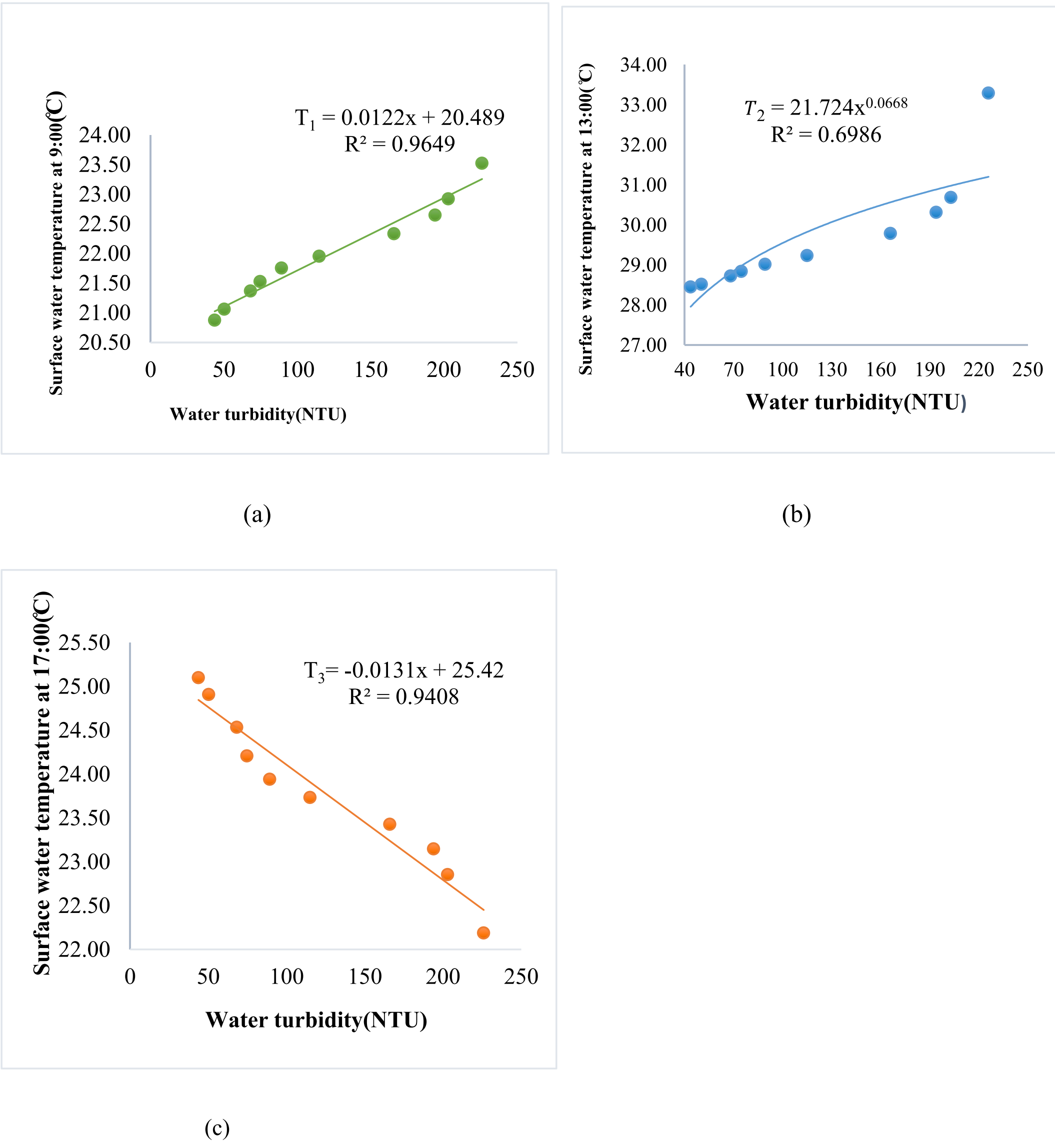

Fig. 6. Relationship between turbidity and surface water temperature at (a) 9:00, (b) 13:00, and (c) 17:00 observation hours.

analysis demonstrate the existence of strong positive link between surface water temperature of pools water and turbidity at 9:00 and 13:00 observation hours, with Spearman-ranked correlation coefficient of determination value of +1 and $P <. 001$. This relationship was observed after carefully observing the results of Spearman ranked correlation coefficient and other different models. But with a Spearman-ranked correlation coefficient of r-1 and a $P < .001$ at 17:00 observation hour, there is strong negative relationship between turbidity and surface water temperature. An ANOVA test and simple linear regression results indicated that the association between turbidity and surface water temperature is statistically significant, with a fixed ratio of $F\,(1, 8) = 126.730$, 28.989, and 219.301 and P values of $P < .001$, $P = .001$, and $P < .001$ for the three observation hours, respectively.

The values of R squared for the three observation data were reported as 0.9649, 0.6986 and 0.9408, respectively. The equation of the lines for the given observation data at three observation hours are listed below.

$$T_1 = 0.0122Tu + 20.489 \quad T_2 = 21.724\ Tu^{0.0668} \quad T_3 = -0.0131Tu + 25.42$$

where, T_1, T_2 *and* T_3 represent surface water temperature at 9:00, 13:00, and 17:00 observation hours, respectively, and Tu represents water turbidity.

From slope of the lines for linear functions (Fig. 6 a; c) and coefficient of the line for power function **(**Fig. 6b) above, the surface water temperature of the same turbid water varied depending upon the variation in the intensity of incoming net solar radiation striking the surface of the water. Near midday, when solar radiation striking the surface of the water is high, surface water temperature also intensifies for all samples, with extreme heightening for most turbid water. The positive coefficients of line depicted that the relationship between turbidity and surface water temperature is direct, and the negative coefficient showed an indirect correlation between turbidity and surface water temperature for a given observation hour.

3.3. *Vertical alteration of water temperature*

There was stratification of water temperature within pool water and variation of water temperature among pools water at the same depth with the change in turbidity values. A vertical disparity in water temperature occurred among water pools and within the pool at different layers. For all water samples and at all observation hours, the water temperature at the top layer (1 cm below the water surface) was greater than the water temperature at the mid-depth and bottom layer (1 cm above the bed of the pool). Due to strong incoming solar radiation at midday, the data recorded at 13:00 observation hour was used to analyze the vertical variation of water temperature in all pools (for ten samples with different magnitude of the turbidity) at different levels.

Fig. 7 above illustrates that significant vertical alteration of water temperature occurred along with turbidity variation. The water temperature fluctuation at the surface and bottom layers is greater than the water temperature variation at the middle layer for all water samples with turbidity variation, according to the above plot. There is one outlier that was a recorded surface water temperature of most turbid water at 13:00 observation hour. The visual examination of the Q-Q plot and the Shapiro-Willk's P test value of 0.641 suggested that the double-squared transformed water temperature was roughly normally distributed, with a kurtosis of 0.427 (SE = 0.833) and a skewness of −0.003 (SE = 0.356). The F and P values from the univariate general linear model, which were produced after the data were transformed using double square root transformation, were used to assess the statistical significance of the finding.

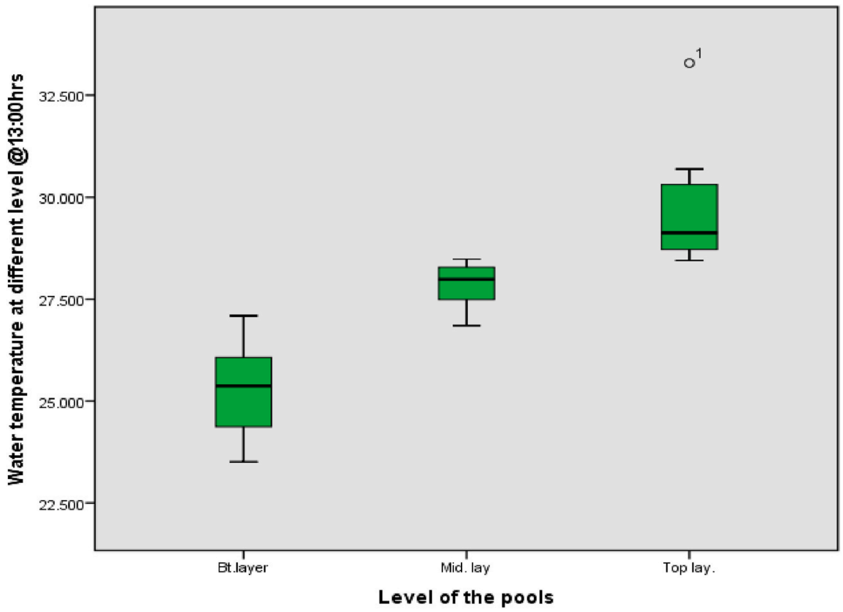

Fig. 7. Box and Whisker plot depicting vertical alteration of turbid water temperature in all pools at 13:00.

According to the model, there was a substantial vertical change in water temperature associated with turbidity fluctuation with $F(2, 27) = 39.587$ and $P < .001$.

From Fig. 8 above, the vertical alteration of water temperature was more prominent for most turbid water sample (226 NTU) than for the least turbid water sample (43.7 NTU). For most turbid water, the water temperature decreased highly, and for least turbid water, it decreased smoothly from the top to the bottom layer vertically, with R squared values of 0.9675 and 0.8194 for most and least turbid pool water, respectively. Because, most turbid water has a high absorption rate and scatters a large amount of the net solar radiation that strikes it, the water temperature at the bottom of the pool is typically substantially lower than it is in the least turbid water, as indicated on the above graph. Due to the release of net solar radiation absorbed by suspended particles into the water, which contributes additional energy and raises the surface water temperature, the most turbid water has a higher surface water temperature than the least turbid water.

3.4. Reservoir water evaporation

The reservoir water evaporation was determined from the recorded pans evaporation for different turbid-water samples. Pans water evaporations were converted to reservoir evaporation using class A pan coefficient for all water samples. Both measured pans and estimated reservoir water evaporation were given in Table 3 underneath for their respective turbid-water sample.

From collected data during field test from September 11 to October 20 (inclusive), the average daily surface water evaporation from the pans were 4.722 mm and 3.097 mm for the most turbid and the least turbid water samples, respectively. The average daily surface water evaporations from the reservoir for both most and least turbid water samples were 3.542 mm and 2.323 mm, respectively as indicated in Table 3 above. These average daily reservoir evaporations were obtained from average daily pans evaporation and pan coefficient value (0.75). The results depicted that, if water turbidity increased, both pans and reservoir evaporation also raised. The analyzed reservoir evaporation data showed a direct association between turbidity and surface water evaporation.

Fig. 9 above illustrates that reservoir evaporation increased along with the raise of water turbidity. An equation of the line for all observation data is given as:

$$E_r = 0.0067\,Tu + 2.0306.$$

where, Tu represents reservoir water turbidity and E_r represent an average surface water evaporation from the reservoir.

By carefully observing the results of the Spearman-ranked correlation coefficient and other different models, this analysis discovered that there was a strong positive relationship between turbidity and the intensity of average reservoir evaporation, achieving a Spearman-ranked correlation coefficient value of r +1 and $P < .001$. From simple linear regression and ANOVA test results, the relationship between turbidity and average surface water evaporation was statistically significant, with the coefficient of determination (R squared) values of +1, a fixed ratio value of $F(1, 8) = 14443999.960$, and $P < .001$. It concluded that an increase in water turbidity amplified surface water evaporation from the reservoir.

3.5. Estimation of the volume of the water evaporated from the reservoir

As observed from the test results, if the reservoir turbidity increased, the water evaporated from it also increased. The volume of water lost from the reservoir is directly proportional to reservoir turbidity and evaporation from it.

As revealed by field tests results in Table 4 above, when reservoir turbidity rose from 43.7 to 226 NTU, the pans evaporation also increased from 3.097 mm to 4.722 mm. Owing to these change in pans evaporation, the corresponding reservoir evaporation logged

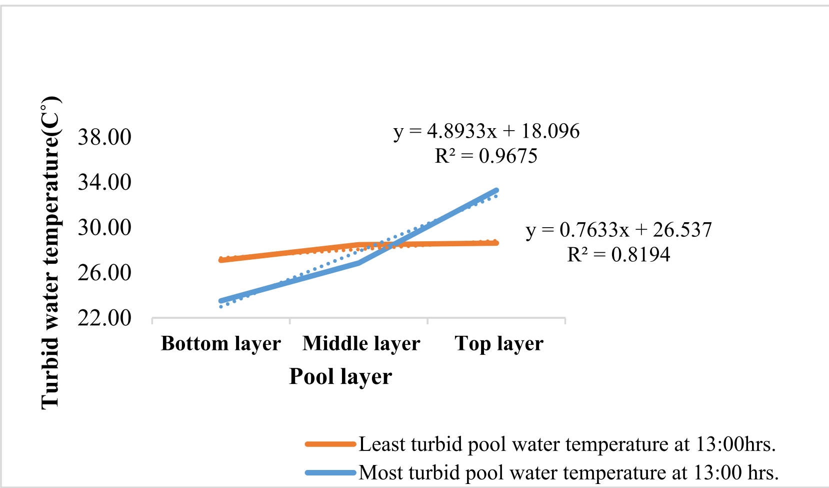

Fig. 8. Vertical variation of turbid water temperature along with turbidity alteration.

Table 3
Average daily pans evaporation and their respective reservoir evaporation from each turbid water sample.

Sample number	Turbidity **(NTU)**	Average daily pan evaporation (mm)	Average daily reservoir evaporation (mm)
1	226	4.722	3.542
2	203	4.517	3.388
3	194	4.437	3.328
4	166	4.187	3.140
5	115	3.733	2.799
6	89.3	3.503	2.628
7	74.72	3.374	2.530
8	68.2	3.315	2.487
9	50.3	3.156	2.367
10	43.7	3.097	2.323

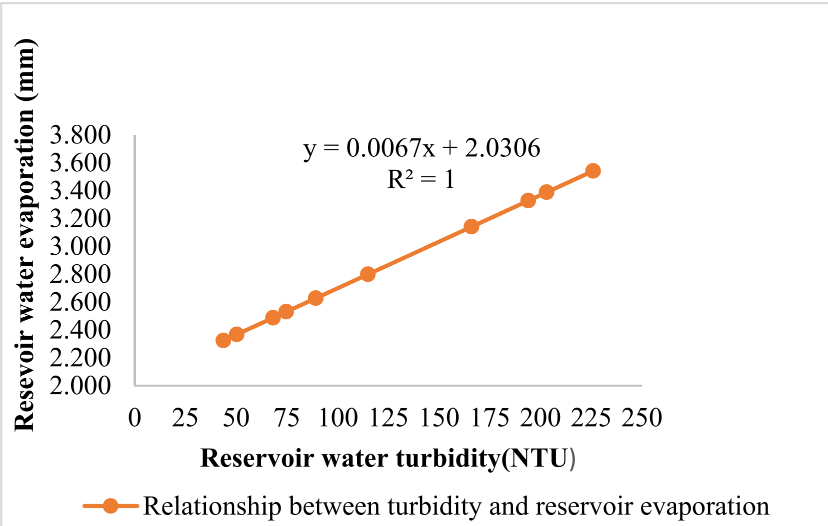

Fig. 9. Relationship between turbidity and reservoir evaporation for all samples.

Table 4
Estimated volume of the water lost due to evaporation from Gilgel-Gibe I reservoir.

Sample number	Turbidity (NTU)	Reservoir evaporation (mm)	Reservoir surface area (km^2)	Volume of water evaporated from GG-1 reservoir (m^3)
1	226	3.542	54	191.241
2	203	3.388	54	182.938
3	194	3.328	54	179.689
4	166	3.140	54	169.580
5	115	2.799	54	151.169
6	89.3	2.628	54	141.891
7	74.72	2.530	54	136.627
8	68.2	2.487	54	134.273
9	50.3	2.367	54	127.811
10	43.7	2.323	54	125.429

were, 2.323 mm and 3.542 mm for both least and most turbid water samples, respectively. With respect to an increment in reservoir evaporation, the volume of water evaporated from the reservoir increased from 125.429 to 191.241 cubic meters. These volumes of the water evaporated from the reservoir were estimated by using the reservoir's surface area at full supply level (54 km^2) and reservoir evaporation depth (mm) for each sample. The difference in the volume of the water evaporated was reported as 65.812 cubic meters. Fig. 10 below shows that there is direct positive relationship between turbidity and the volume of water evaporated from the reservoir, with coefficient of determination (R squared value) of +1. An equation of the line is given as:

$$V_e = 0.361 Tu + 109.65.$$

where Tu represents water turbidity and V_e, the volume of water evaporated from Gilgel Gibe I reservoir.

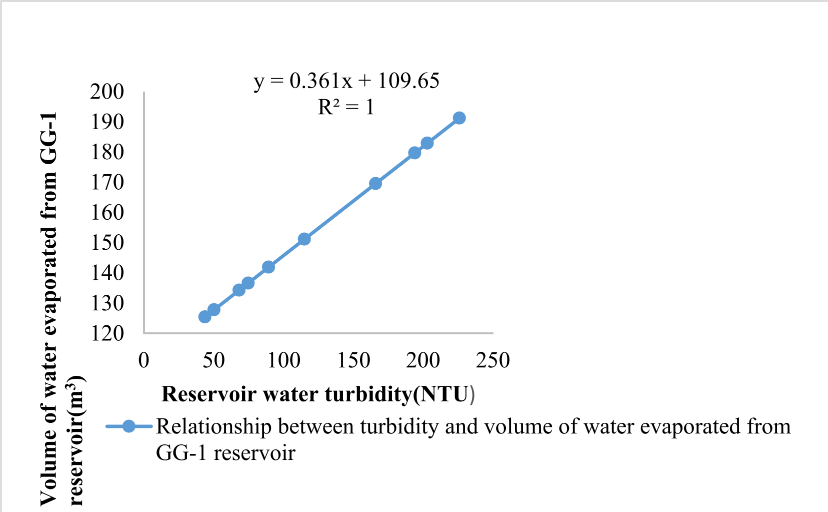

Fig. 10. Relationship between turbidity and volume of the water evaporated from Gilgel gibe I reservoir for all water samples.

3.6. Discussions

Quantities of suspended particles entered into the Gilgel Gibe I reservoir vary during the wet season. Water samples taken from reservoirs had recorded turbidity values ranging from 43.7 to 226 **NTU**. The main factors identified as the causes of reservoir water turbidity variation were the intensity of the rainfall, improper integrated catchment management, and an anthropogenic action executed in the reservoir's catchment area. When the intensity of the rainfall heightens, and most part of the catchment area of the reservoir is exploited for farming (late May to mid-July), the amount of suspended particles entering the reservoir has been amplified with a maximum turbidity value of 226 NTU, due to an increase in soil erosion from the upstream catchment area of the reservoir. Eddies that were generated from the reservoir bed brought small-sized soil particles closer to the water surface, which in turn increased the concentration of suspended particles in the reservoir. Throughout the study period, Gilgel Gibe I reservoir water had a maximum total suspended solids measurement of 75.33 mg/L. This maximum value of total suspended solids was recorded when most of the reservoir catchment area was bare (during the farming season) and rainfall intensity was high. The total suspended solids (TSS) concentration in this reservoir was much higher than the maximum value of the guideline ambient environment standards for Ethiopian reservoirs, which is 50 mg/L. Suspended particles entered into the reservoir, decreases the quality of the reservoir water, lessen the performance of the reservoir, and harm the lives of aquatic inhabitants (mostly fish) [9].

As illustrated in a previous study done by many scholars, there was a change in water turbidity with rainfall events and intensity alteration. According to [2,30], the small natural puddles and natural rivers depicted the turbidity of the surface water body step-up along with rainfall events and intensity increment. The range of recorded reservoir turbidity values in this study was proximate to 40–155 NTU, which was measured by Ref. [27], and 47.07–95.3 NTU, which was measured by Ref. [9] for the same reservoir. But, some logged turbidity values in this study were greater than the values reported by both [9,27] on the same reservoir (Gilgel Gibe I). This was due to all samples were taken near the time the rainfall events ceased. According to the results recorded by the above scholars, there is a temporal variation in reservoir water turbidity. Therefore, as stated by these scholars, the main cause of reservoir water turbidity variation was the difference in rainfall intensity in the reservoir catchment area, change in landuse landcover and the improper implementation of integrated watershed management which this study also confirmed. The aforementioned findings confirmed that the Gilgel Gibe I reservoir was extremely turbid, and the impact of this turbidity must be studied to take mitigation measures to lessen reservoir turbidity and its impacts.

The reservoir is impacted by changes in the turbidity of the water temporally and spatially. The quantity and quality of the reservoir water are both diminished owing to the increased number of suspended particles. These suspended particles flowing in the reservoir also absorb incoming net solar radiation and release it into the water, which triggers the rise of water temperature. It is physical characteristic of water that causes a change in other physical characteristics, mostly water temperature. Due to turbidity, light rays from the sun can't penetrate as far into the water, and as a result, the temperature of the surface of the water is raised. As the turbidity of the water increases, the average surface water temperature rises, contingent upon the incoming net solar radiation.

Time determines how the temperature of surface water increases in relation to the rise in turbidity. According to field test results, surface water temperature increased for all observation hours except at 17:00. However, at 17:00, there was an inverse relationship between surface water temperature and water turbidity. In contrast to the least turbid water, most turbid water had lower sunlight penetration depth. Most solar energy was stored near the surface of the water for most turbid pool water and it promptly released to the air, when air temperature was lower than surface water temperature (late afternoon) to balance air and surface water temperature. However, in least turbid water, solar energy mostly stored in the entire depth of the pool water was released gradually and thereof it took a longer time to cool the water in the pool. The average surface water temperature differences for most and least turbid water pools were given as 2.65 °C, 4.84 °C, and −2.91 °C at 9:00, 13:00, and 17:00 observation hours, respectively. For the first two opted observation hours, the association between turbidity and surface water temperature was directly proportional, but they were inversely proportional for the third. Due to the higher intensity of incoming net solar radiation during midday (13:00), the water temperature ascended dramatically with the increment of water turbidity. The amount by which surface water temperature rose relied on the strength of net incoming solar radiation for the same value of water turbidity.

According to Ref. [28], the amount of dissolved oxygen in water decreased as surface water temperature rose. Aquatic life in the reservoir died as a result of a significant decrease in dissolved oxygen, because the aquatic life depends on the dissolved oxygen in the water to survive. The economic development of a country may be slightly impacted by the fluctuations in water temperature in this reservoir due to its abundance of fish, as the locals' livelihoods rely on the money they get from selling the fish they have caught. Livestock around this reservoir may suffer, if the water quality deteriorates due to the deaths of aquatic inhabitants within the reservoir. The majority of children in the vicinity of the reservoir have bathed at its edges; hence, the health of those living close to the reservoir may suffer if the reservoir quality deteriorates for the reasons indicated above. If the increase in suspended particle concentration in Gilgel Gibe I reservoir is not properly regulated, it usually has a negative direct or indirect impact on the lives of those who live nearby.

The relationship between turbidity and surface water temperature was also presented by Ref. [25], which stated that as the turbidity of the water increased, the surface water temperature also rose, except during the late afternoon. Suspended soil particles in water increased surface water temperature and, furthermore, changed the temperature dynamics of small water collections during the daytime. As stated by them, the surface water temperature of the pools rose to or exceeded 42 °C when the turbidity of the water increased, and the result of this study was proximate to this value, which was 33.29 °C for the most turbid water at 13:00. We have generalized that the upsurge in water turbidity heightens the surface water temperature of water body typically reservoir. Water temperature needs to be maintained at optimum level in order to achieve the reservoir storage purpose.

There is the stratification of water temperature within a pool water due to the absorption and scattering of the net solar radiation striking the water surface. The existing suspended particles diminished the penetration depth of this net solar radiation. When the depth of water increased, the strength of light rays to penetrate the water decreased and stored near the surface of pool water which made the water near the surface warmer than the water at the middle and bottom layers. The main factors that cause water temperature stratification were the absorption and scattering of light rays by suspended particles and the release of absorbed light into the water. The water temperature existed in many forms at different strata due to all of these factors.

Variation in water temperature among different turbid pools water occur owing to dissimilar absorption and scattering rates of the net solar radiation. There was a greater diminishment of net solar radiation in most turbid water than the other samples with less turbidity The results showed that different pools of water with varying turbidities had different water temperature readings at the same level. The alteration of water turbidity stimulated a variation in water temperature, for which there was the least penetration of the net solar radiation in the most turbid water pool.

To show the variation of water temperature between/among pools water and differences in water temperature within a pool water at different layers, only three-time points of recorded data were selected (9:00, 13:00, and 17:00). It illustrated that there was a significant variation in water temperature at midday (13:00) than at 9:00 and 17:00 within a pool water and between/among pools water. For most turbid pool water, the difference in water temperature between the top and bottom layers was 9.78 °C, and for least turbid water, it was 1.53 °C at midday (13:00). There was more extinction of light rays in the most turbid water than in the least turbid water, as shown by the above two results of water temperature differences between the top and bottom layers of pool water. In most turbid water, the temperature at the surface was high, and at the bottom layer, it was very low. However, the water temperature at the top and bottom layers was near each other for the least turbid.

Based on the box and whisker plot, the interquartile range (25–75 %) is represented by the box; the minimum and maximum values are displayed by the range bar; an outlier is represented by the small circle and the black line within the box signifies the median. The box and whisker plot revealed that there was a prominent vertical alteration of water temperature along with turbidity variation. Due to the absorption and scattering of the net solar radiation, the temperature of the water decreased vertically from the top surface of the water to the bottom layer. The box and whisker plot depicted that significant variability in water temperature at the top and bottom layers of the pools water occurred, but at the middle layer, water temperature variability was less relative to the bottom and top layers.

The box and whisker plot showed that there was variation in the surface water temperature of the pools water in relation to changes in water turbidity. The surface water temperature for the second most turbid and least turbid pool water at the top layer was represented by the upper and lower edges of box and whisker plot. However, the surface water temperature for the most turbid pool water was very high, which was denoted by an outlier. The greater size of this box at the top layer depicted that there was greater variability in surface water temperature with respect to the change in water turbidity. At the middle layer, the lower and upper edges of the box and whisker plot represented the water temperature at this layer for both the most and least turbid pools water, respectively. The smaller size of this box revealed, water temperature variability in the middle of the pools was low with respect to turbidity variation. The water temperature extremely varied at the bottom layer of the pool in relation to changes in turbidity. The water temperature at the bottom layer for the least turbid pool water and the most turbid pool water was represented by the upper and lower borders of the box and whisker plot, respectively. These two boxes generally depicted that there was a significant difference in water temperature with respect to turbidity alteration at the top and bottom layers. At the top layer, it was because of the presence of excessive absorption and scattering of light rays by suspended particles, as well as the release of absorbed light rays into the water, but, at the bottom layer, high variability in water temperature occurred due to the greater extinction of light rays with the raise of pools water turbidity.

According to Ref. [25], the temperature of the water was stratified more in the most turbid than in the least turbid water. This study determined that there was a very large variation in water temperature around midday (13:00), which was also demonstrated by the above researchers. Hence, sunlight penetrates turbid water columns only to certain depth, which depend on water turbidity and the strength of the incoming sunlight. The deep water depth was not reached by the light rays that caused lowering of water temperature in most turbid water at this layer. We have concluded that the change in reservoir water turbidity caused the alteration of water temperature vertically, which made the top layer warmer than the middle and bottom layers. Therefore, turbidity affects reservoir water by varying the water temperature at different layers. The accuracy of the measured water temperatures at different layers were high since, during the measurements all factors those could affect the logged results were greatly considered.

Turbidity and the reservoir surface water evaporation were directly correlated. Water evaporation in pans was measured for forty days, and the average values were used to estimate the daily pan evaporation of two samples. Water lost owing to evaporation was replaced in each pan during the experiment by adding water, when the water level dropped to 30 cm below the pans rim. The measured pans water evaporation for the most and least turbid water samples were 3.097 mm/day and 4.722 mm/day, respectively. These measurements were done at the same time for different pans. By interpolating all recorded turbidity values and pan evaporation for the aforementioned two samples, pan water evaporation for the remaining samples was calculated. Due to the scarcity of equipment, only two pans were used to measure pans evaporation for different turbid water samples. It may be taken as a limitation of this research, but careful interpolation was done to estimate the pan evaporation for the other samples (for the eight turbid water samples for which their pan evaporation did not measured in the field experiment).

The logged pan evaporation during the field experiment and the class A pan coefficient value of 0.75 were used to determine the surface water evaporations of the reservoir water. For reservoir with the same surface area with pan, reservoir water evaporations were estimated as 3.542 mm/day for most turbid sample and 2.323 mm/day for the least turbid water sample. These findings showed that, the reservoir surface water evaporation was less than pan evaporation because, the pan provides extra energy, which exacerbates the pan surface water evaporation.

Variations in the surface water evaporation of the pans and reservoir were induced by a change in the turbidity of the reservoir water. When reservoir water turbidity increased, surface water evaporation also aggravated. The amount of water particles that escaped from the reservoir surface was usually increased due to turbidity amplification, which also raised the temperature of the surface water.

According to Ref. [25], an increase in water temperature was brought on by an increase in water turbidity, which in turn increased reservoir water evaporation. They claimed that variations in the turbidity of pool water alter the rate of surface water evaporation by intensifying it. An average evaporation rate of 3.8 mm/day was reported in their measurement in a pool with identical clear water, however, as turbidity raises both water temperature and evaporation rates also heightens with an extreme aggravation for most turbid water. This study confirmed their idea about the amplification of reservoir water evaporation when the concentration of suspended particles in reservoir water increased. The values reported in this study deviated from the output observed by them due to temporal variation of the experimental period, spatial variation of test field, and differences in concentration of suspended particles in water samples, but it was within the limited range of 1.6–5 mm/day. In general, we came to the conclusion that surface water evaporation from the pan and reservoir was increased by the intensification of suspended particle concentration.

The volume of water evaporated from the reservoir surface increases, due to an eminent increment in surface water temperature, which caused the escaping of water molecules from the reservoir, if the reservoir turbidity upsurges. The amount of water kept in the reservoir is influenced by the amount of suspended particles in it. From these test results, when the water turbidity rose from 43.7 to 226 NTU, the volume of water evaporated from the reservoir increased from 125.429 to 191.241 cubic meters. A change in the volume of the water was reported as 65.812 cubic meters, which caused an eminent reservoir storage change due to the raised surface water turbidity that results in the rise of surface water evaporation and then the fall of reservoir storage.

The rise in water turbidity increases surface water evaporation, which decreases the longevity of water in the puddles [25]. This study concluded that if water turbidity increased in the reservoir, it caused a change in reservoir storage by decreasing the quantity of water stored in the reservoir.

4. Conclusion

This study concluded that variation in reservoir water turbidity significantly affected the amount of water stored in the reservoir. Reservoir water turbidity varied depending on different factors triggering the entrance of soil particles into the reservoir from its watershed. The study discovered that there was a strong negative correlation between turbidity and surface water temperature at 17:00 observation hour with a spearman-ranked correlation coefficient of $r\ -1$ and strong positive association at 9:00 and 13:00 observation hours with a spearman-ranked correlation coefficient of $r\ +1$. It was discovered that the temperature of the water near the surface increased along with reservoir turbidity. There was a vertical variation in the water temperature within the pool and among the pools water due to the absorption and dispersion of the net solar radiation, which decreased its penetration depth. This study demonstrated that a significant positive link between reservoir water turbidity and surface water evaporation exist with a spearman-ranked correlation coefficient of $r{+}1$. Reservoir water evaporation increased dramatically as a result of the enhanced mobility of reservoir water particles brought on by the rise in surface water temperature. When reservoir turbidity rose, so did the temperature of the surface water and the rate of evaporation. This finding also explicitly described the occurrence of the significant storage change in the reservoir due to turbidity variation. The significance of this study was, it delivered new information on the impacts of reservoir turbidity variation on stored water in Gilgel-Gibe I reservoir, identification of factors that caused reservoir turbidity amplification, it provides information on need of implementing mitigation measures to lessen reservoir turbidity and its outputs. It vehemently outlined the procedures that must be followed in order to keep the water that has been stored in the reservoir in order to achieve the reservoir intended purpose. This reservoir measured turbidity was higher than the recommended turbidity of Ethiopian reservoirs, thus, mitigation measures are needed to meet the objective of reservoir water in a sustainable manner. Reducing the amount of suspended particles entering the reservoir through the implementation of soil erosion control mechanism is essential to reduce the turbidity of the reservoir. Any human activities that leverage soil erosion needs to be controlled and the catchment area of the reservoir should have properly managed to degrades reservoir turbidity and significant storage change. Generally, the main achievement of this study was evaluating the impact of turbidity on Gilgel Gibe I reservoir storage.

Data availability statement

The data supporting the results of research study is confidential, and is deposited at: https://repository.ju.edu.et/handle/123456789/6363.

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CRediT authorship contribution statement

Aduna Birmachu: Writing – review & editing, Writing – original draft, Visualization, Validation, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Tolera Feyissa:** Visualization, Validation, Supervision, Conceptualization. **Bikila Diriba:** Validation, Supervision, Conceptualization.

Declaration of competing interest

We hereby declare that, we have no known financial or interpersonal conflicts that would appear to have influenced the work described in this paper. Any potential financial or non-financial support was not provided by any individuals or agencies for the work reported or outside of this work.

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References

[1] A.C. Ziegler, Issues related to use of turbidity measurements as a surrogate for suspended sediment, Water (Iso 7027) (2002) 2001–2003 [Online]. Available: http://ks.water.usgs.gov/Kansas/rtqw/.
[2] R.K. Gelda, S.W.W. Effler, A.R.R. prestigiacomo, Effler.P.A.J. Perg, B.A. Wagner, M.G. Perkins, D.M.O.D. Susan, D.C. Pierson, Characterizations and modeling of turbidity in a water supply reservoir following an extreme runoff event, Inl. Waters 3 (3) (2013) 377–390, https://doi.org/10.5268/IW-3.3.581, 2013.
[3] C. Modini, 2nd Joint Federal Interagency Conference, Las Vegas, NV, 2010.
[4] Dibaba Wakjira, Adugna Tamene, Tamam Dawud, The effects of land use land cover change on hydrological process of Gilgel Gibe, Omo Gibe Basin, Ethiopia, Int. J. Sci. Eng. Res. 7 (8) (2016) 117–128.
[5] F. Jansen, A. Teuling, Evaporation from a large lowland reservoir – (dis)agreement between evaporation methods at various timescales, Hydrol. Earth Syst. Sci. Discuss. (2019) 1–27, https://doi.org/10.5194/hess-2019-393, no. August.
[6] S.J. Kerr, Silt, Turbidity and Suspended Sediments in the Aquatic Environment: an Annotated Bibliography and Literature Review, 1995.
[7] D.A. Szatten, Z. Babinski, M. Habel, Reducing of water turbidity by hydrotechnical structures on the example of the Wloclawek reservoir, J. Ecol. Eng. 19 (3) (2018) 197–205, https://doi.org/10.12911/22998993/85739.
[8] A.R. Prestigiacomo, S.W. Effler, D.M. O'Donnell, D.G. Smith, D. Pierson, Turbidity and temperature patterns in a reservoir and its primary tributary from robotic monitoring: implications for managing the quality of withdrawals, Lake Reserv. Manag. 24 (3) (2008) 231–243, https://doi.org/10.1080/07438140809354064.
[9] B. Woldeab, A. Beyene, A. Ambelu, I. Buffam, S.T. Mereta, Seasonal and spatial variation of reservoir water quality in the southwest of Ethiopia, Environ. Monit. Assess. 190 (3) (2018), https://doi.org/10.1007/s10661-018-6527-4.
[10] L. Benyahya, A. St-Hilaire, T.B.M.J. Ouarda, B. Bobée, J. Dumas, Comparison of non-parametric and parametric water temperature models on the Nivelle River, France, Hydrol. Sci. J. 53 (3) (2008) 640–655, https://doi.org/10.1623/hysj.53.3.640.
[11] S. Zhu, E.K. Nyarko, M. Hadzima-Nyarko, Modelling daily water temperature from air temperature for the Missouri River, PeerJ 2018 (6) (2018) 1–19, https://doi.org/10.7717/peerj.4894.
[12] A. Kohli, K. Frenken, Evaporation from artificial lakes and reservoirs, FAO AQUASTAT Reports (2015) 10.
[13] R.A. Wurbs, R.A. Ayala, Reservoir evaporation in Texas, USA, J. Hydrol. 510 (2014) 1–9, https://doi.org/10.1016/j.jhydrol.2013.12.011.
[14] J.D. Lenters, T.K. Kratz, C.J. Bowser, Effects of climate variability on lake evaporation: results from a long-term energy budget study of Sparkling Lake, northern Wisconsin (USA), J. Hydrol. 308 (1–4) (2005) 168–195, https://doi.org/10.1016/j.jhydrol.2004.10.028.
[15] Z. Yan, S. Wang, D. Ma, B. Liu, H. Lin, S. Li, Meteorological Factors Affecting Pan Evaporation in the Haihe River Basin and China, 2019, pp. 1–18, https://doi.org/10.3390/w11020317.
[16] S. Assouline, K. Narkis, D. Or, Evaporation suppression from water reservoirs: efficiency considerations of partial covers, Water Resour. Res. 47 (7) (2011) 1–8, https://doi.org/10.1029/2010WR009889.

[17] D. Martínez-Granados, F.F. Maestre-Valero, J. Calatrava, V. Martínez-Alvarez, The economic impact of water evaporation losses from water reservoirs in the Segura basin, SE Spain, Water Resour. Manag. 25 (13) (2011) 3153–3175, https://doi.org/10.1007/s11269-011-9850-x.

[18] C.D. Coelho, D.D. da Silva, G.C. Sediyama, M.C. Moreira, S.B. Pereira, Â.M.Q. Lana, Estimates of monthly and annual evaporation rates and evaporated volumes per unit time in the Tucuruí-pa and Lajeado-to hydroelectric power plant reservoirs based on different methods, Eng. Agric. 38 (1) (2018) 38–46, https://doi.org/10.1590/1809-4430-Eng.Agric.v38n1p38-46/2018.

[19] K. Wolka, Watershed management:an option to sustain dam and reservoir function in Ethiopia, Journal of Environmental Science and Technology 5 (2012), https://doi.org/10.3923/jest.2012.262.273.

[20] B. Woldeab, et al., Heliyon Depth profile of reservoir water quality in the Southwest of Ethiopia, Heliyon 9 (7) (2023) e17474, https://doi.org/10.1016/j.heliyon.2023.e17474.

[21] M.P. Alvarez, M.J. Pereda, E.F. Carta, B.M.M. Duran, J.E. Guillen, M. Dekker, S.B. Shrestha, S.W. Nicolson, H. Kang, K.J. Kwak, H. Mahvi, E. Bazrafshan, G. R. Jahed, B.Y.G. Shabir, et al., 2.0 experiment on determination of turbidity, Water (2014), https://doi.org/10.2105/AJPH.51.6.940-a.

[22] B.G.B. Kitchener, J. Wainwright, A.J. Parsons, A review of the principles of turbidity measurement, Prog. Phys. Geogr. 41 (5) (2017) 620–642, https://doi.org/10.1177/0309133317726540.

[23] S. Neupane, J.R. Vogel, D.E. Storm, B.J. Barfield, A.R. Mittelstet, Development of a turbidity prediction methodology for runoff-erosion models, Water Air Soil Pollut. 226 (12) (2015), https://doi.org/10.1007/s11270-015-2679-9.

[24] D. Althoff, L.N. Rodrigues, D.D. da Silva, Impacts of climate change on the evaporation and availability of water in small reservoirs in the Brazilian savannah, Clim. Change 159 (2) (2020) 215–232, https://doi.org/10.1007/s10584-020-02656-y.

[25] K.P. Paajiamans, W. Takken, A.K. Githeko, A.F. Jacobs, Effect of Turbidity on near water temperature of larval habitats of malaria mosquito; Anopheles gambiae, Int. J. Biometro 52 (2008) 747–753, https://doi.org/10.1007/s00484-008-0167-2.

[26] M. Kagiso, M.Sc. thesis in IWRM "Integration of Physicochemical Assessment of Water Quality with Remote Sensing Techniques for the Dikgathong Dam in Botswana Integration of Physicochemical Assessment of Water Quality with Remote Sensing Techniques for the Dikgathong Dam in Botswana,", May, 2016.

[27] A. Ambelu, K. Lock, P.L.M. Goethals, Lake and Reservoir Management Hydrological and anthropogenic influence in the Gilgel Gibe I reservoir (Ethiopia) on macroinvertebrate assemblages Hydrological and anthropogenic influence in the Gilgel Gibe I reservoir (Ethiopia) on macroinvertebrate assemblages 2381 (2013), https://doi.org/10.1080/10402381.2013.806971.

[28] L.F. Lazem, A.K. Resen, Long Term Monitoring of Water Characteristic of Three Restored Southern Marshes during the Years 2005 , 2006 , 2007 and 2008, April, 2016.